Submarine slope instabilities in gas hydrate-bearing sediments: peak strength versus strain softening

Photography encouraged

Nabil Sultan - Ifremer, Géosciences Marines, France
nabil.sultan@ifremer.fr

Introduction

- Gas hydrates (GH) content can significantly increase the peak shear strength of hydrate bearing sediments while developing its strain softening.
- Recent publications have reported the occurrence of slope instabilities within the gas hydrate stability zones suggesting a mechanical cause for the failure rather than a thermodynamic one (*Sultan et al., 2011; Mountjoy et al., 2014*).

➲ This work aims to examine, through a computational numerical approach, the potential link between gas hydrate content, strain softening behavior and slope stability in gas hydrate-bearing sediments.

A - Behavior of gas hydrate-bearing sands: strength versus strain softening

- Elastic modulus, peak strength and dilation angles of hydrate-bearing sands increase with hydrate saturation
- Remolded strength remains constant

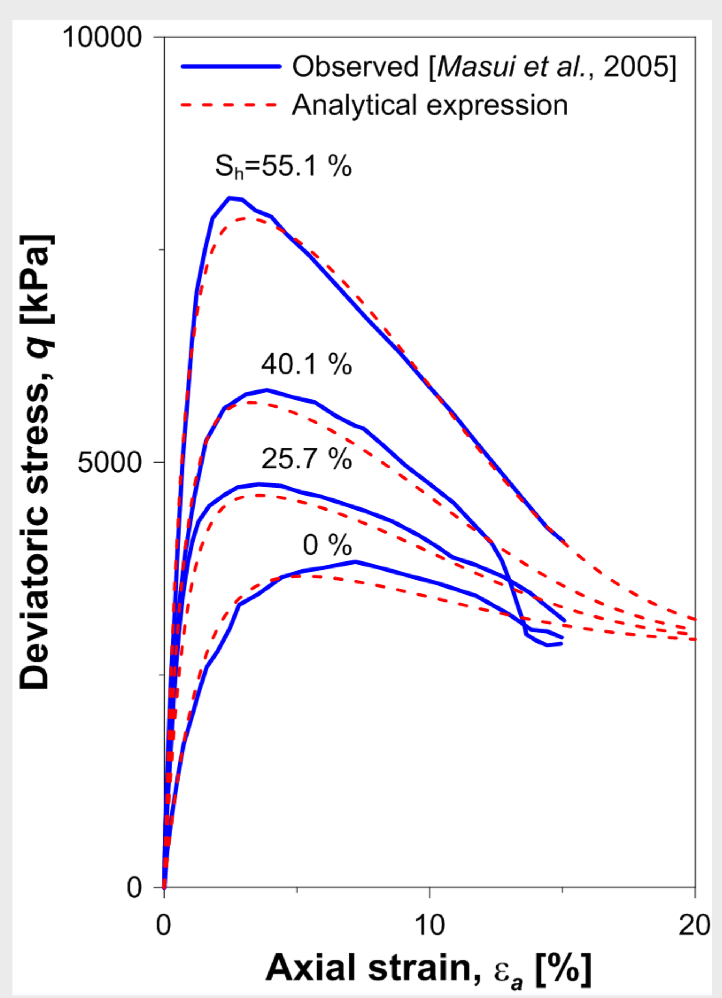
➲ We propose an empirical expression of τ/τ_p with four control parameters on the shape of the stress-strain curve:

β: elastic stiffness of the material and is proportional to the Young's modulus

St: sensitivity

α and δ are two shape parameters

$$\frac{\tau}{\tau_p} = \left[\left(1-\exp(-\beta.\gamma)\right) + \left(\exp(-\delta.\gamma^{\alpha})-1\right)\left(1-\frac{1}{St}\right)\right]$$

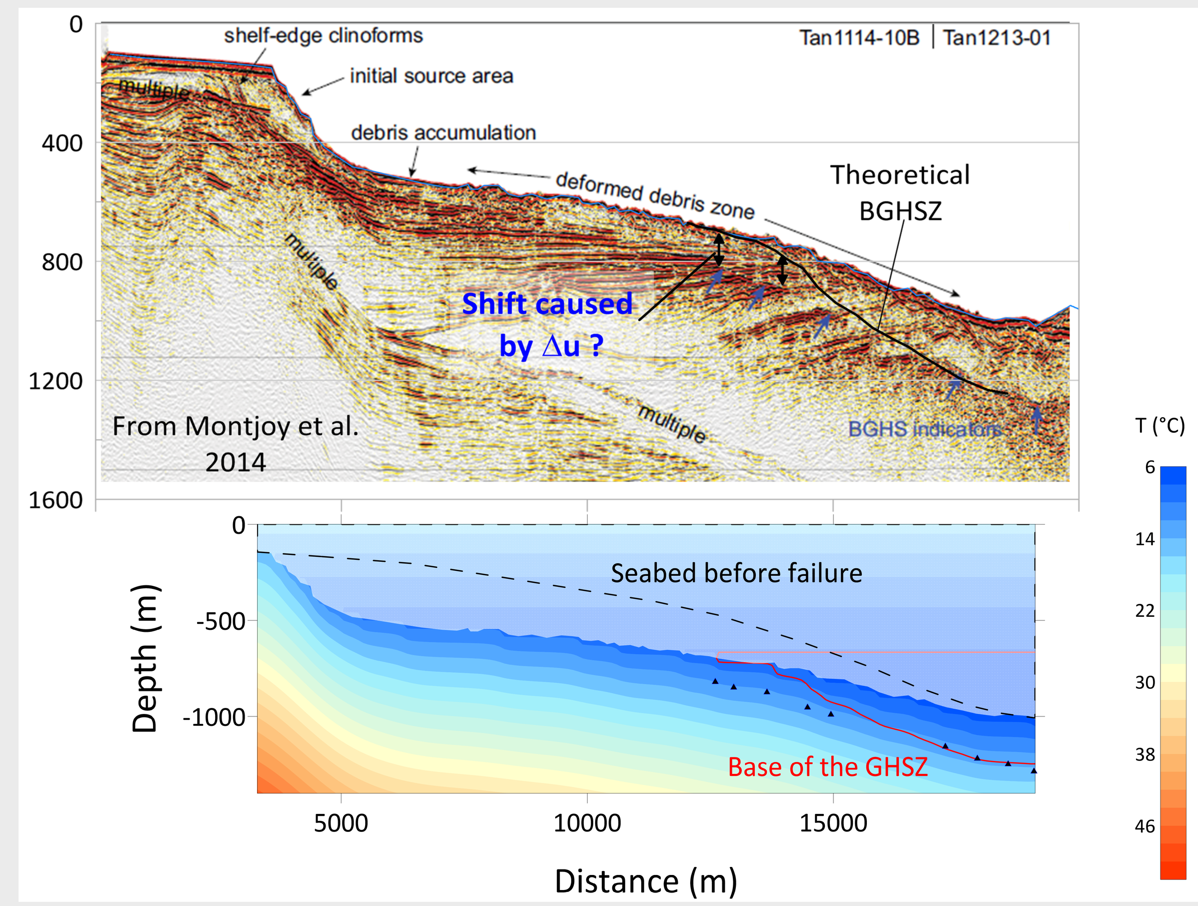


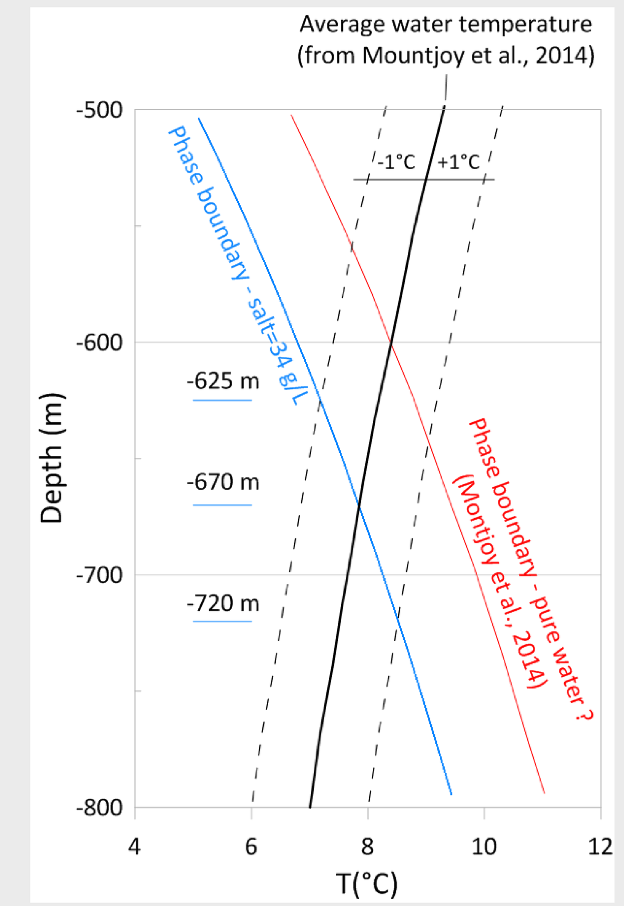
B - 3D slope stability modeling with strain softening behavior

This was implemented in a 3D slope stability model (SAMU-3D: *Sultan et al., 2007*) by adding to the classical limit analysis method a shear strain field compatibility equivalent to the velocity field compatibility (Sultan et al., 2011).

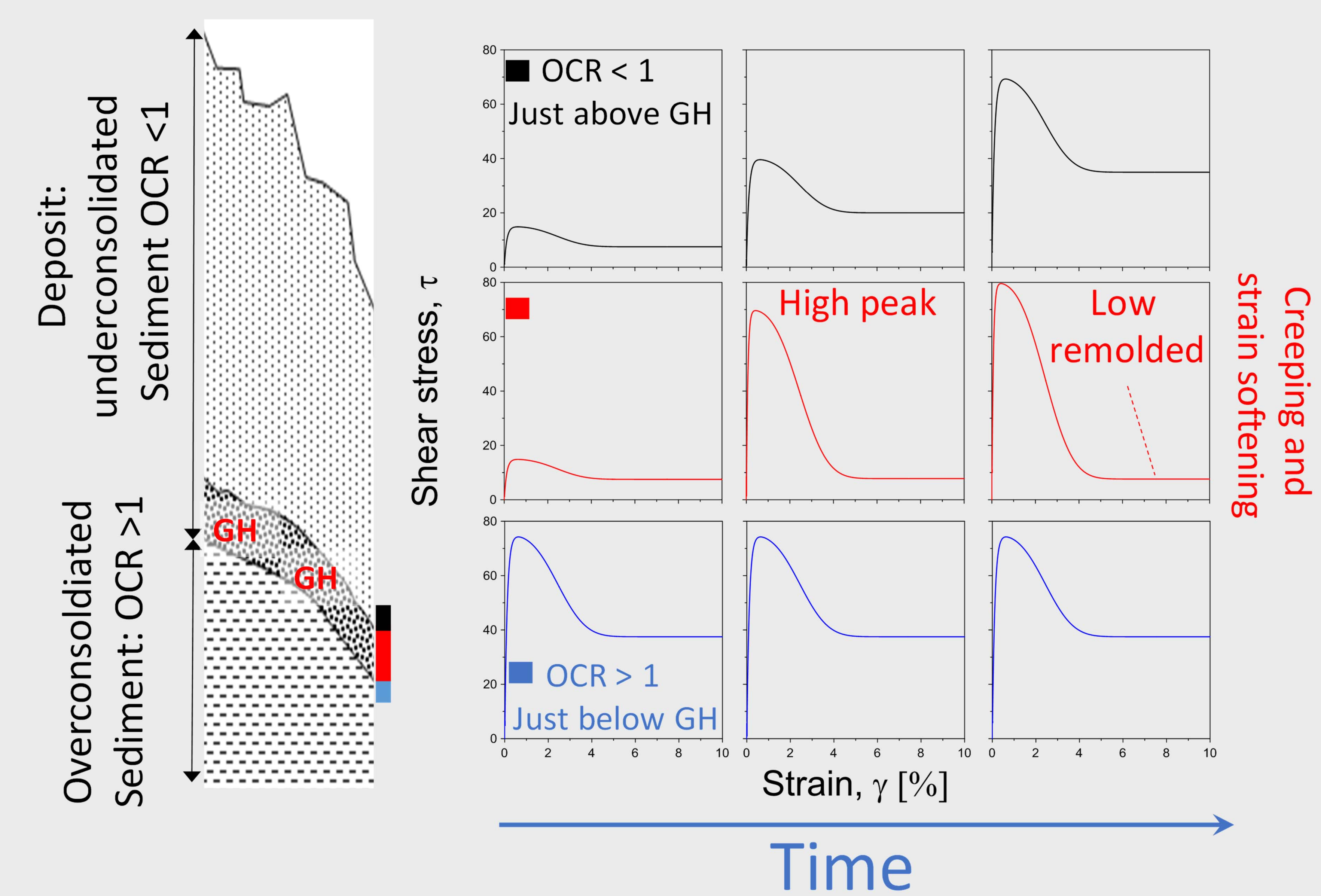
C – Gas hydrate stability zone: Hikurangi Margin, New Zealand

- The Tuaheni Landslide Complex on the Hikurangi margin shows evidence for active, creeping deformation (*IODP 372 Scientific Prospectus and Montjoy et al. 2014*). Gas hydrate may be linked to creeping (*IODP 372 Scientific Prospectus , initial hypothesis*)
- This "*seems unlikely because gas hydrates occur > 65 meters beneath the slide mass*" (**IODP data –** *Screaton et al., 2018*).



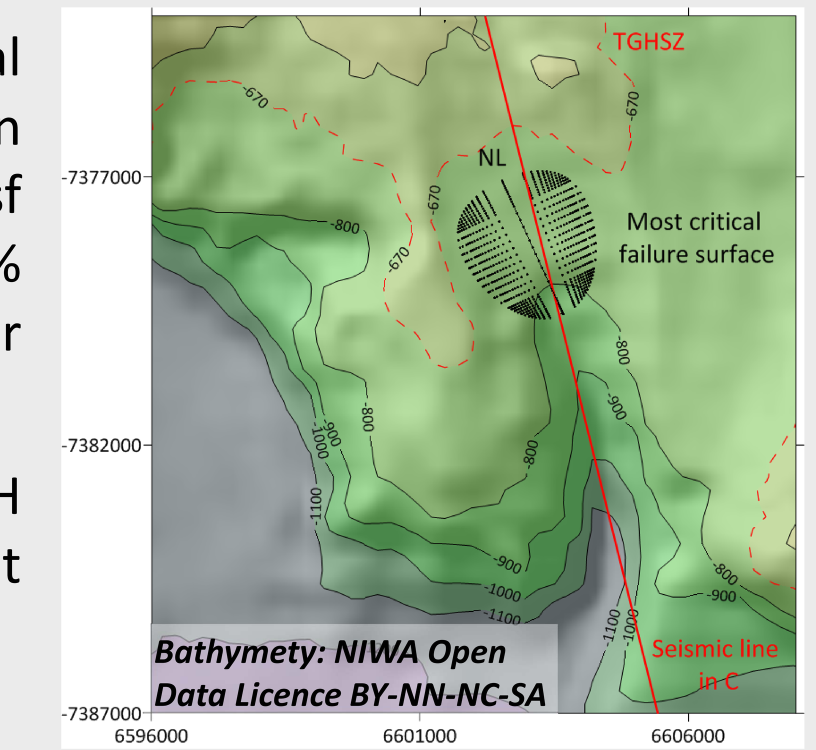


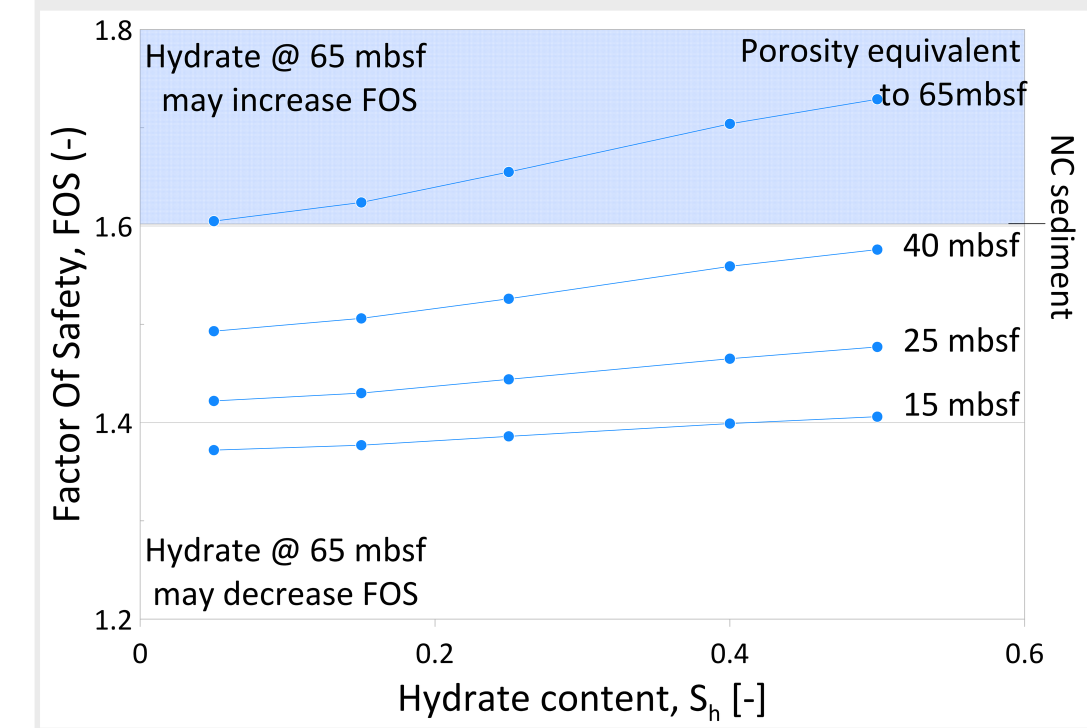
D – Possible mechanism involving under-consolidated sediments, GH, strain softening and creeping deformations

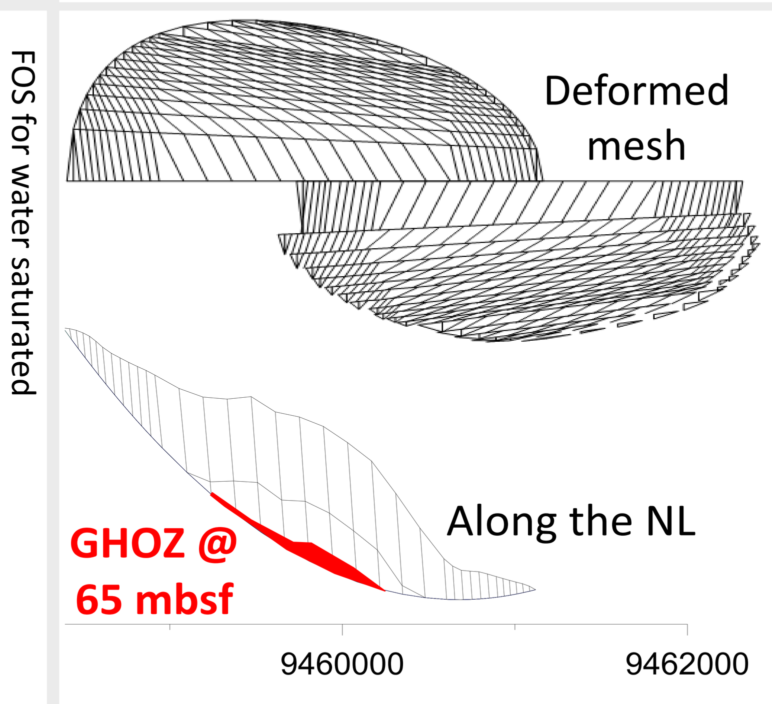


E – Undrained slope stability analysis using SAMU-3D-SS: case of the Tuaheni landslide with virtual mechanical parameters

- Under the considered mechanical conditions (Su(kPa)=z(m) and γ' between 8 and 13 kN/m³), GH formed at 15 mbsf with a degree of hydrate saturation of 5% may reduce the FOS of the water saturated slope by 17%.
- FOS sensitive to the degree of GH saturation and the consolidation state at which hydrates were formed.







Conclusion

➲ Strain softening of gas hydrates-bearing sediments could be prejudicial for submarine slope stabilities and may completely erase the supposed benefic effect of gas hydrates on their host sediments strength.

➲ FOS values depend strongly on the depth at which hydrates were formed and on the degree of hydrate saturation.

➲ Tuaheni landslide: Gas hydrates at 65 mbsf may be at the origin of seabed creeping process

References

Barnes et al. International Ocean Discovery Program Expedition 372 Scientific Prospectus.

Masui et al., 2005. Effects of methane hydrate formation on shear strength of synthetic methane hydrate sediments. In: Proceedings of the 15th International Offshore and Polar Engineering Conference, Seoul, 364-369.

Mountjoy et al. ,2014. Shallow methane hydrate system controls ongoing, downslope sediment transport in a low-velocity active submarine landslide complex, Hikurangi Margin, New Zealand, G3.

NIWA Open Data Licence BY-NN-NC-SA version 1

Screaton et al., 2018. Impact of sea-level and bottom water temperature change on methane-hydrate stability: IODP Site U1517, Hikurangi Margin, AGU abstract.

Sultan et al., 2007. Analysis of slope failures in submarine canyon heads: an example from the Gulf of Lions. Journal of Geophysical Research. 112(F1): F01009.

Sultan et al,. 2011. Gas hydrate occurrences and seafloor deformation: investigation of strain-softening of gas-hydrate bearing sediments and its consequence in terms of submarine slope instabilities. 2011 Offshore Technology Conference.