Background

Gas hydrate dissociation caused by climate induced change of temperature and sea level has been proposed as a trigger mechanism for submarine slides. Seabed instability around hot wells and pipelines is of concern for the petroleum industry.

A large effort is put on development of methodology and techniques for detection and quantification of gas hydrate. However, there is a lack of understanding of how the hydrate dissociation process may affect the geomechanical properties of soils. Soil strength reduction is a key element in assessment of risk related to dissociation of gas hydrates.
Gas hydrate melting caused by climate change after deglaciation

Geothermal gradient 50°C/km
Storegga North Flank BSR and paleoslide

Gas/Fluid escape features?
Storegga North Flank BSR and paleo slide
Simulation of melting zone around wells

FE-analysis showing gas hydrate melting zone around hot gas well after 22 years production time

![Diagram showing radial distance and depth with melting zones indicated with contours](image.jpg)
Simulation of heat flow around pipelines
Objective of ongoing research:

Improve knowledge and understanding of effect of gas expansion and gas hydrate melting on soil strength

• What happens physically during and after the dissociation process
  – GH dissociates to water + gas forming gas/water bubbles on the GH surface
  – bubble expansion causes pore pressure increase in the gas and water phase
  – cavity expansion in the clay matrix -> hydraulic fracture -> fluid migration -> pressure drop
  – Change in effective stresses in “bubbly” soil matrix?

• How does gas hydrate and gas hydrate dissociation affect the geotechnical properties of clays
  – primarily strength related to slope stability and foundation of structures, but also compression (bulk) and shear modulus
Methodology:

• Improved understanding of physical process through visualisation of GH dissolution and gas expansion process
• Develop material models
• Analytical /numerical modelling
• Compare with tests on soil elements under realistic stress conditions and model tests
Methodology first phase:

• Study gas exsolution in clays
  – Visualisation
  – Effect on material properties
• Study gas hydrate formation and dissociation
  – visualising GH melting and gas expansion effects in transparent Laponite clay
• Perform laboratory test on natural marine clay
• CT-scanning of gas-fluid flow and GH-formation and melting?
• EM and S-waves for improved mapping of GH?
Air exsolution and expansion in Laponite

1. Laponite covered by water layer
2. Air pressure above water 6 bar (7 atm) for several weeks
3. Air diffusion into Laponite
4. Pressure reduction
5. Gas bubble formation

Third test on laponite with air
Third test on laponite with $\text{CO}_2$
Hydrate melting/gas expansion experiments with R11 in Laponite gel

- **8.5°C < T < 24°C**: Mix to gel above hydrate formation temperature.
- **0°C < T < 8.5°C**: Shrink due to hydrate formation?
- **8.5°C < T < 24°C**: Expand back due to melting? Expand further due to R11 "boiling” forming gas bubbles.
- **24°C < T < 30°C**: Water + Laponite + R11

Water + Laponite + R11

Water + Laponite + R11

Water + Laponite + R11

Water + Laponite + R11
Tests with R11 hydrate layer in Laponite

29g R11 + 250ml H₂O

Hydrate layer embedded in Laponite

Hydrate disassociation – bubble formation
Tests with R11 hydrate layer in Laponite

29g R11 + 250ml H₂O

R11 Hydrate distributed in Laponite

Short video
Results so far

Gas exsolution tests in Laponite

• Gas exsolution testing indicated limited expansion of gas bubbles for moderate $\Delta T$ and $\Delta p$ for samples saturated with air

• High pressure relief (7 to 1 atm) with CO2 saturated samples showed large release of gas, fracturing of clay matrix and formation of gas escape routes

• Clay matrix cracked but material not seemingly disturbed between cracks and bubbles
Results so far

- Hydrate formation in clay:
- Previous tests with Methane circulation through natural marine clay not successful. No signs of hydrate formation
- R11 Hydrate formation in Laponite at 1 atm and 8°C below theoretical melting temperature not successful. Formation inhibited by Laponite - no free water?

- Hydrate formation with water and then mixing with clay:
  - R11 hydrate easy to form and mix into Laponite in various forms of distribution
  - Visibility in Laponite good
Results so far

Hydrate dissolution and gas expansion tests:

• Introductory tests show successful in visualising processes
• Laponite 5% has low strength, Thixotropic and visco-plastic, difficult to measure effect on material strength.
• Bubble flow through material rather than fracturing
• Increase strength by increasing Laponite content, and still maintain visibility
• Material will not transform into a foam under deepwater conditions in situ
• Sample disturbance of deepwater soil samples should be high and effect of gas hydrate dissolution should be very clearly visible if gas hydrates are present
• Test so far had very high "gas expansion potential" compared with deepwater conditions. Test with more realistic GH concentrations will be performed
Hydrate melting/gas expansion experiments with intact natural marine clay

Workscope: Study (and visualise?) the melting and gas expansion process at elevated pressures
- Onsøy intact marine clay samples
- R11 - CO₂ or CH₄ -> Hydrate -> Water and gas
- Circulate gas saturated water or diffusion through rubber membrane? At high pressure and “low” temperature
- Increase temperature/reduce pressure
- Melting->Volume increase -> bubble formation? Fracturing?
- Change in consistency – strength?
- Visualisation of bubble growth – fluid escape formation?-> CT?
High pressure triaxial test equipment:
- Stress control vertical and lateral
- Pore pressure/backpressure
- Methane saturation and circulation system
- Cooling system
- Temperature control (3 thermistors)
- Resistivity measurement (hydrate indication)
Velocity, saturation and fluid distributions measured by a 4D-CT laboratory method
Acoustic / CT

The integrated CT / acoustic laboratory for simultaneous imaging of fluid distribution and measurement of wave velocity under reservoir pressure
Acoustic / CT

Example of CT-imaging of gas saturation from an experiment with nitrogen injection into an initially decane filled core.

Absolute value plots

Subtraction plots

Hot colour indicates high density

Hot colour indicates high gas concentration

Sg=35.5% Sg=0%

Sg=35.5%