

Waves on the horizon

After recent events in Japan and the Indian Ocean, the world is alert to the risk posed by earthquake-generated tsunamis. A team of scientists are now seeking to understand a rarer type of tsunami caused by huge underwater landslides, and determine whether climate change might affect their frequency. Project leader Peter Talling, of the National Oceanography Centre, talks to *Nature Climate Change*.

■ What causes these tsunamis?

We are looking at tsunamis that are triggered by the motion of underwater landslides, rather than the uplift or subsidence of the seafloor during an earthquake. The collapse of volcanic islands can also generate huge landslides, but our focus is landslides on non-volcanic continental slopes, where slope failure occurs on gradients of just 1–2°. For comparison, a Premiership football pitch has a gradient of around 1°. Models of failure on such remarkably shallow inclines are poorly tested, and it is possible that earthquakes sometimes provide the final trigger. The huge scale of some underwater landslides will come as a surprise to many people, and can be difficult to convey. The Storegga Slide that occurred around 8,200 years ago offshore from Norway was larger than Scotland (Fig. 1), left an upper headwall 300 km long and involved more than 3,000 km³ of material 300 times the annual sediment output from all the world's rivers. Tsunamis generated by slides are less frequent than those caused by earthquakes, but are more difficult to warn against and can be very destructive. The Storegga Slide produced a tsunami that reached heights of up to 20 meters along surrounding coastlines. For countries located far from major fault lines or active volcanoes, there are few other natural processes that have the potential to inflict such severe damage.

■ What are the key questions?

The first is, how often do slides occur? Landslides can be difficult to date precisely, but six very large landslides are thought to have taken place in the Nordic Seas in the last 20,000 years, which would indicate a return interval of around three to four thousand years in this region. That might sound rare enough, but the UK exerts a legal requirement on certain key infrastructure providers to address hazards events that occur once every 10,000 years or less, and current evidence may put landslide-induced tsunamis into this category. These slides occur on remarkably low gradients, and this brings us to another important question: how is failure triggered on such low inclines? A widely held theory is that rapid accumulation of impermeable

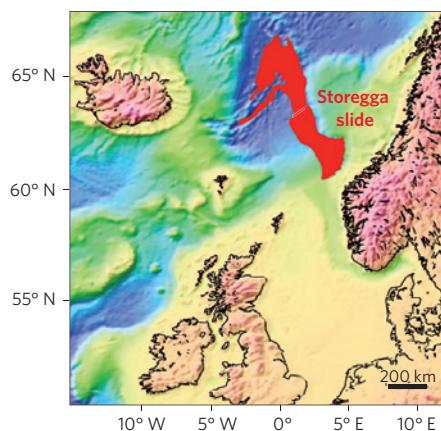


Figure 1 | Map of the Storegga Slide. Figure reproduced with permission from S. Bondevik et al. *Eos* **84**, 289–300 © 2003 AGU/Wiley.

sediment is needed to precondition a slope to fail, with the final trigger being a large earthquake. However, huge failures are also observed in areas of very slow sedimentation, and in regions with few large earthquakes, so this explanation does not explain all mega-slides. A final question is simply, how do these landslides move? This is important because it determines the size of the tsunami wave generated, but difficult to answer because we are yet to study one of these landslides in action. The Storegga Slide seems to have moved very quickly (tens of metres per second), but a lack of tsunami deposits associated with other large landslides suggests that they can sometimes move rather slowly.

■ What's the evidence for these landslides?

The chunks of material missing from the seafloor can be identified through detailed mapping, as can the accumulations of sediment at the bottom of the slope. These bathymetric maps often resemble images of snow-slab avalanches, but on a huge scale, with failure occurring along distinct horizons over large areas (Fig. 1). Coring and dating of the sediment draped on top of the landslide can help to document when the slide occurred. The Storegga Slide is one of the few really well-dated slides. Only after around

100 cores were taken did it become apparent that the slide was essentially one event; it was previously thought to have occurred in three stages.

■ What about the tsunamis themselves?

The evidence for tsunami waves is primarily from so-called tsunami deposits, which include relatively coarse-grained sediments deposited on low-lying areas landward of the coastline. These layers need to be carefully distinguished from the sediments left by large storms, but tsunami deposits tend to extend further inland. The recent Japanese and Indian Ocean tsunamis have helped us to understand the distinctive features of these deposits, and where they are best preserved. The Storegga tsunami is well documented around the Northeast Atlantic, but in a few locations in the Shetland Islands there is evidence for younger tsunamis that reached the UK ~ 1,500 years ago. Continuing fieldwork aims to map the extent of these more recent tsunami deposits, and understand the most likely source.

■ Is there a link to climate change?

Landslide tsunamis are rare events, but we need to know whether their frequency is set to change significantly with the climate. It has been proposed that climate changes could increase slide frequency in two ways. The first is methane hydrate dissociation — the release of methane gas from a previously stable state in the sediment — which could cause structural weakness and initiate a slip. The second is crustal rebound, where loss of an ice sheet releases pressure from the Earth's crust allowing it to 'spring back' to a new equilibrium position. Such adjustments would be likely around Greenland if substantial amounts of ice were lost, and could potentially initiate slides in that region. These ideas remain poorly tested. Enigmatically, the timing of the Storegga Slide coincides closely with the last major abrupt change in global climate, the so-called 8.2 kyr BP climatic event seen in the Greenland ice cores.

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