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# Failure processes in submarine landslides: A geomorphometric approach.

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Geomorphometry is the quantitative description and measurement of topography and landforms. Whereas geomorphometric techniques have become a standard tool in the investigation of terrestrial and planetary landscapes, their application in the study of submarine environments has been more infrequent. Here we present a novel, GIS-based methodology for the quantitative analysis of submarine elevation data. The method integrates three main morphometric techniques: (1) morphometric attributes and their statistical analyses, (2) feature-based quantitative representation, and (3) automated topographic classification. These techniques allow the objective extraction of useful morphological information from bathymetric data that can enhance submarine geological investigations significantly. We apply these techniques to high resolution bathymetric data from the Storegga Slide, one of the largest known submarine landslides, to investigate three aspects of submarine mass movements and demonstrate the effectiveness of the geomorphometric approach:

(i) Spreading: A poorly understood type of submarine mass movement, spreading is shown to be widespread within the Storegga Slide. We combine geomorphometric techniques with side scan sonar imagery, seismic data, limit-equilibrium and mechanical modeling to identify the potential triggers and understand the mode of failure. Two modes of failure can be identified for submarine spreading. The first involves retrogressive slide development via the unloading of the headwall. The second entails the extension downslope by gravity of a thin, coherent slab of semi-consolidated material. Both modes of failure involve the break up of surface sediment units into coherent blocks and their displacement along planar slip surfaces. The block movement pattern entails an exponential increase of displacement, and thinning of the failing sediment, with distance downslope. Loss of support and seismic loading are proposed as the main triggering mechanisms of submarine spreading.
(ii) Fractal statistics and morphology: Fractal analysis of 115 headwall morphologies within the Storegga Slide reveals the occurrence of spatial scale invariance. One explanation for this scale invariance is that the Storegga Slide is a geomorphological system that exhibits self-organised criticality. Spatial scale invariance may also be linked to the retrogressive nature of the Storegga Slide. The shape and fractal dimension of headwalls, on the other hand, can be used as a proxy for the type of the formative mass movements. The implications of these results are important in terms of submarine mass movement modelling and hazard assessment.
(iii) Slide development: A geomorphometric analysis of the seafloor was carried out in the north-eastern Storegga Slide to map submarine mass movements in detail and identify the geological factors and processes responsible for their occurrence. The results were integrated with side scan sonar and seismic data to propose a revised development model, consisting of four major events, which emphasises the role of gas hydrate dissolution/dissociation and contourite deposition in controlling the location and extent of slope failure across the north-eastern Storegga Slide.