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Stress transfer in the Storegga area, offshore mid-Norway

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Abstract

The recently discovered large gas-field 'Ormen Lange' within the Storegga submarine slide area, offshore mid-Norway, poses important questions as to the origin of these large submarine slides and their possible implications in terms of the safety of the development and the production. In this respect, the present study was initiated with the main objective of investigating the possibility of stress transfer as triggering mechanism for multiple earthquake occurrence and hence for the Storegga submarine slide ca. 8200 years before present (BP).

Stress changes following different scenario earthquakes along the selected faults in the area are modeled and computed for a number of cases. Using the Coulomb failure criterion we demonstrate the possibility of large earthquakes triggering multiple ruptures along neighbouring fault segments. The combined effect of the co-seismic slip and strong ground shaking due to a large earthquake ($M \sim 7$) accompanied by the stress transfer on the optimally oriented normal fault-planes which are analogous to the slide-scar, may have played an important role for the triggering of the Storegga submarine slide.

Keywords: Storegga; Submarine slide; Stress transfer; Earthquake triggering.

1. Introduction

The Storegga Slide, located offshore mid-Norway, is one of the world's largest submarine slides (Bugge, 1983; Bugge et al., 1987, 1988; Bryn et al., 2005; Haflidason et al., 2005) (Fig. 1). It occurred approximately 8200 years before present (BP) and has displaced more than 5600 km^3 of continental margin sediments. As a result of the sliding, a gigantic tsunami (up to 10–12 m high) swept the Norwegian coast and generated tsunami deposits that could be distinguished on land (Bondevik and Svendsen, 1994, 1995; Harbitz, 1992; Svendsen et al., 2000; Ward, 2001). It is scientifically very interesting to discuss the origin of such large submarine slides (Sejrup et al, 1998; Kjærnes et al., 2000).

In the present study, the static stress changes that can be caused by earthquakes (of different size above a critical magnitude threshold) along a selected set of faults in the Storegga area are computed based on various scenarios. The main aims are to address the stress transfer as one possible mechanism for the initiation of the Storegga slide. This is investigated along two parallel lines; (i) to find the possible interaction between faults leading to multiple ruptures in neighboring segments in the Storegga area, and (ii) to outline the areas of increased stress as a result of stress transfer from different earthquake scenarios. In addition, another important factor, which may have played a role in the triggering, is obviously the actual strong ground motion and the associated dynamic loading on the sea-bottom sediments during the earthquake. This is addressed in another study (Lindholm et al., 2005). Furthermore, results from stress transfer modeling can also be used to quantify the static stress changes that can be expected from the future earthquakes of similar size.

2. Background

Earthquakes as triggering mechanism for landslides have been known for many years and documented in detail in several case studies (e.g. Youd, 1978; Keefer, 1984; Wilson

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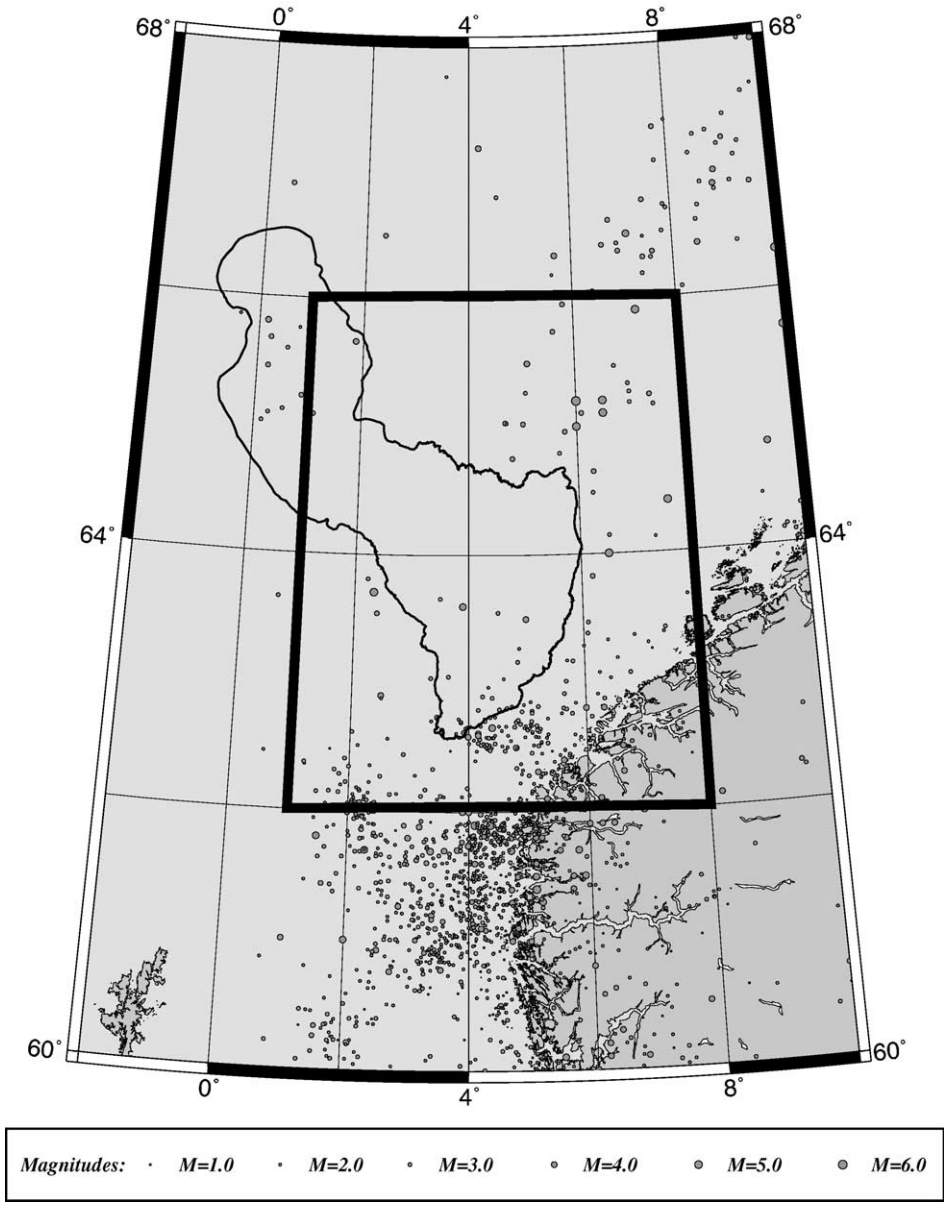

Fig. 1. The approximate location of the Storegga submarine slide (shown in thin black polygon—from Haflidi Haflidason, pers. comm.). Earthquake epicentres (since 1745) are shown as grey circles (data from the Norwegian National Seismic Network operated by the University of Bergen). It should be noted that the majority of the epicentres are from the digital instrumental period since 1982. Earlier earthquakes (especially the historical ones) may have significant uncertainties in their location. The black box outlines the area where stress transfer analyses are performed for selected faults (Fig. 2).

and Keefer, 1985). A significant part of the destruction observed in large earthquakes is often related to landslides. More than half of all deaths in large ($M>6.9$) earthquakes in Japan between 1964 and 1980, were caused by landslides (Kobayashi, 1981). One important recent example is the January 13, 2001 El Salvador earthquake of magnitude 7.6, which caused considerable damage to property and loss of lives. In Norway, landslides triggered by earthquakes are documented from the 1819 Rana earthquake with magnitude 5.8, along the northern coast of Norway (Hicks et al., 2000a), and from Etne in Western Norway, related to the $M_L=4.4$ earthquake of January 29, 1989 (Engell-Sørensen et al., 1989; Atakan et al., 1996). It is therefore reasonable to expect that similar magnitude or larger earthquakes along the offshore faults could trigger landslides in the nearby areas.

It has previously been suggested that earthquakes are the most likely mechanism for triggering the Storegga submarine slide (Bugge, 1983; Bugge et al., 1987, 1988). However, no specific study has been conducted to verify this hypothesis, except from the recent work by Lindholm et al. (2005); Bungum et al. (2005). In general, it is reasonable to assume that an earthquake with sufficient energy would be capable of triggering the Storegga submarine slide. The occurrence of such a large earthquake in the area of interest (i.e. with sufficient energy to trigger a submarine landslide),