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V. Lykousis · D. Sakellariou · J. Locat (Eds.)

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Submarine Mass Movements and Their Consequences

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Submarine Mass Movements and Their Consequences

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CD-ROM enclosed, containing full colour images which are printed in black-and-white in the book.

FOREWORD

Submarine mass movements and their consequences are of major concern for coastal communities and infrastructures but also for the exploitation and the development of seafloor resources. A tragic example of the vulnerability of coastal communities has been provided by the Indonesian tsunami of December 2004. Since 2005, as part of the scientific community efforts to minimize the impact of such natural disasters, the International Union of Geological Science (IUGS) and the United Nation, Educational, Scientific, and Cultural Organization (UNESCO) have sponsored an International Geoscience Program on Submarine Mass Movements and Their Consequences (IGCP-511). One of the main objectives of IGCP-511 members is to hold bi-annual symposia on these types of marine and coastal geohazards. The first symposium of this series was held in Nice (2003) and the second in Oslo (2005).

This 3rd Symposium on submarine Mass Movements and Their consequences provides an opportunity to review the state of the art in risk evaluation from submarine landslides, deposit characterization and its implication for coastal and offshore development. By bringing together professionals from the industry and academia with a range of different expertise, these proceedings hope to cover the full spectrum of aspects related to subaqueous mass movements and related consequences. The interdisciplinary views gathered in this book, arising from the conference, help identify future challenges, mitigation strategies and better management of the seafloor. To that effect, the Santorini is quite a unique venue for scientists and engineers interested in marine and coastal geohazards.

The book is organized in 7 sections from environmental settings along margins to mass movements and tsunamis. It also brings together our recent knowledge on submarine failure and post-failure analysis and in situ monitoring of stress and geotechnical properties. It also presents recent techniques for either in situ or laboratory analysis. Over the recent years new areas along the coast, fjords and estuaries have been investigated and are reported on herein. Finally, the venue of the symposium at Santorini provided a unique incentive to present various case histories of submarine mass movements and consequences around volcanic islands.

We want to offer special thank to Petra Van Steenbergen of Springer for her cooperation during the preparation of this book.

This series of symposia on Submarine Mass Movements and Their Consequences shall continue in the future to maintain the necessary momentum to keep our community vibrant. We are strongly convinced that this is only by meeting and sharing our views that we can hope for a better understanding and mitigation of the consequences of these catastrophic geohazards. And, for the readers of this book, we only hope that the enthusiasm and dynamism of our scientific community will transpire from the various papers.

Vasilis Lykousis, Dimitris Sakellariou and Jacques Locat
May 15th 2007

Section 1 - Role of submarine slides in margin development

FRACTAL STATISTICS OF THE STOREGGA SLIDE

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Abstract

The statistics of submarine mass movement inventories are poorly characterised in comparison to those of subaerial mass movements. In this study we investigate the aggregate behaviour of the Storegga Slide by carrying out a statistical analysis of its constituent mass movements. By using area as a proxy for mass movement magnitude, we demonstrate that the non-cumulative frequency-magnitude distribution of mass movements within the Storegga Slide is a power law with an exponent of 1.52. The Storegga Slide has the characteristics of a dissipative system in a critical state, where the input of sediment is continuous in the form of hemipelagic sedimentation and glacial deposition, and the output is represented by mass movements that are spatially scale invariant. We conclude that the Storegga Slide may be modelled as a large-scale geomorphic system that exhibits self-organised critical (SOC) behaviour. In comparison to subaerial mass movements, the aggregate behaviour of submarine mass movements is more comparable to that of the theoretical 'sandpile' model. The origin of SOC may be linked to the retrogressive nature of the Storegga Slide. Since SOC is an emergent feature, the large-scale behaviour of the Storegga Slide should be autonomous of the smaller-scale elements. A power law distribution also implies that incomplete submarine mass movement inventories may be extrapolated within the limits of power law behaviour, which is important in terms of hazard management.

1. Introduction

Concepts of non-linear dynamic systems, such as scale invariance and the fractal model, provide a powerful approach to the representation of a wide range of geoscientific data (e.g. fluvial systems (e.g. Pelletier 1999), coastal profiles (Southgate and Möller 2000). Scale invariant properties of data inventories are identified by demonstrating a single power law exponent in a frequency-magnitude distribution (Mandelbrot 1983). A power law distribution implies that when we compare the number of events of size A or greater, with the number of events of size ηA or greater (η is an arbitrary factor), the number always differs by the same factor $\eta^{-\beta}$, regardless of the absolute size of the events (Hergarten 2003). A power law distribution can be replaced with other measures of the size of the event (e.g. area, volume and thickness of mass movements are strongly correlated with each other, and a distribution can be converted between variables (Hovius *et al.* 1997)); thus a power law distribution is free of a characteristic scale and can be described as fractal (Mandelbrot 1983).

The Storegga Slide, located 120 km offshore Norway, is a mega-scale geomorphic system (Figure 1). Like most other submarine slides, the Storegga Slide has been investigated using an engineering approach. In subaerial geomorphology, the statistical characteristics of landslide inventories have become a recent focus of study (e.g.

V. Lykousis, D. Sakellariou and J. Locat (eds.), Submarine Mass Movements and Their Consequences, 3–10.

Guzzetti *et al.* 2002). In comparison, the statistics of submarine mass movement data are still poorly characterised. The extensive coverage and the excellent quality of the acoustic imagery from the Storegga Slide allow us to investigate the aggregate behaviour of the Storegga Slide and carry out a statistical analysis of its constituent mass movements. The objectives of this study are to assess whether the size statistics of the Storegga Slide mass movements exhibit scale invariance, and to explain the origin and implications of such behaviour.

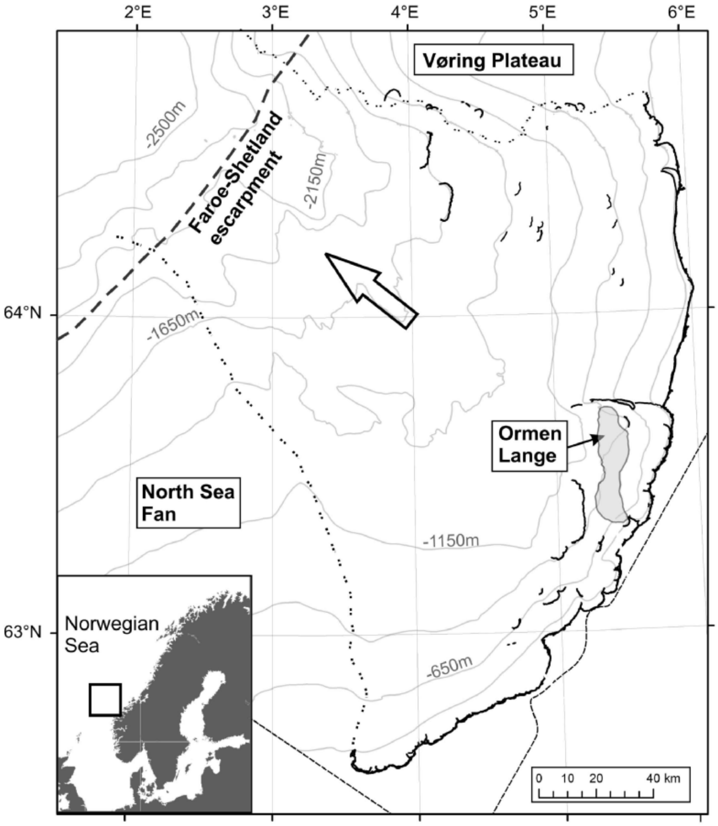

Figure 1. Bathymetric contour map of the Storegga Slide (contour interval of 250 m). The headwalls that were extracted from the bathymetric data set are represented by solid black lines. The arrow indicates the direction of sediment mobilisation. The location of the Storegga Slide is shown in the inset.

2. Method

The study is based on a high resolution multibeam bathymetry data set covering the slide scar from the main headwall down to a water depth of ca. 2700 m (Figure 1). Most of the data have a horizontal resolution of 25 m or better. A mass movement is defined as a single episode of slope failure where sediment moves downslope under the influence of gravity. The area of the mass movement is delineated by a steep scarp at the upslope limit (headwall) and the distal point of the depositional section at the downslope limit. We use mass movement area as a proxy for magnitude. The estimation of the slide area is hindered by the difficulty in defining the boundaries of quasi-simultaneous slides in a retrogressive slope failure. Thus we try to estimate mass movement area using the length of the associated headwalls, which constitute easily identifiable and prominent features located at the upslope limit of the mass movement. Previous studies of the Storegga Slide have estimated the dimensions of sixty-three mass movements (Haflidason *et al.* 2004). We plot the headwall lengths against the mass movement areas from these published data (Figure 2a). $R^2 = 0.91$ implies a strong statistical dependency between area and length in the form:

$$A = 0.87\, l^{\,1.98} \tag{1}$$

where
A is the area of mass movement (in m^2)
l is the length of headwall (in m)

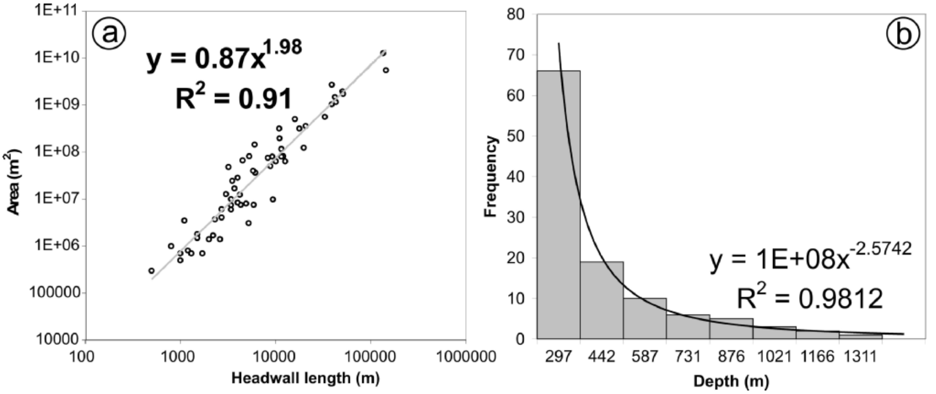

Figure 2. (a) Plot of mass movement area vs. headwall length for the mass movements identified in Haflidason *et al.* (2004). (b) Variation of the number of mass movements extracted from the bathymetric data set (frequency) with depth.

We used a suite of geomorphometric techniques to extract the headwalls automatically from the bathymetric data set. A geomorphmetric map, which is a parametric representation of a landscape decomposed into its elementary morphological units, was generated for the study area. The technique for producing a geomorphometric map is explained in more detail in Micallef *et al.* (2007). Headwalls are extracted as one-cell thick lineaments. Since the geomorphometric techniques delineate headwalls at the resolution of the bathymetric data, rather than at the scale at which the study area is being observed by an investigator, the techniques are more accurate than manual digitisation. Using geomorphometric mapping we were able to extract one hundred and five individual headwalls. The extent of a headwall is defined by the section of the headwall where sediment evacuation has occurred perpendicularly to the lineament. The length of each headwall was calculated using a Geographic Information System, and the area of the mass movement associated with each headwall was estimated using equation (1). A cumulative frequency-area graph was plotted for the mass movements. A non-cumulative distribution, defined in terms of the negative of the derivative of the cumulative distribution with respect to A, was then derived to enable comparison with previous studies (e.g. Guzzetti *et al.* 2002).