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The significance of weak layers for submarine slope failure

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Submarine landslides are gravitational mass movements that are common on continental slopes worldwide. They have the potential to damage expensive subsea infrastructure such as pipelines or telecommunication cables, and generate hazardous tsunamis. Numerous studies have shown that slope morphology and stratigraphy, in particular the sequencing of layers with different physical properties or permeabilities, play an important role in controlling where failure surfaces of submarine landslides are formed. The concept of so-called "weak layers" suggests that prominent layers embedded within the slope stratigraphy serve as preferential failure and gliding planes, and therefore, play a major role in the inception of submarine landslides.

Many studies have emphasised the importance of weak layers, which is now a widely accepted concept; however, little is known about the composition and nature of such layers because the slide movement usually removes or remoulds them. Two general key mechanisms have been proposed to explain the formation of failure along these weak layers. The first is due to stratigraphically-controlled permeability variations, which can enable the generation of subsurface excess pore pressures (i.e. above hydrostatic pressure). Low permeability layers such as clay prevent the vertical dissipation of pore fluids and thereby promote the accumulation of excess pore pressure. High permeability layers also have the potential to generate high overpressure, if they comprise compressible or collapsible grains. Prominent examples of such layers include fragile biogenic sediments or embedded volcanic ashes. The loss of sediment structure under loading can rearrange or break down these grains, causing a reduction in volume and subsequent pore pressure increase. This rise in pore pressure reduces the vertical effective stress, which in turn decreases the shear strength of the sediment and reduces slope stability. While several studies have implicated permeability as a strong control on slope failure, it remains unclear precisely where a failure plane is located relative to these permeability interfaces (i.e. at, above or below). The second proposed mechanism is stratigraphically-controlled contrasts in sediment strength and behaviour under loading. Where sediments exhibit strain-softening, for example, they may progressively fail without a need for high slopes or excess pore pressures.

Here we present an initial global synthesis of submarine landslide studies, specifically focusing on the role of weak layers in their inception. We first provide an overview of the environments where slope stability has been controlled by weak layers. Second, we categorise the nature of these weak layers. Finally, we discuss the broader controls on where and why different weak layer mechanisms may dominate in different settings.