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Gas hydrate evolution in glaciated margins

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Centre for
Arctic Gas Hydrate,
Environment and Climate



Norwegian
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Excellence



GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

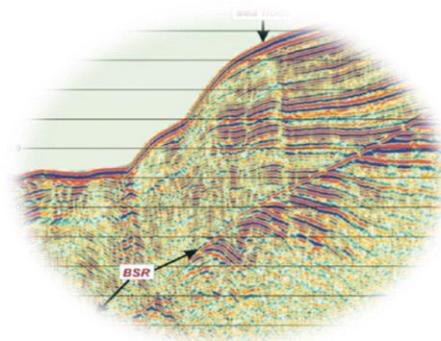


Outline

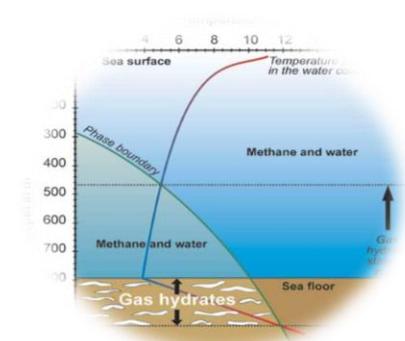
Introduction



Basic elements



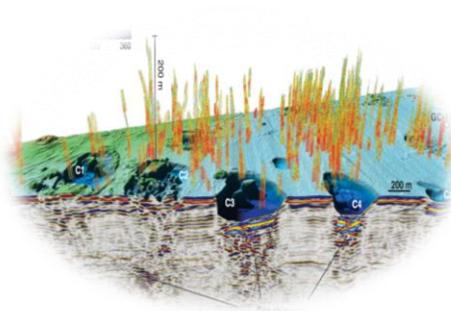
Gas Hydrate Stability



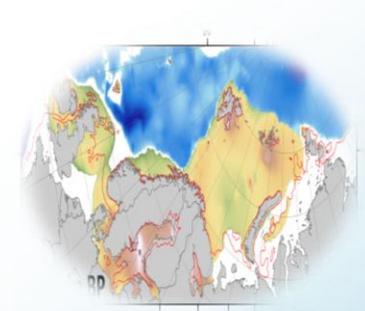
Glaciated margins



Hydrate response

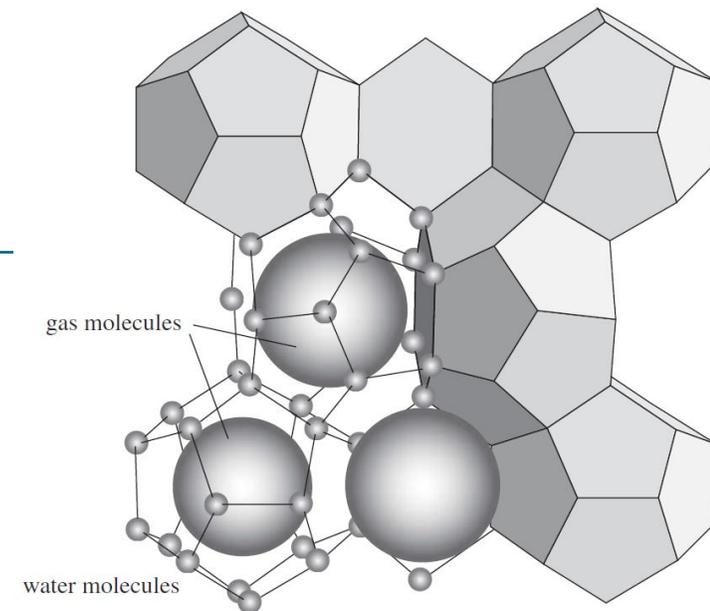


Challenges and Summary

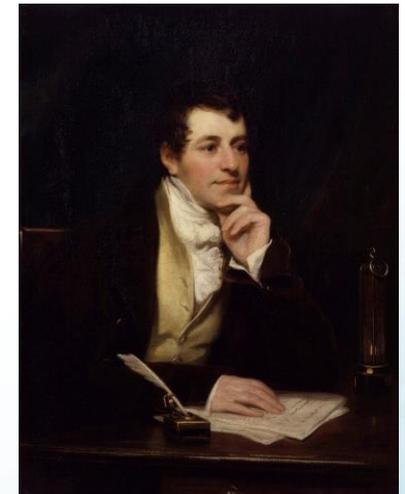


Hydrates are crystalline solids composed of water and gas

- Also known as 'Clathrates'
- Discovered in 1810 by Sir Humphry Davy by producing Chlorine Hydrate
- Can form from gases such as CH_4 , CO_2 , Cl_2 , SO_2 , H_2S , C_2H_6 , C_3H_8 etc.



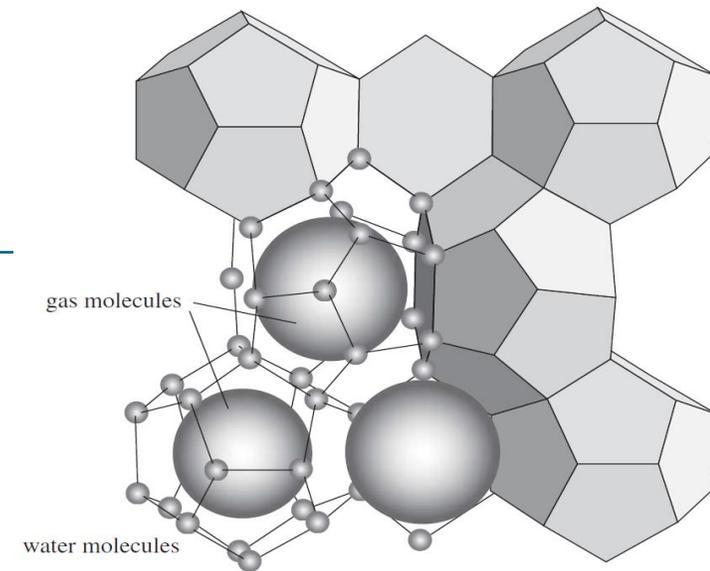
Maslin et al., 2010



Hydrates are crystalline solids composed of water and gas

Three distinct phases of gas hydrate research

- 1810 -1920s: A chemical oddity, laboratory curiosity
- Since the 1930s: Dirty ice clogging natural gas pipelines
- Since the 1970s: Discovery of natural gas hydrates in marine sediments
 - The last two decades: Economic potential and Environmental implications



Maslin et al., 2010



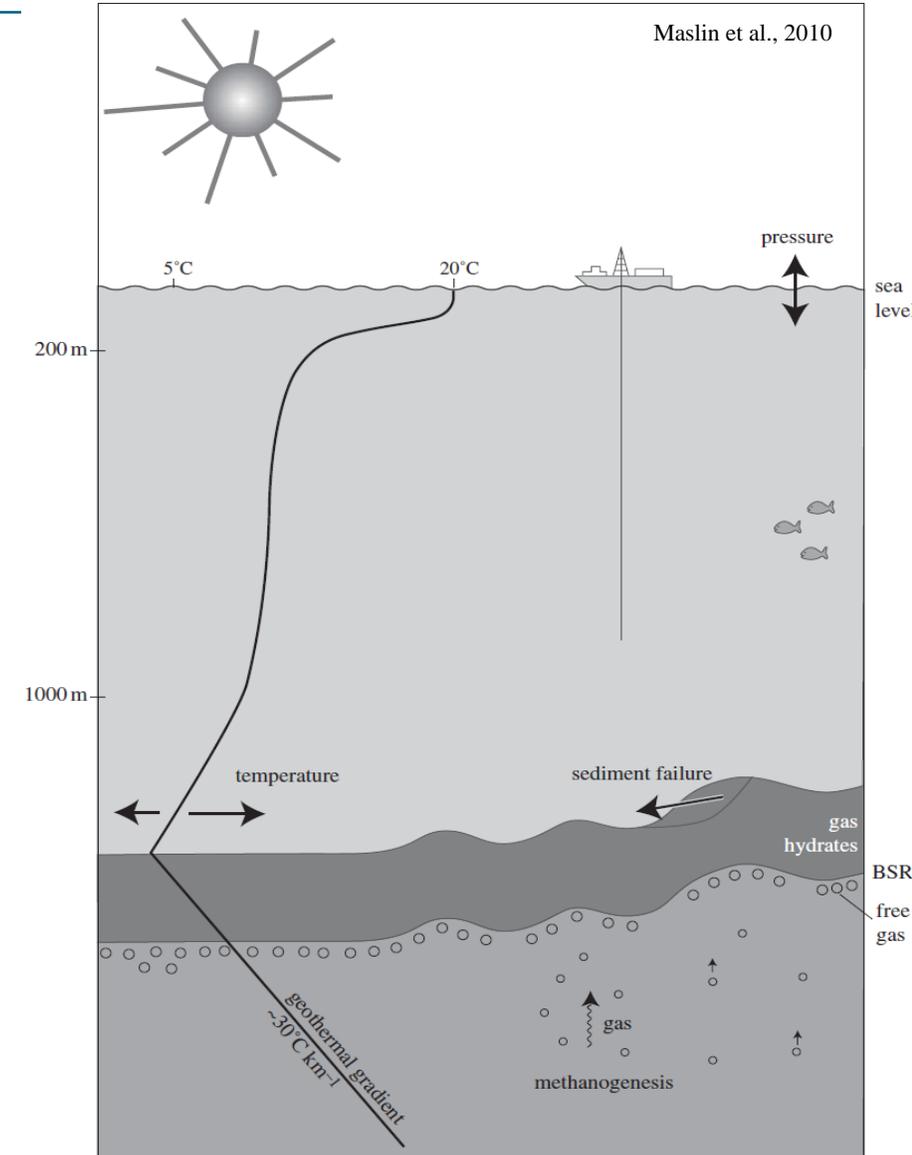
Yang et al., 2006



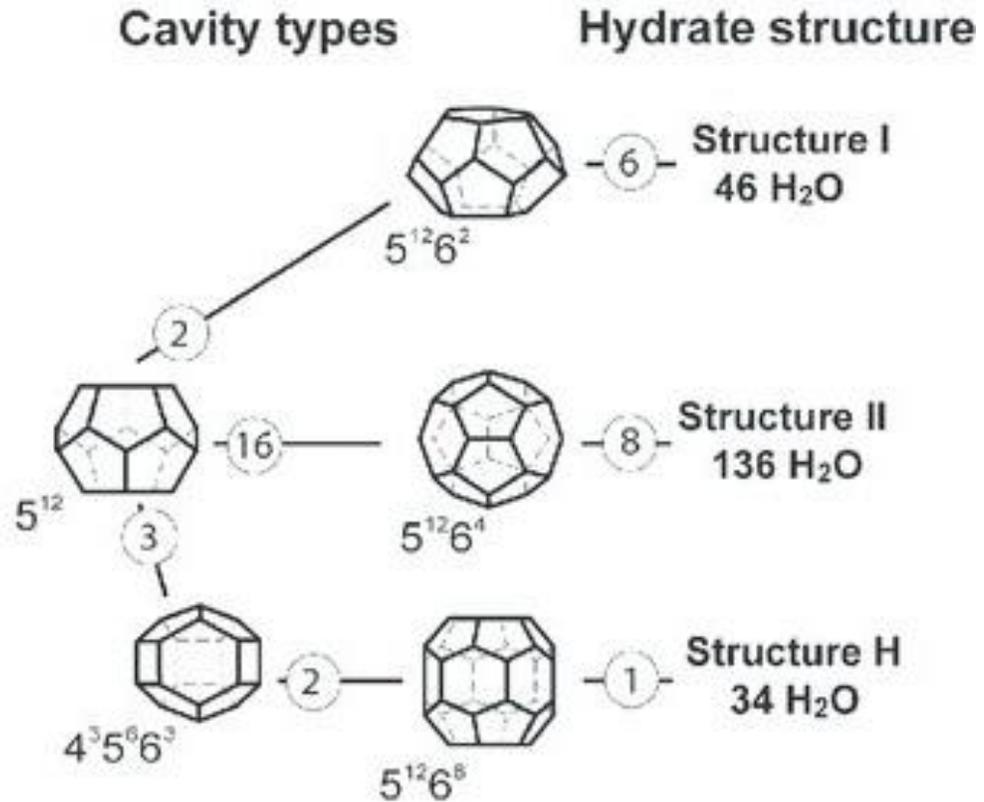
<http://soundwaves.usgs.gov/2002/09/>

Natural gas hydrates consists of water and (mainly) methane gas

- First seafloor samples recovered by Russian vessels in the Black Sea (Yefremova and Zhizhchenko, 1974).
- Form in sediments under low temperature and high pressure conditions with adequate supply of gas.



Three types of hydrates

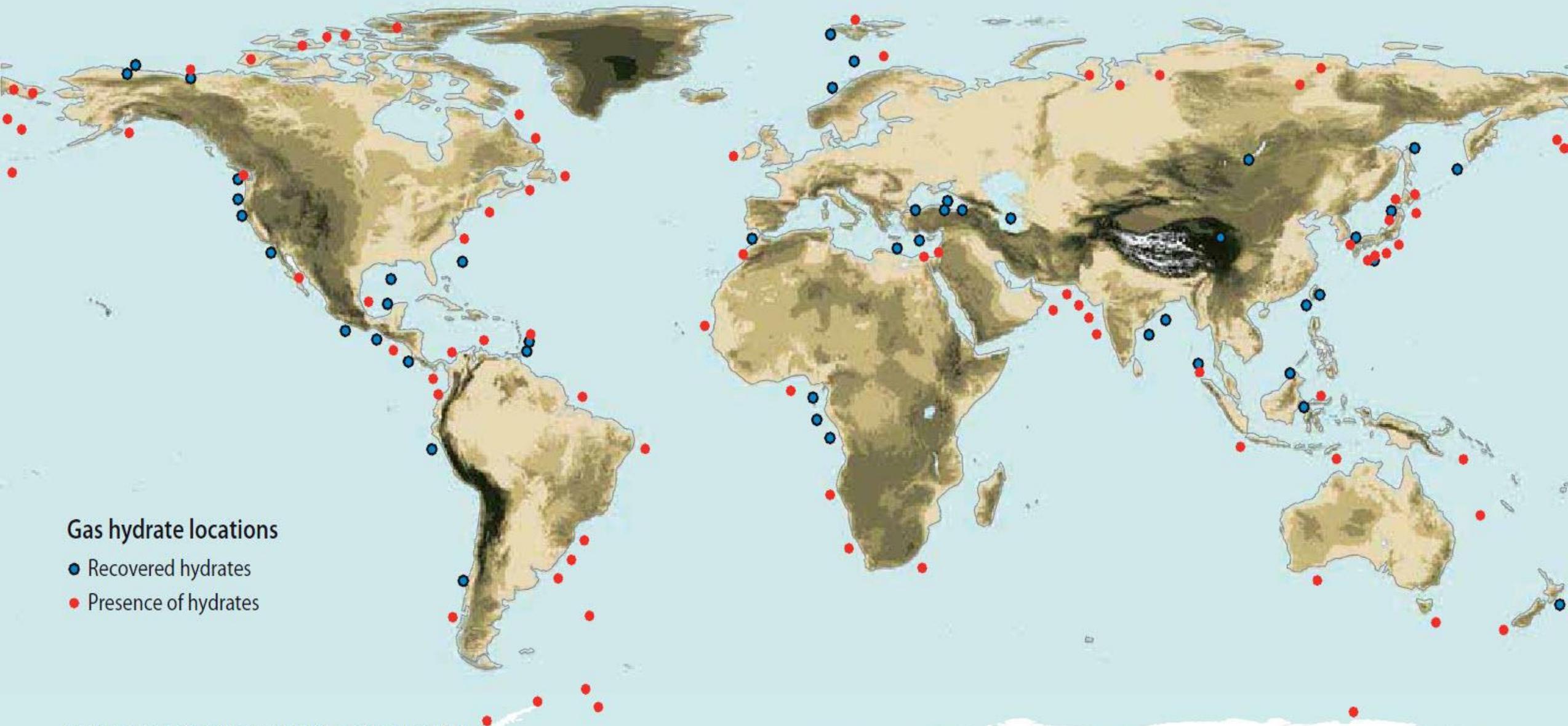


Encapsulates smaller molecules such as Methane

Encapsulates larger molecules such as Ethane, CO₂, Butane etc

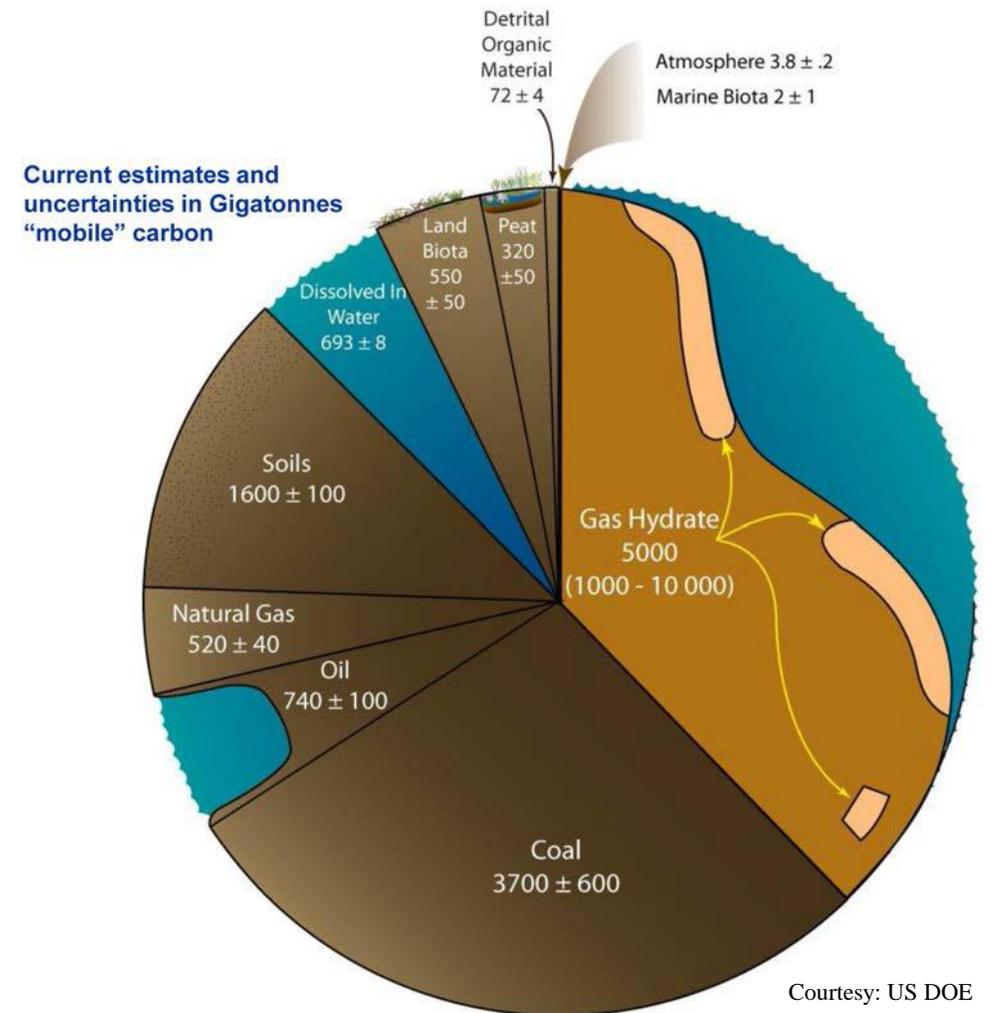
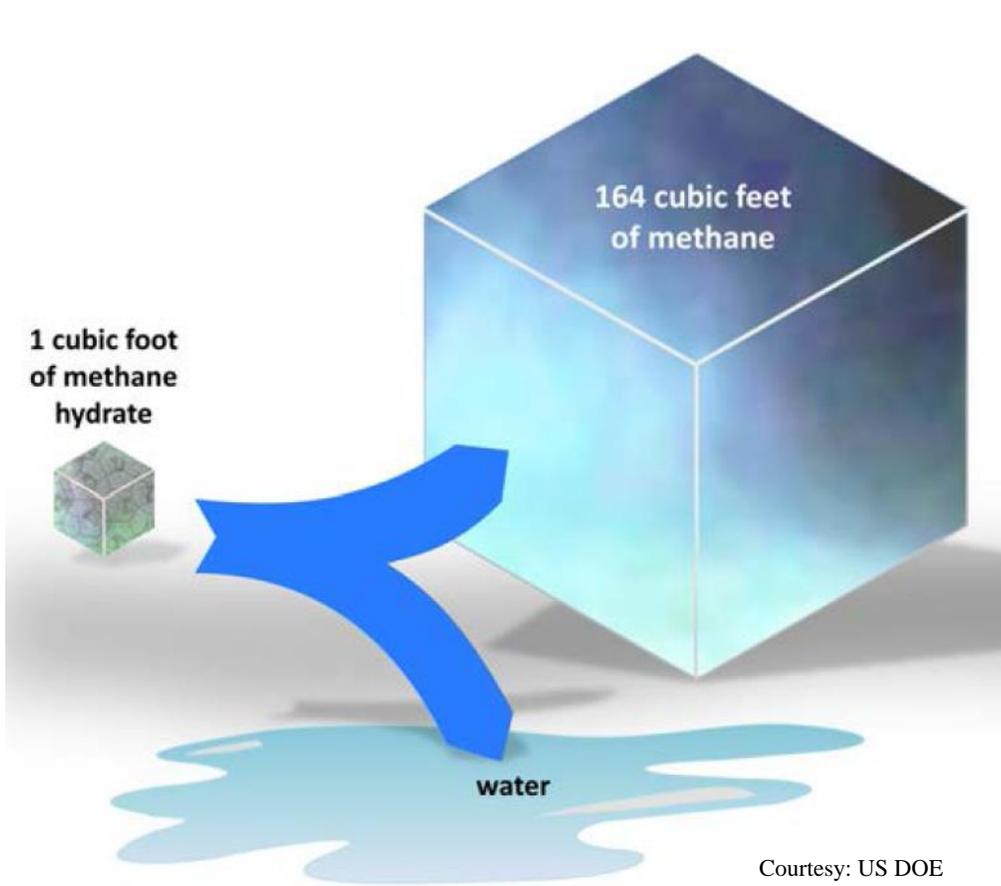
Can encompass even larger molecules such as pentanes and hexanes.

Natural gas hydrates occur on all continental margins and permafrost regions on Earth

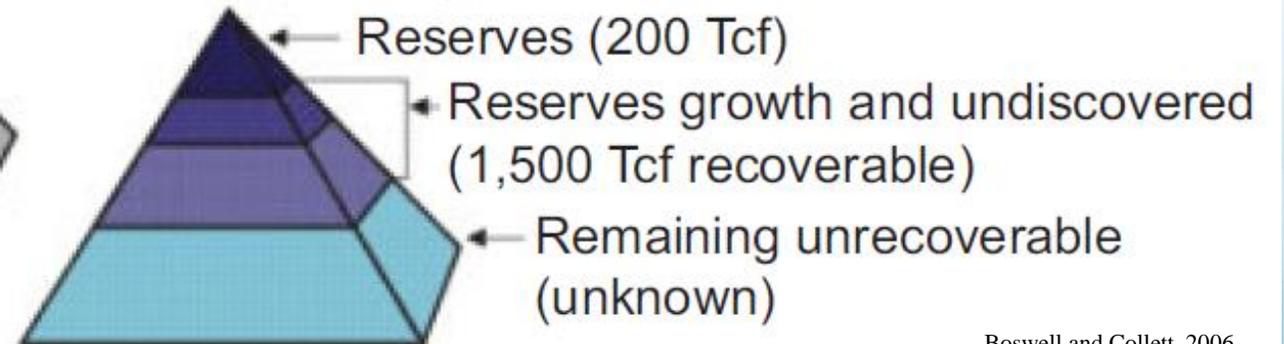
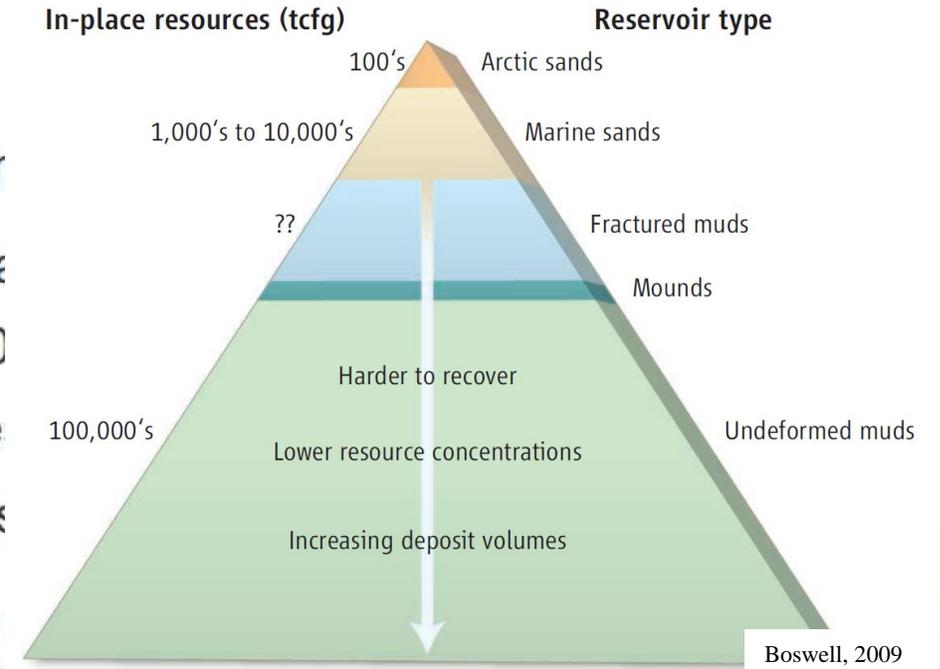
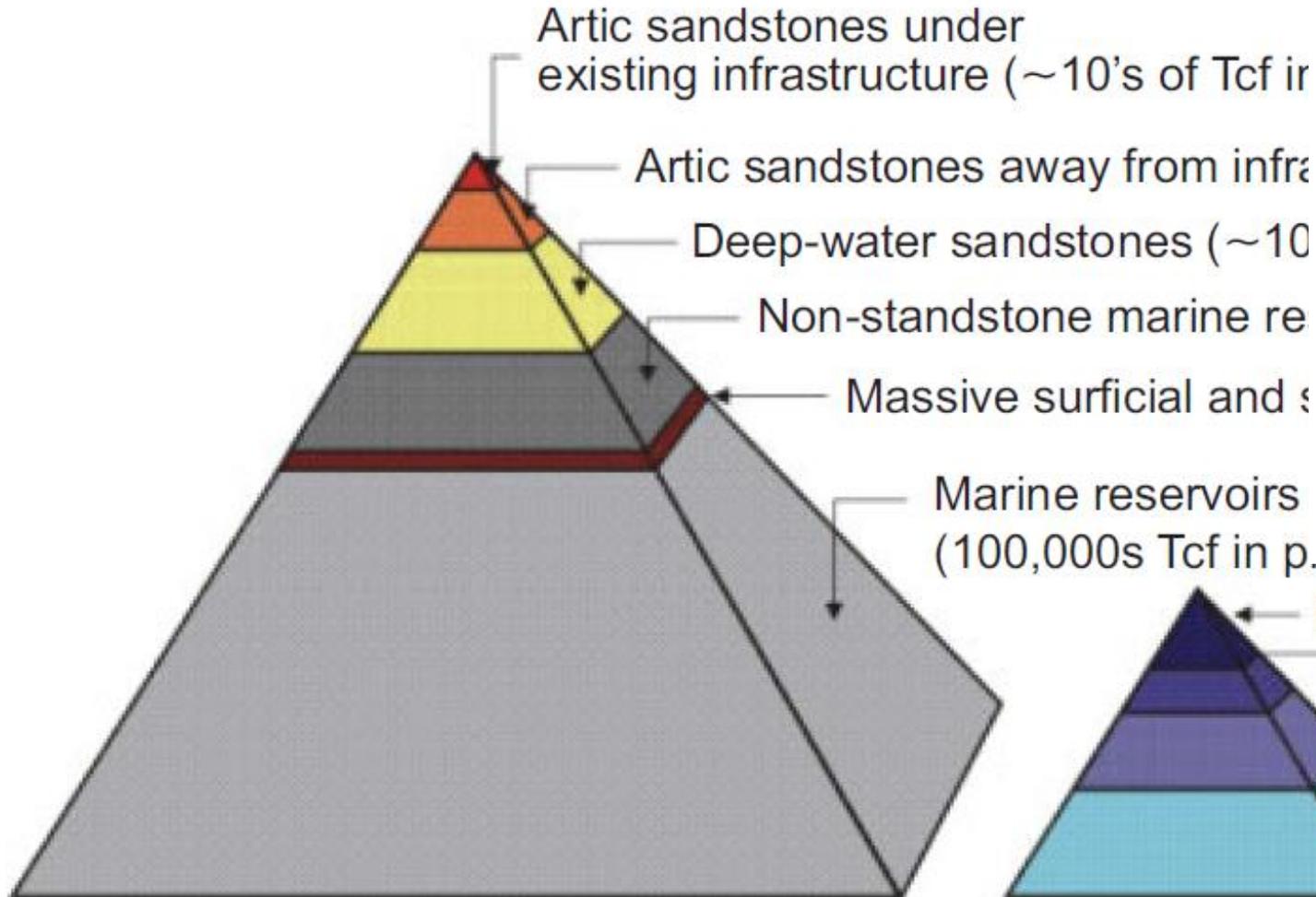


Source: redrawn from Kvenvolden, K.A. and Lorenson, T.D. Environment and Climate
CAOPE, Centre for Arctic Gas Hydrate, Global Inventory of Natural Gas Hydrates Occurrence, USGS, 2010

Natural gas hydrates are the largest carbon reservoirs on our planet

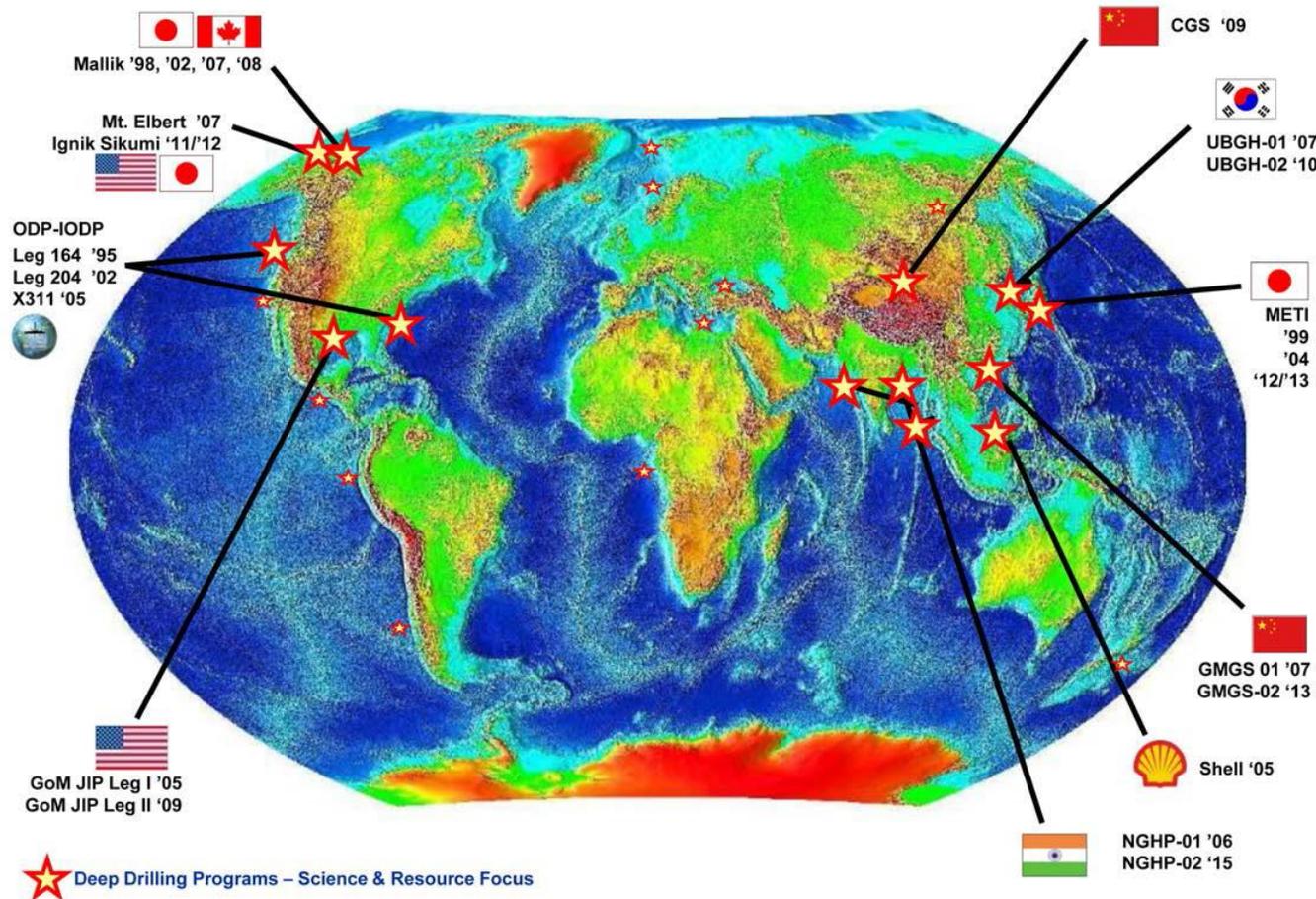


Natural gas hydrates are the largest carbon reservoirs on our planet



Natural gas hydrates are the largest carbon reservoirs on our planet

Many countries are actively pursuing gas production from hydrates



★ Deep Drilling Programs – Science & Resource Focus

Nankai Trough, Japan. Photo credit: JOGMEC.

Tibet (Qilian Mts.) 2009



China (South China Sea) 2007, 2013



Japan (Nankai Trough) 2005, 2012, 2013



Japan-Canada (Mallik test site) 2007, 2008



India (Bay of Bengal, Andamans) 2006, 2014

Korea (East Sea) 2007, 2010



USA (N. Gulf of Mexico) 2005, 2009

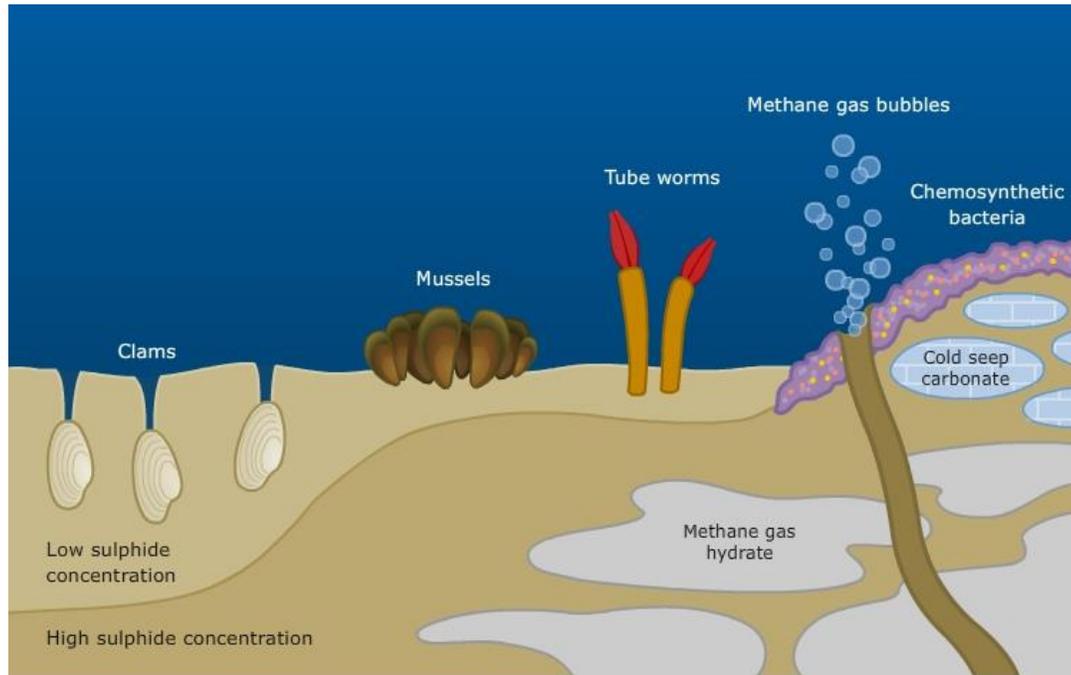


USA (Alaska North Slope) 2007, 2012

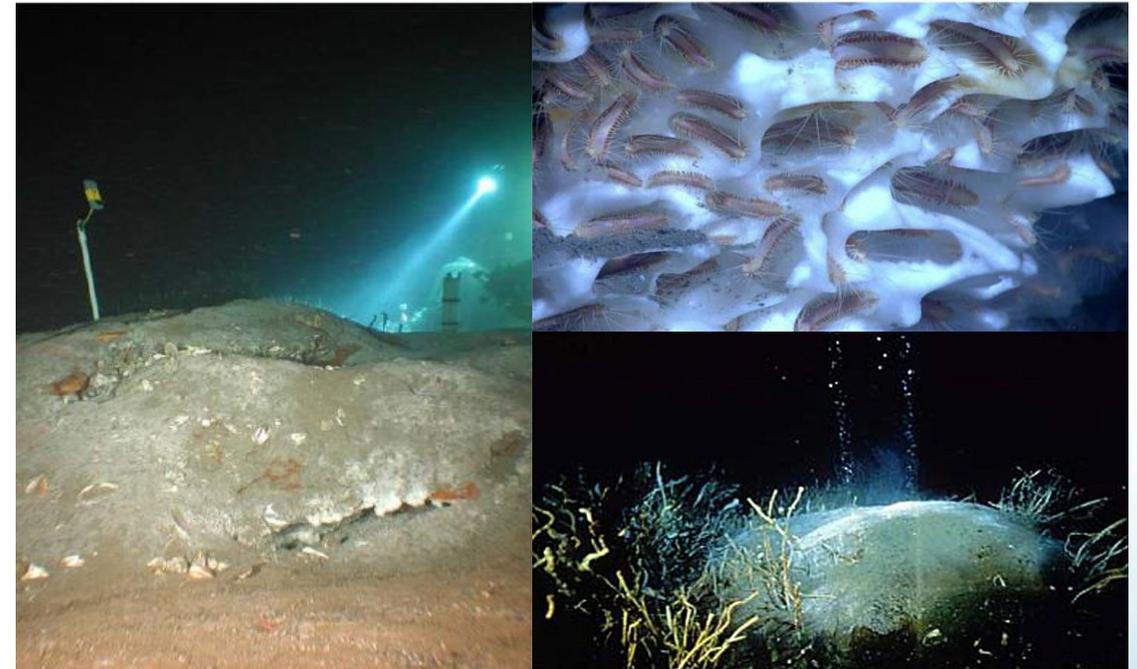


But does it have a much bigger environmental impact?

Hydrate systems are an oasis for marine life



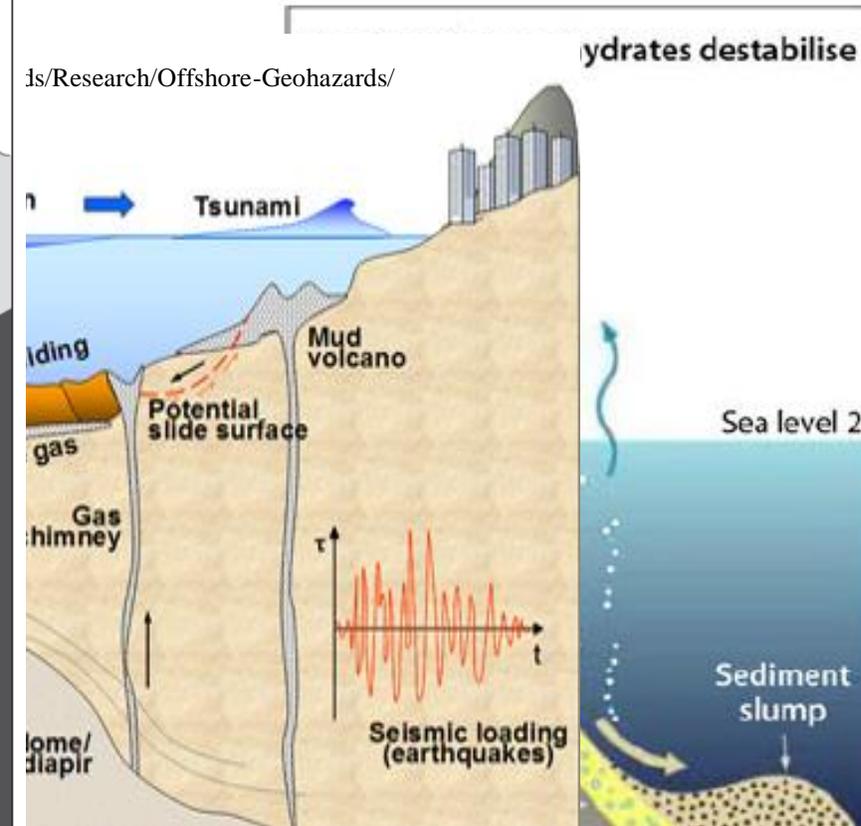
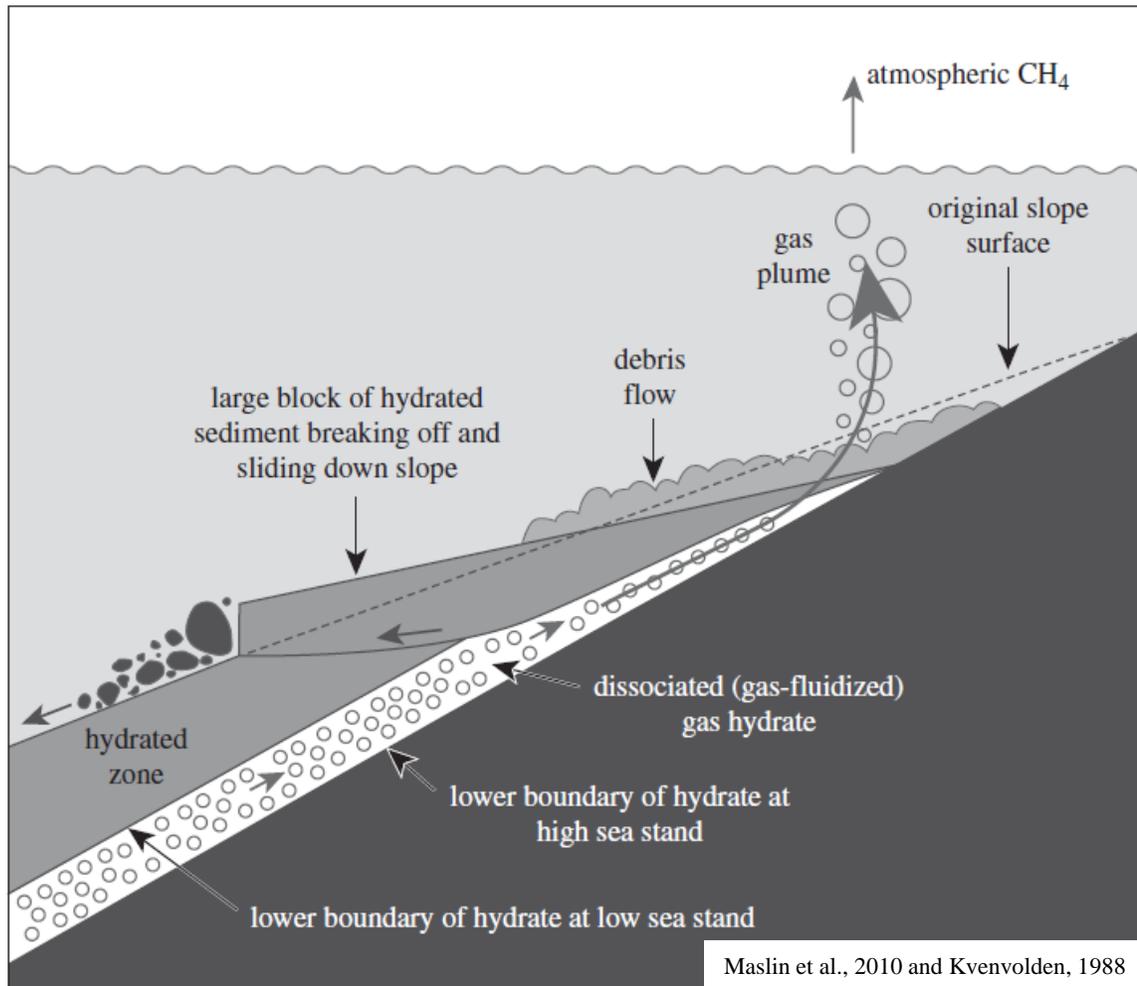
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Courtesy: US DOE

But does it have a much bigger environmental impact?

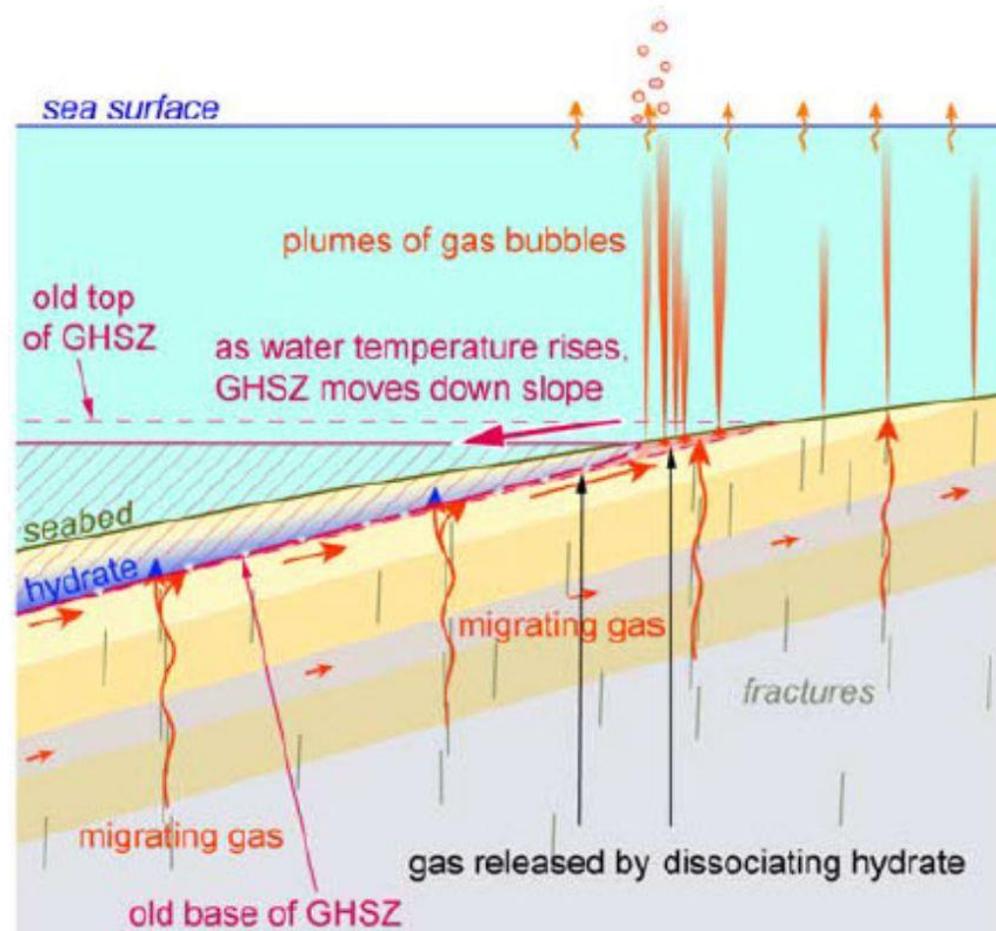
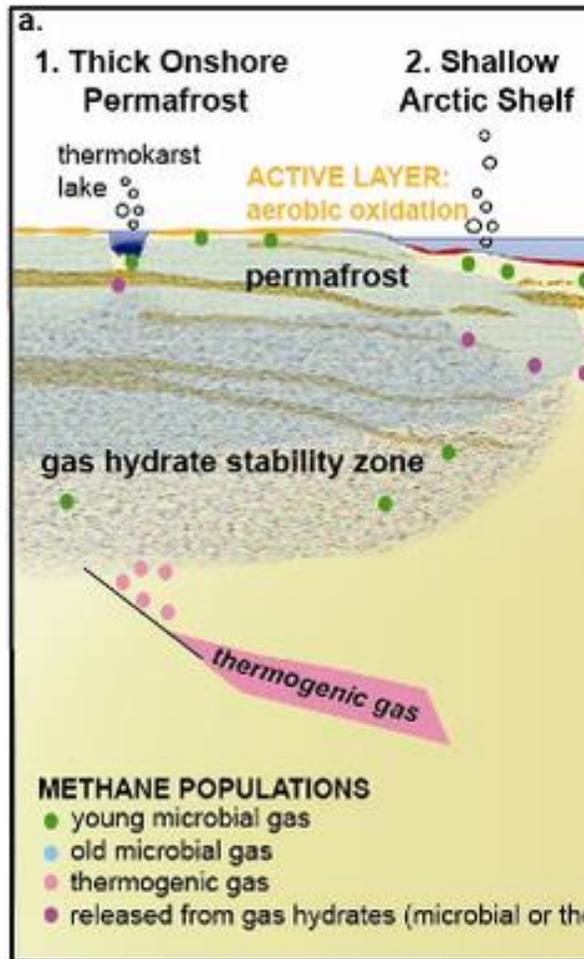
Hydrate dissociation can lead to submarine landslides



facilities, collapse of coastal facilities and the

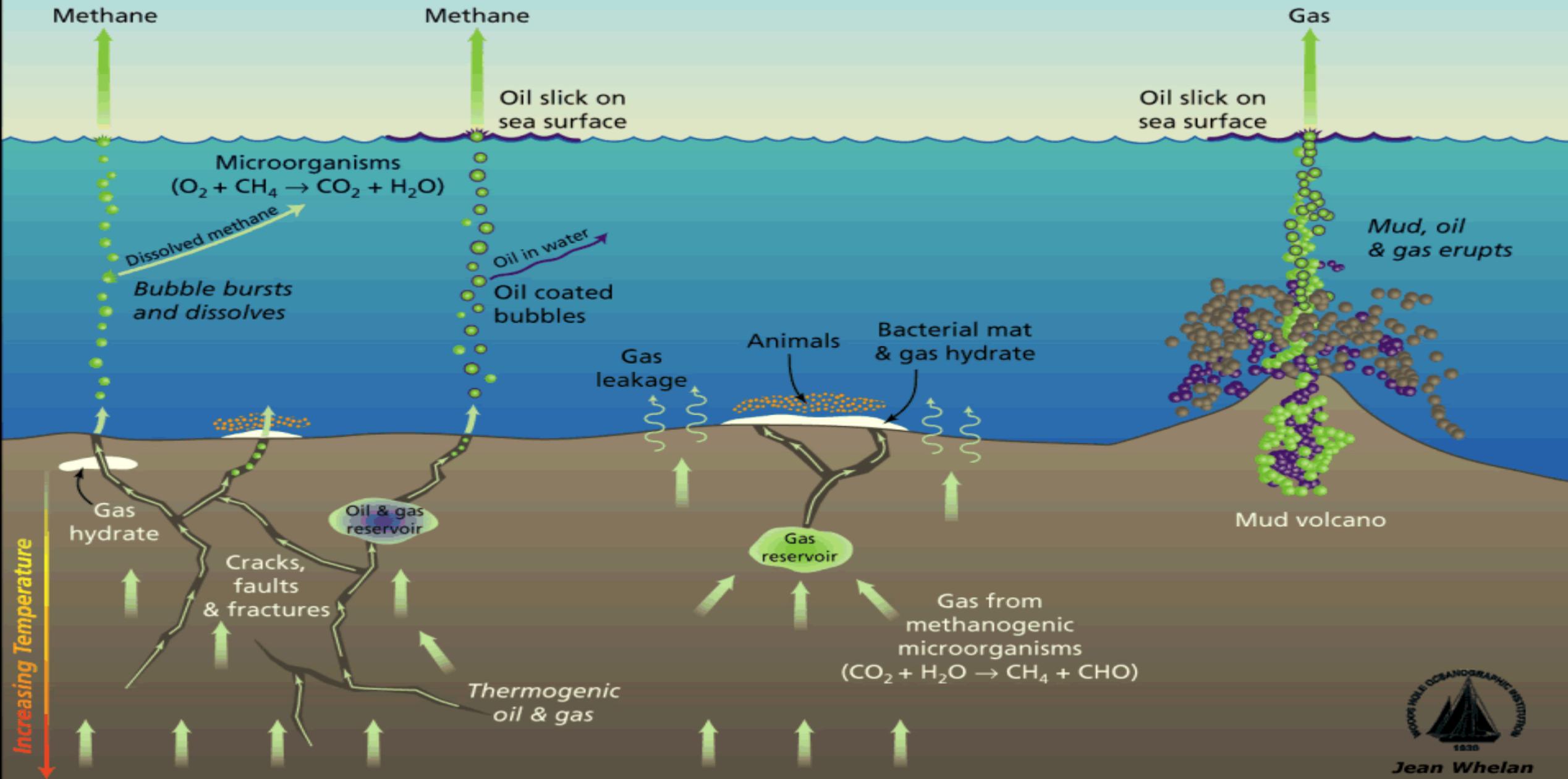
But does it have a much bigger environmental impact?

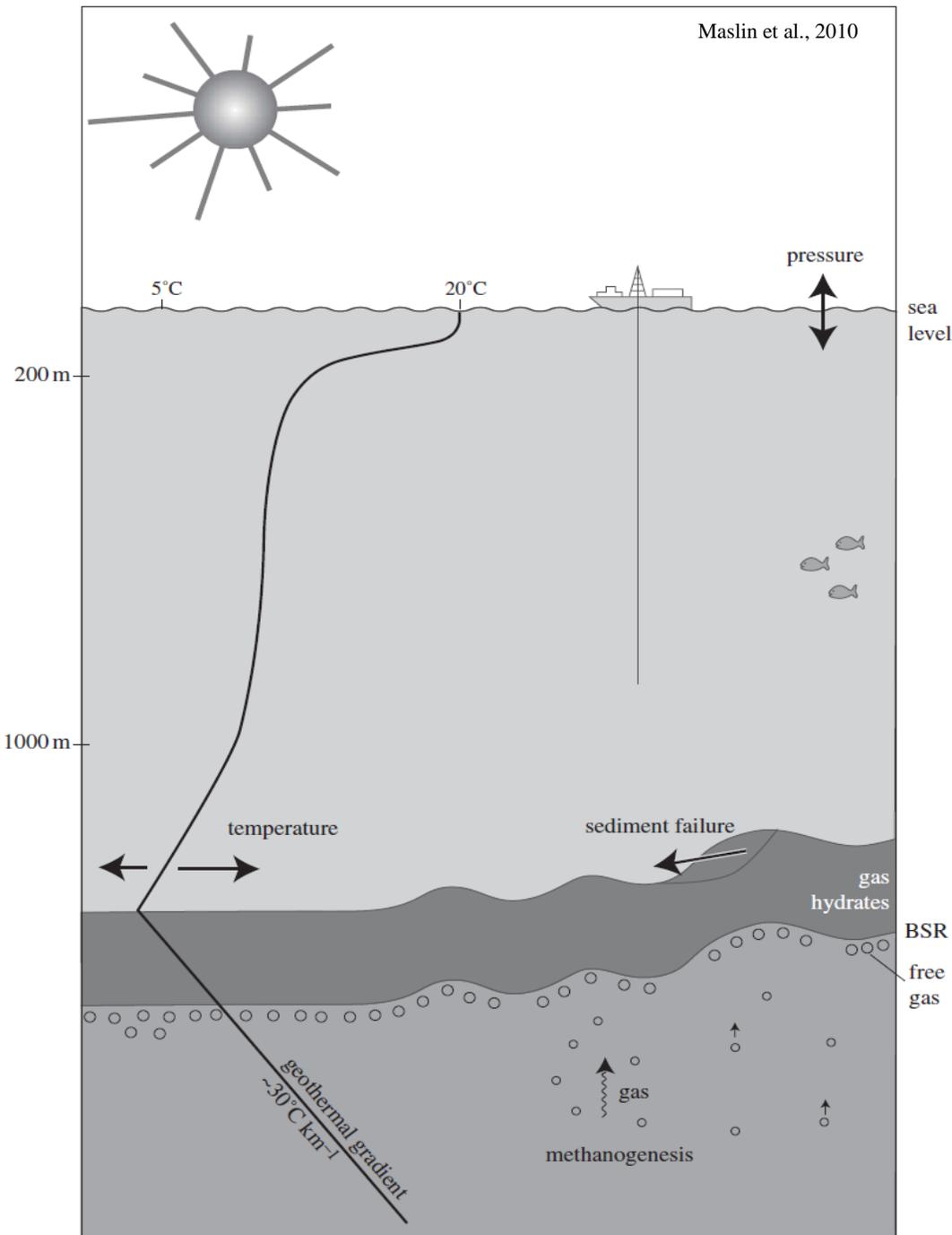
Methane is a greenhouse gas, up to 32 times more powerful than CO₂



Recent studies suggest that most of the methane released into the Ocean is consumed within the water column

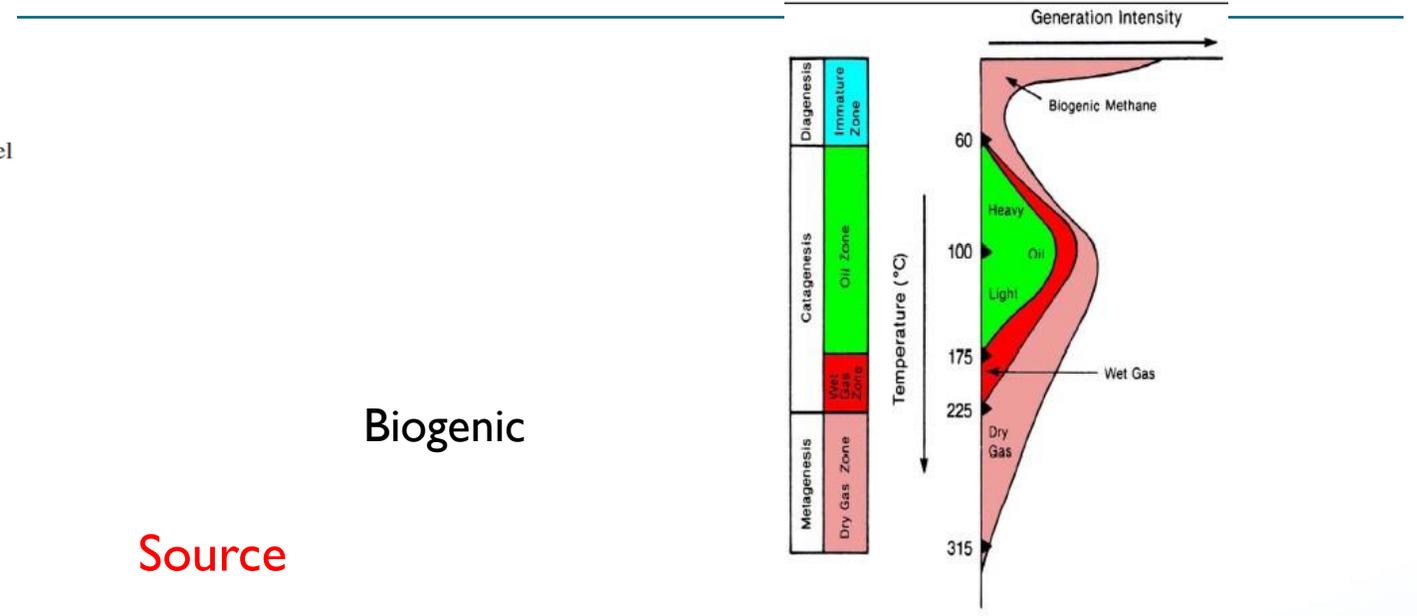
Gas hydrates are part of the fluid-flow system





Elements of a gas hydrate system

Degradation of organic matter



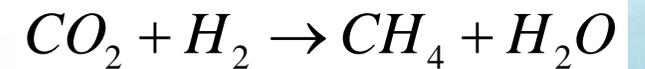
Source

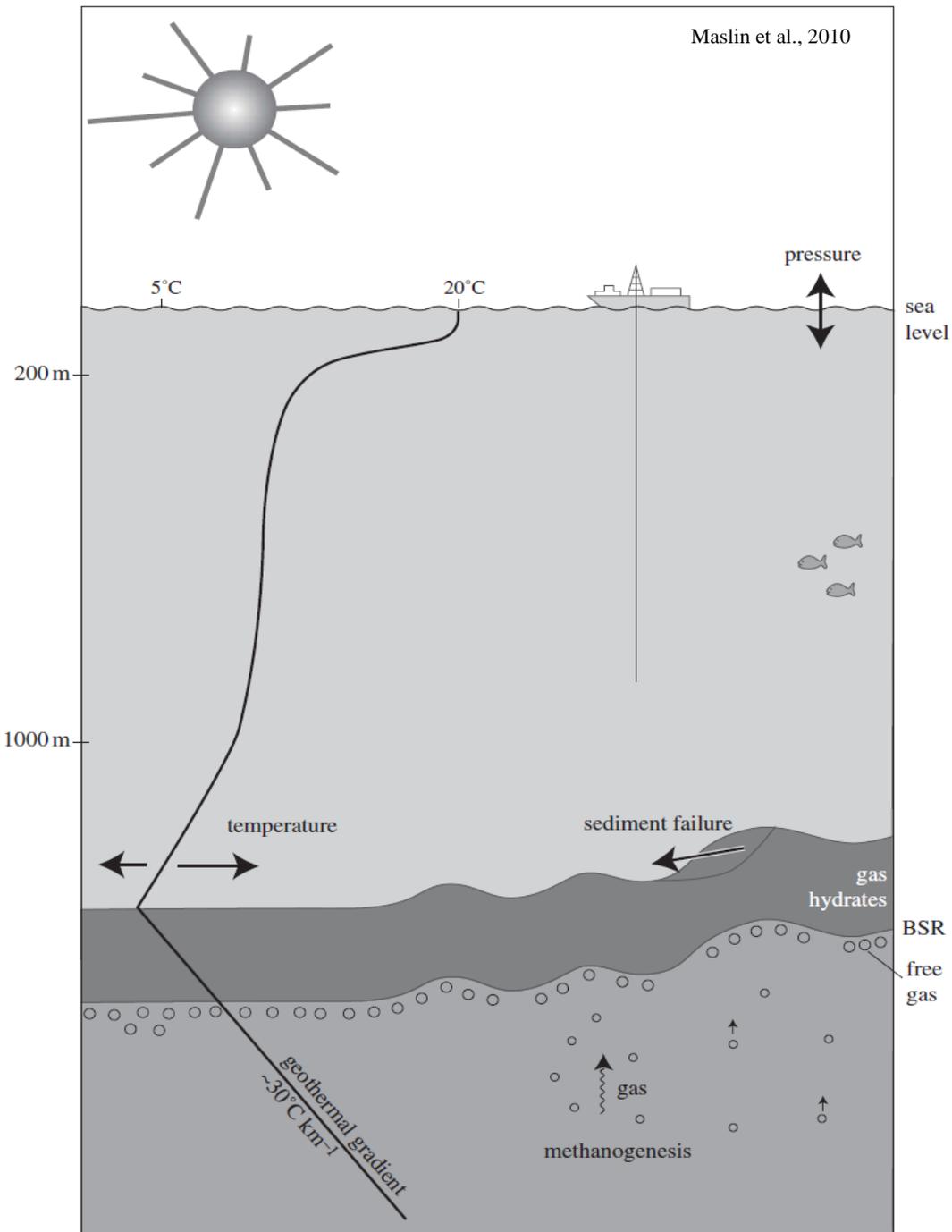
Inorganic generation of methane

Serpentinization

Low T gas-water-rock reactions

Fischer-Tropsch reaction

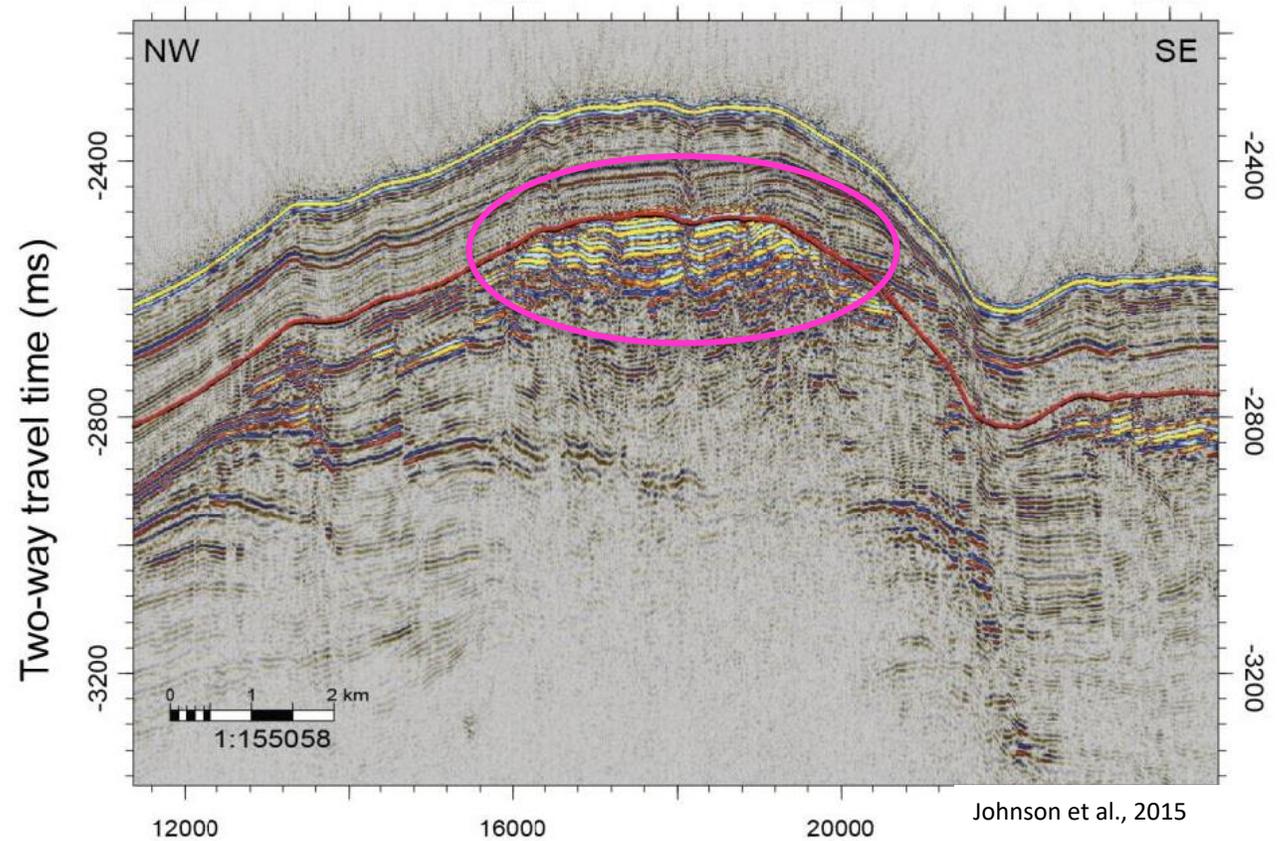


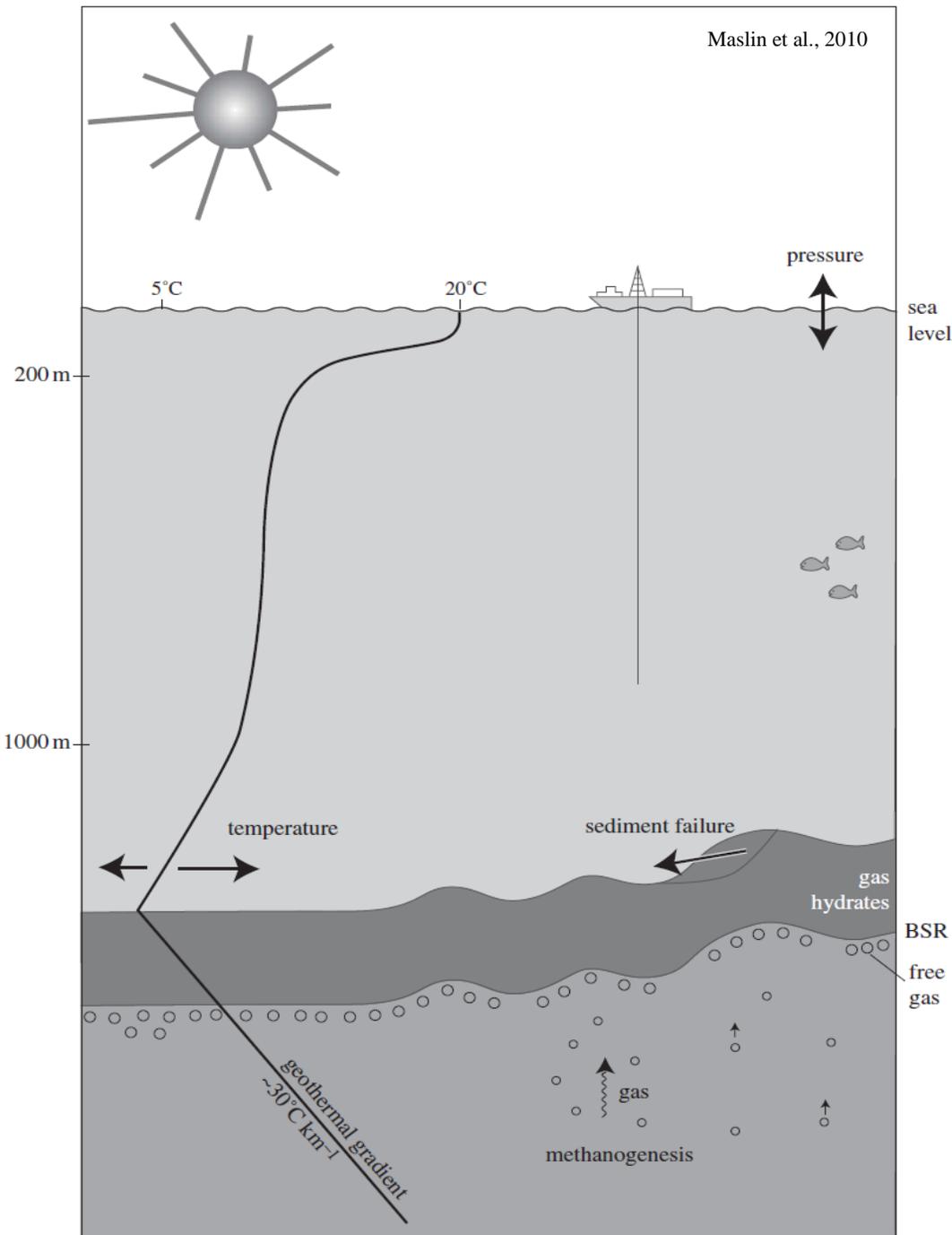


Elements of a gas hydrate system

The free gas zone

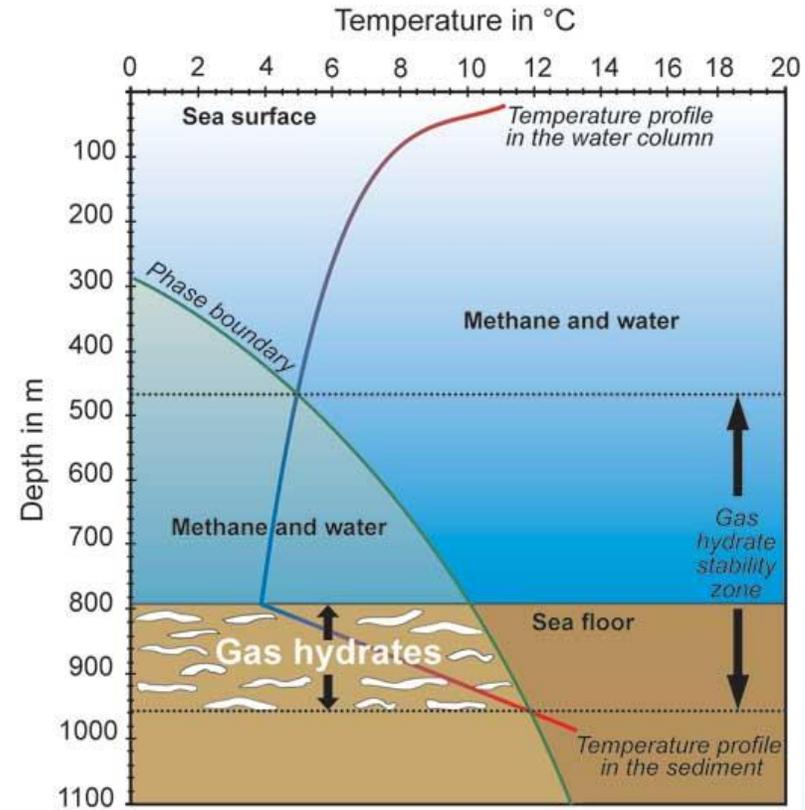
Gas accumulates beneath the base of hydrate stability and forms the free gas zone



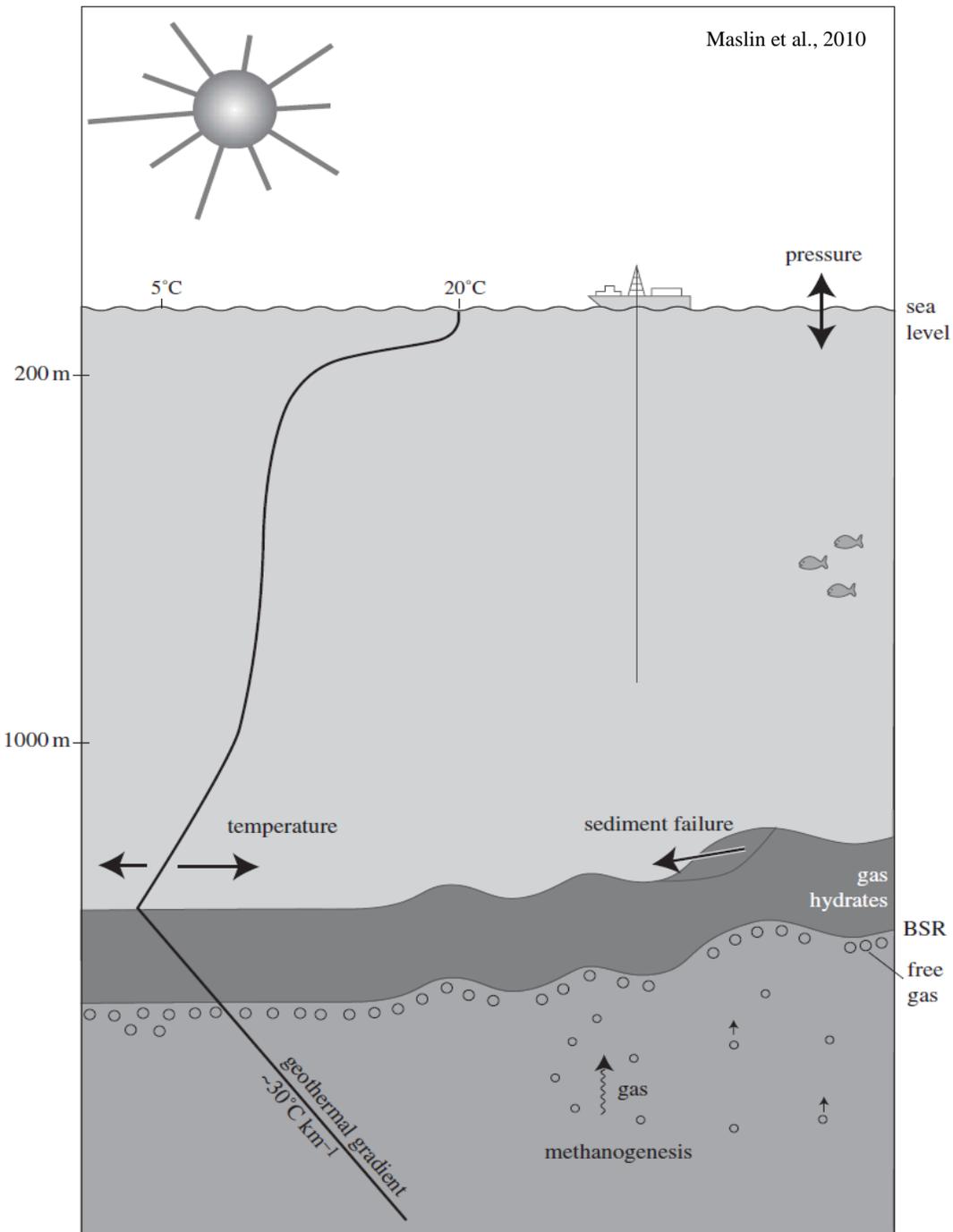


Elements of a gas hydrate system

Gas Hydrate Stability Zone (GHSZ)

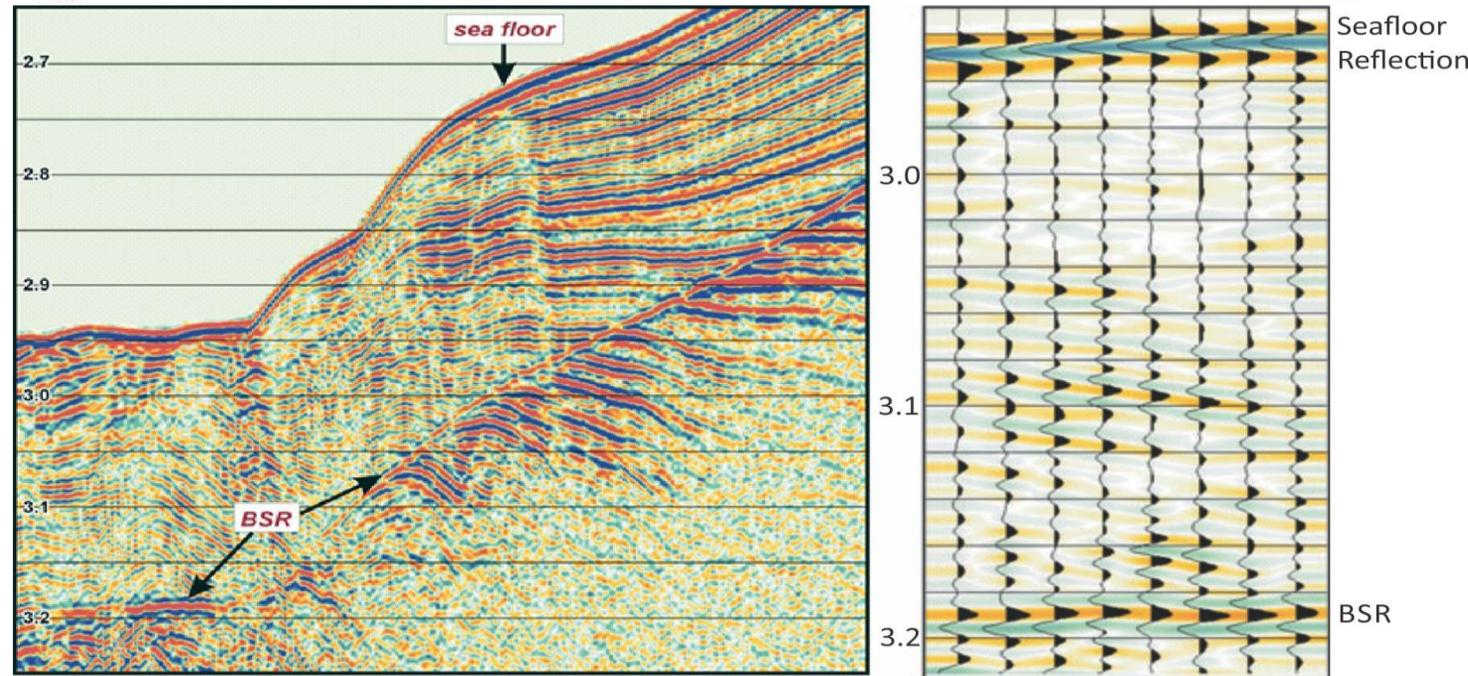


GHSZ represents the region where PT conditions are suitable for hydrate formation



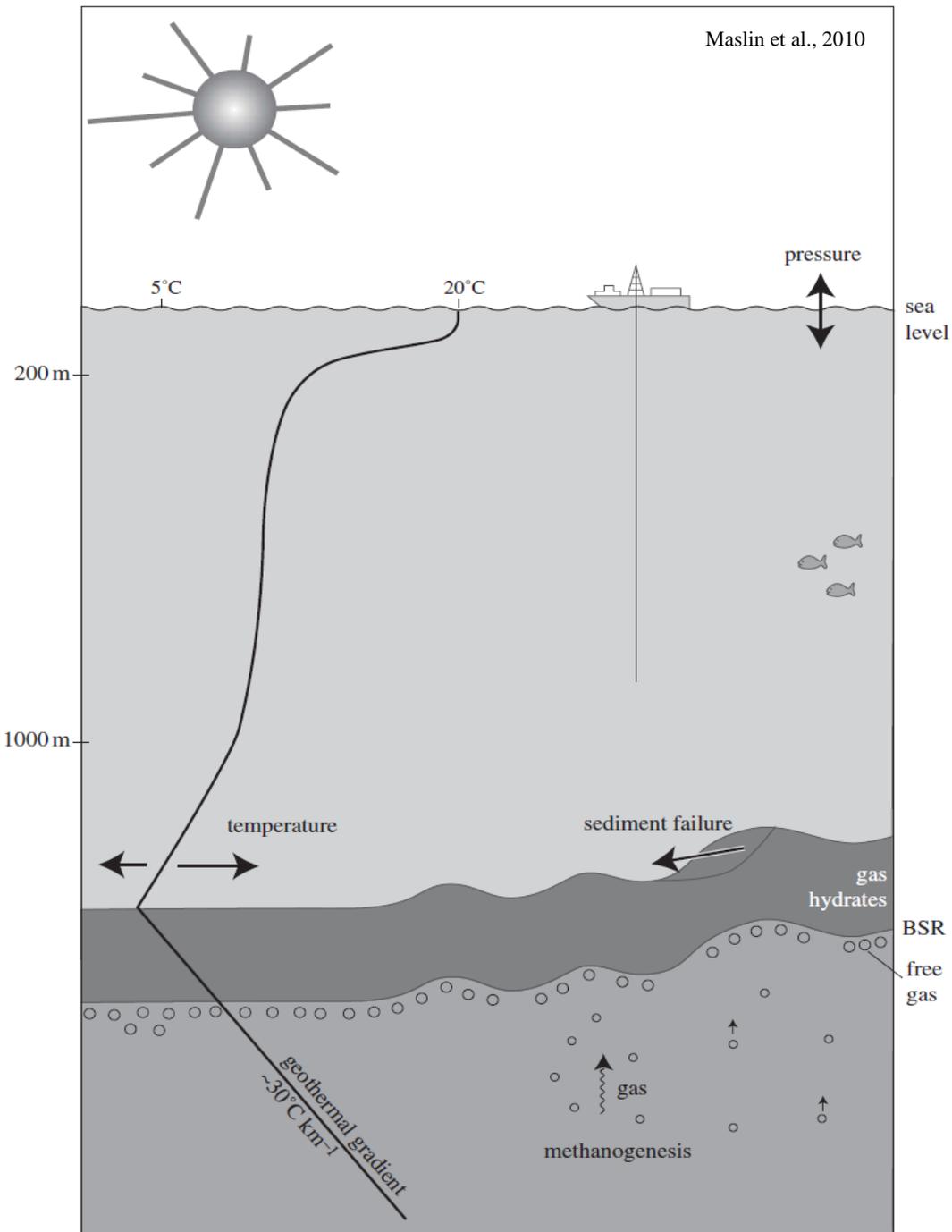
Elements of a gas hydrate system

The Bottom Simulating Reflection (BSR)



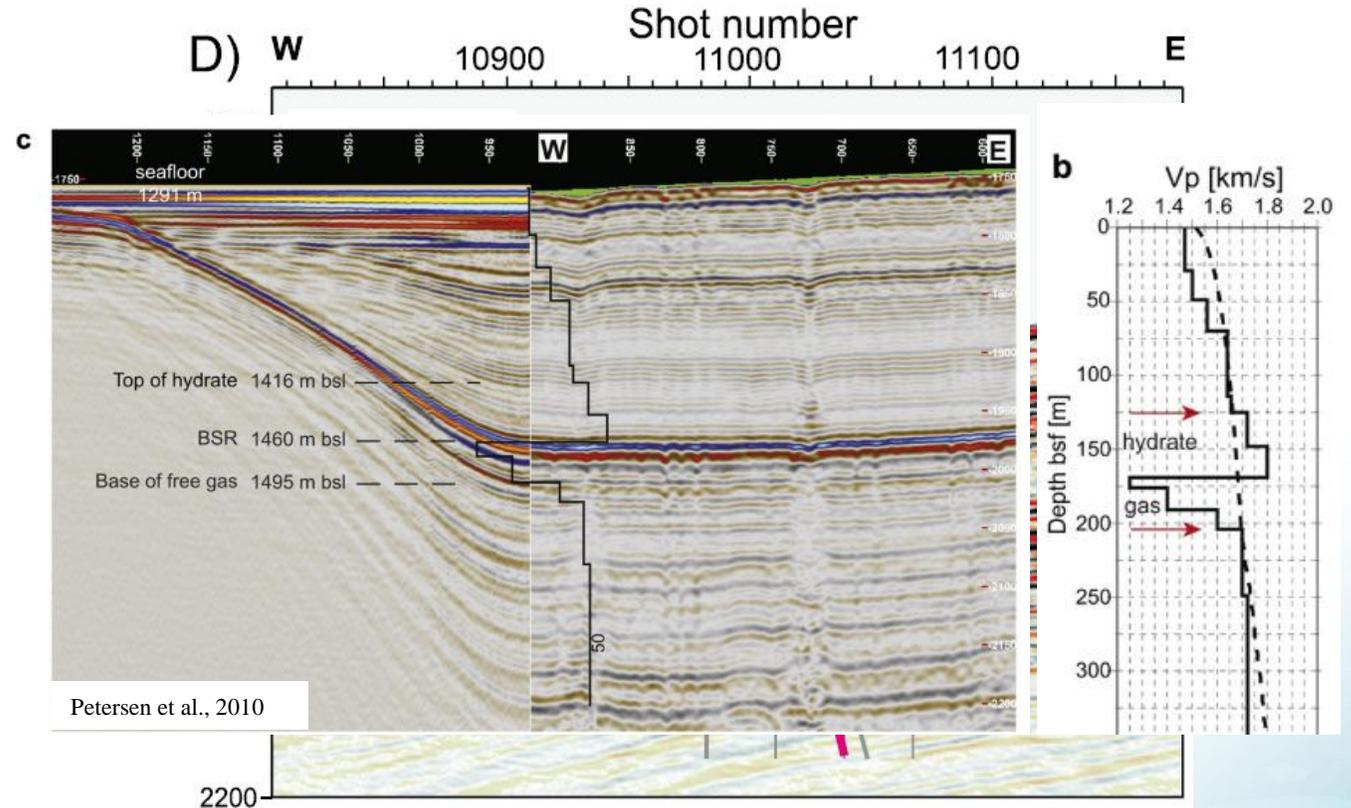
Vanneste et al., 2005

BSR is characterized by high amplitudes, reverse polarity and mimics the sea floor



Elements of a gas hydrate system

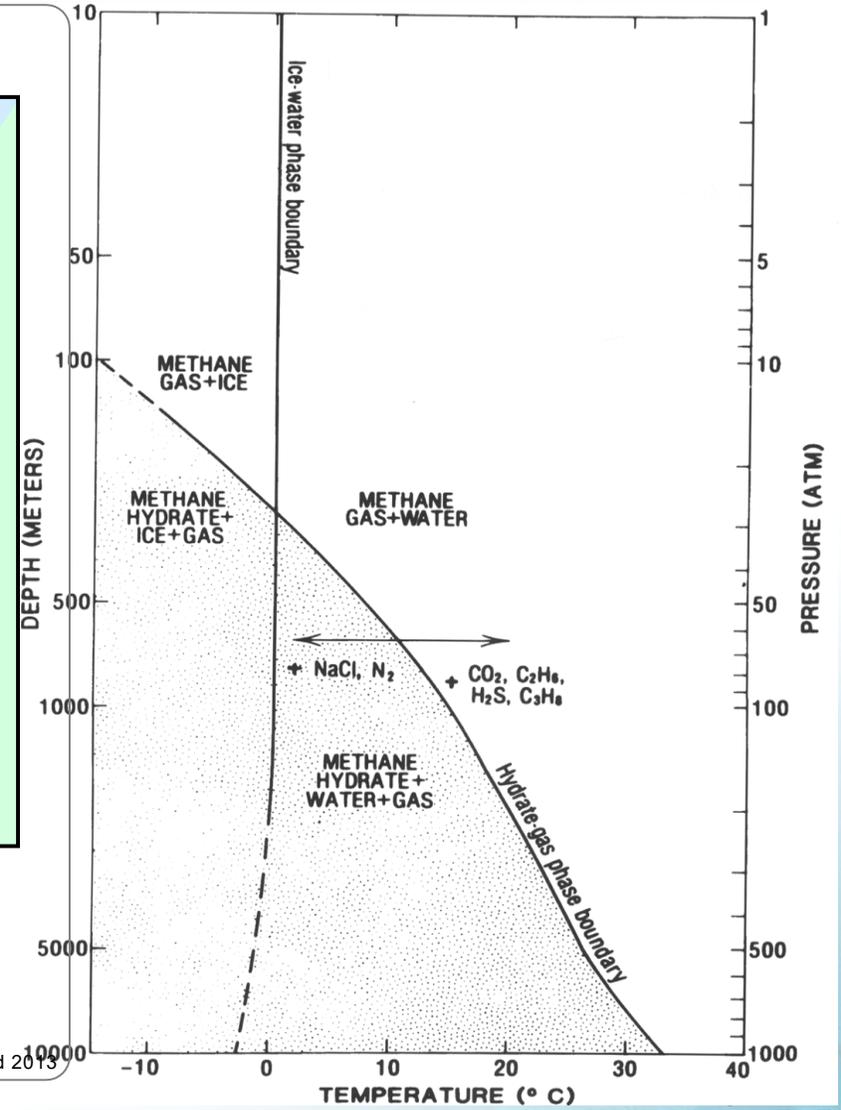
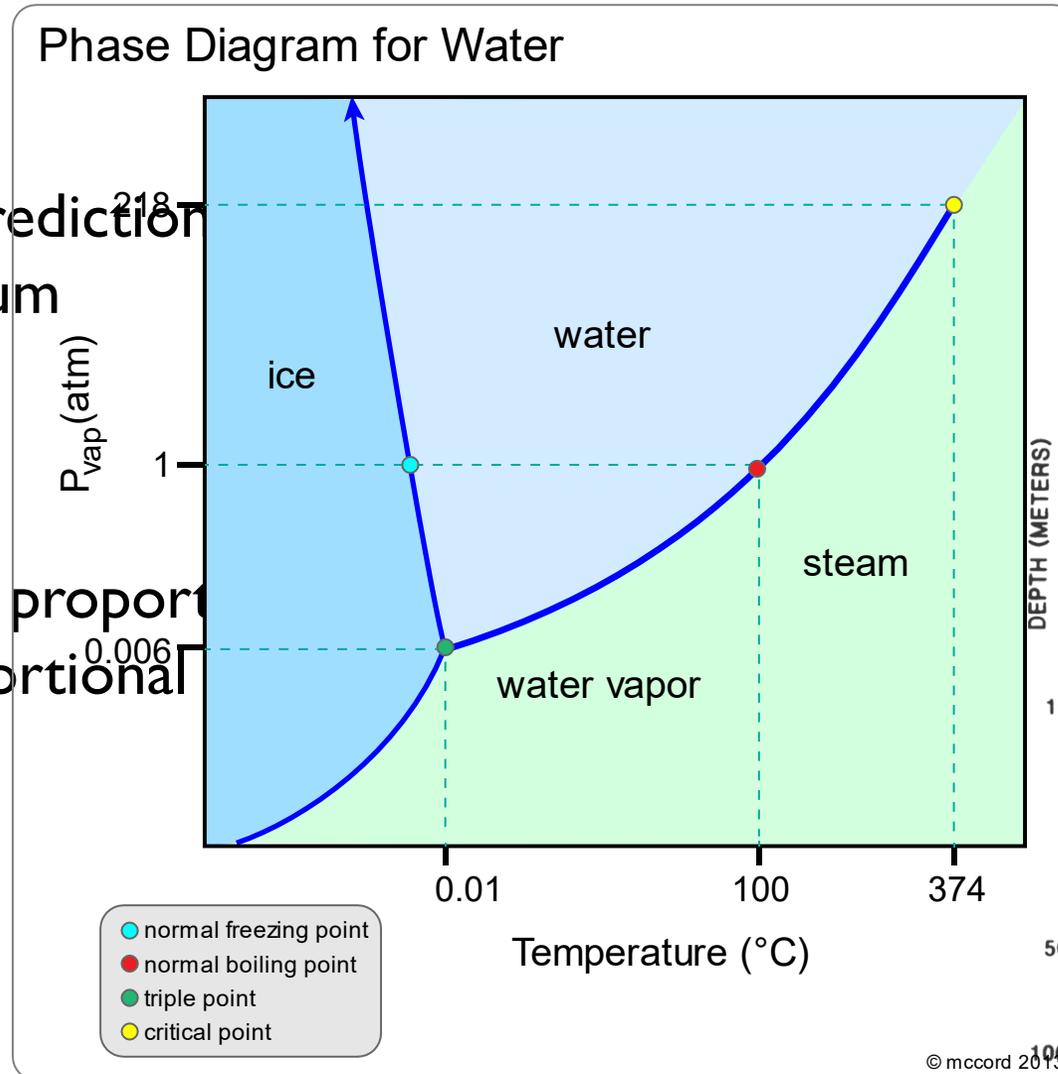
Hydrate Occurrence Zone



Gas hydrates may not occur throughout the hydrate stability zone

The Gas Hydrate Stability Zone can be estimated theoretically

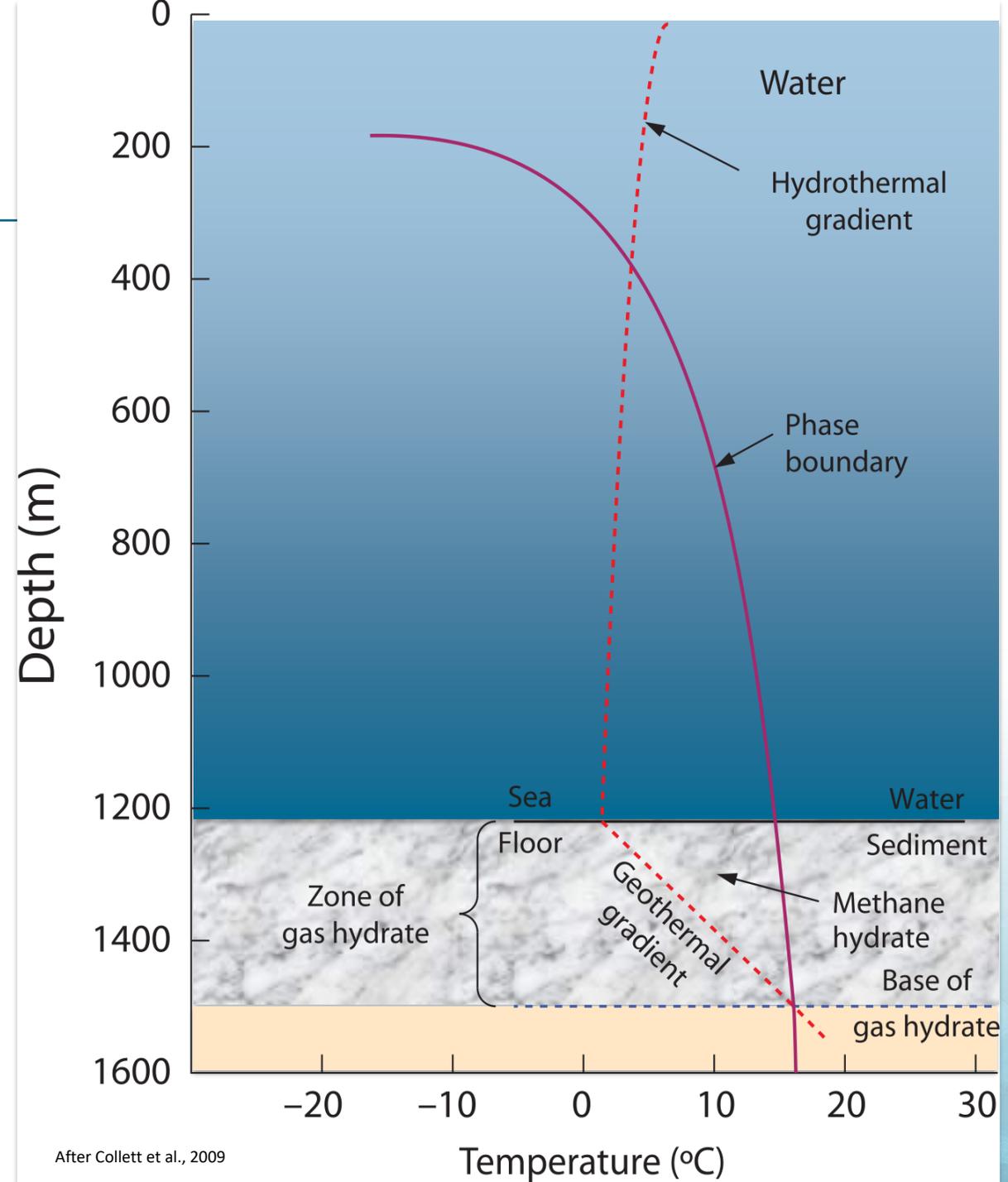
- Thermodynamic prediction (Lw-H-V) equilibrium
- Hydrate stability is proportional to pressure and inversely proportional to temperature



Gas hydrate formation is dependent on various parameters

- * Water depth
- * Bottom water temperature
- * Thermal gradient
- * Pore-water Salinity
- * Gas composition

Assuming abundant gas flux

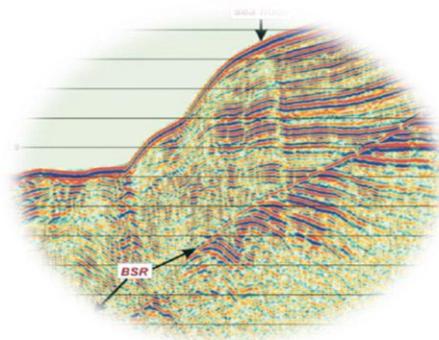


Outline

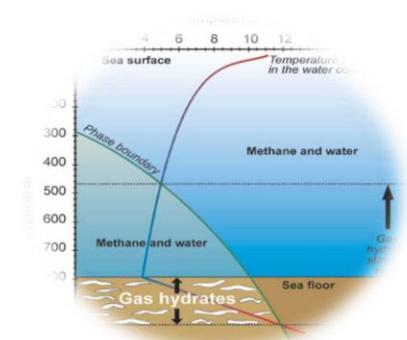
Introduction



Basic elements



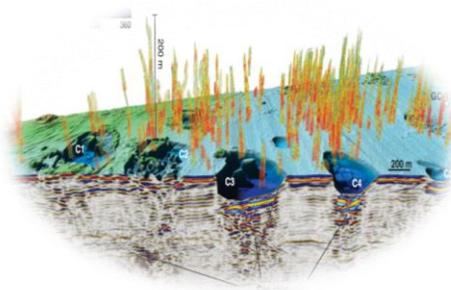
Gas Hydrate Stability



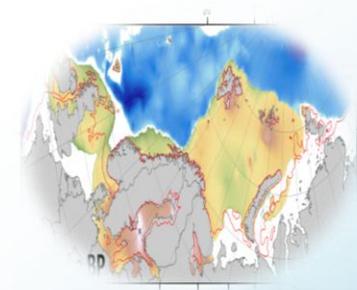
Glaciated margins



Hydrate response



Challenges and Summary



Impact of glaciations on environmental conditions

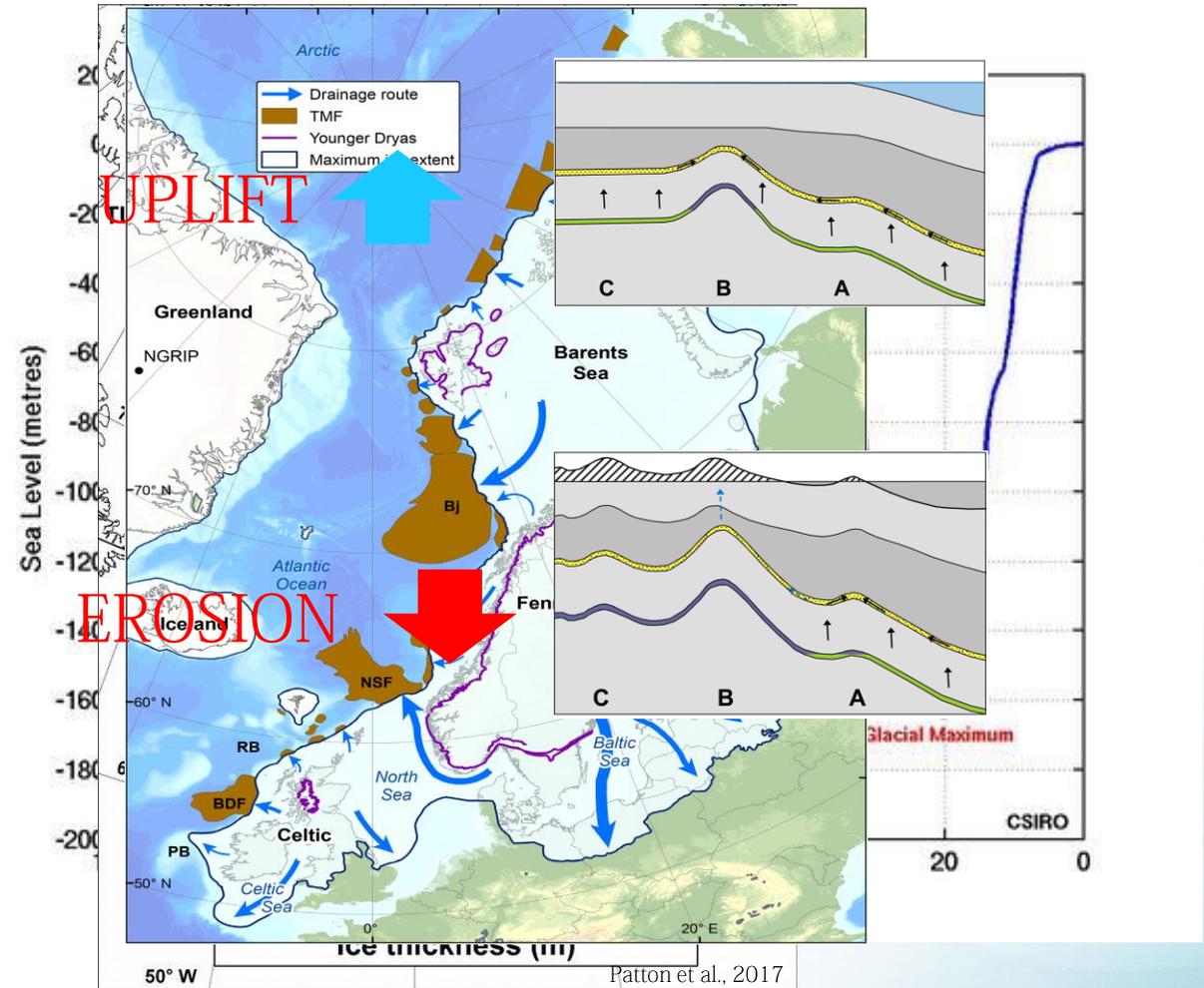
Cold bottom temperature

Pressure changes due to ice load

Sealevel changes

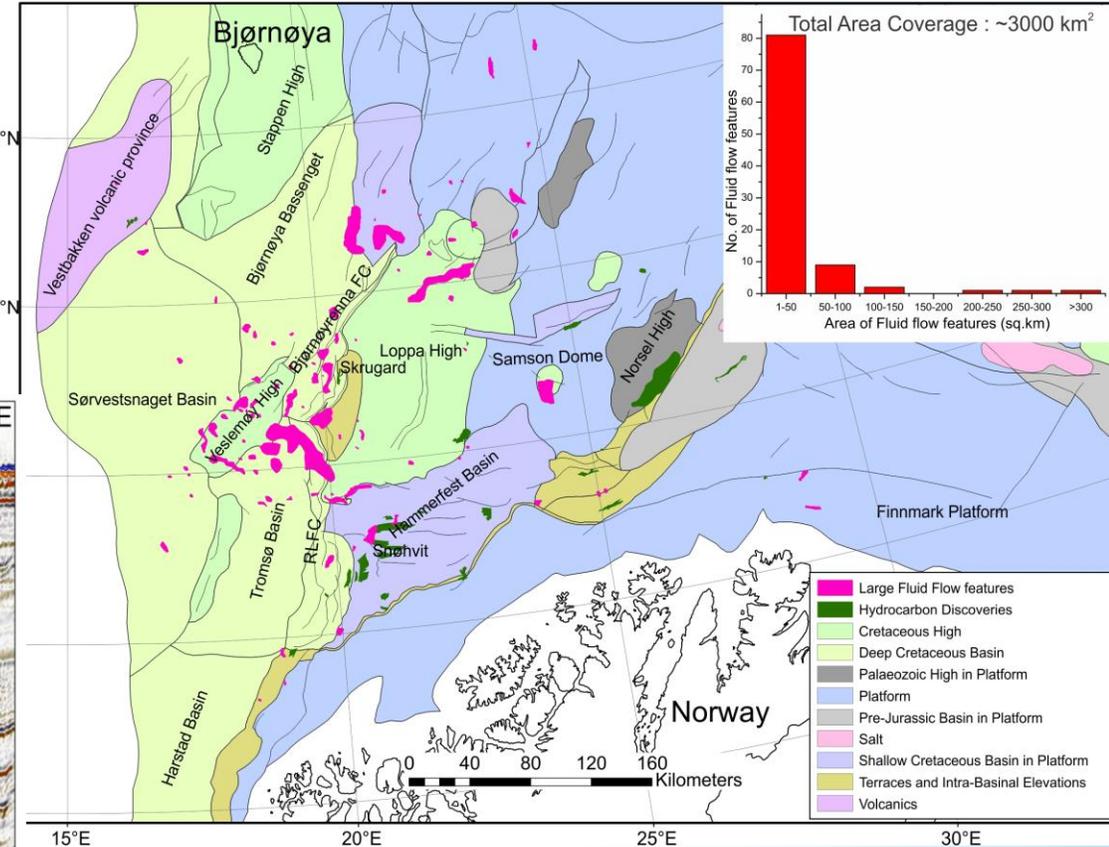
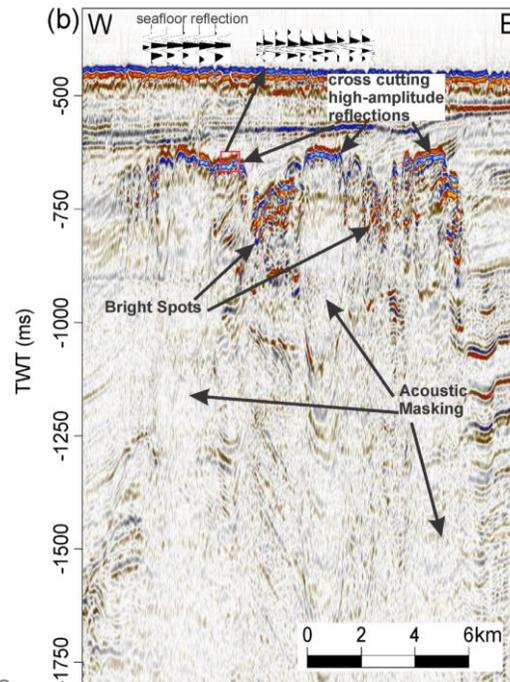
Sedimentation and Subsidence

Uplift and erosion



Impact of glaciations on petroleum systems

- Release of hydrocarbons from traps
- Exsolution of gas from oil
- Widespread fluid flow



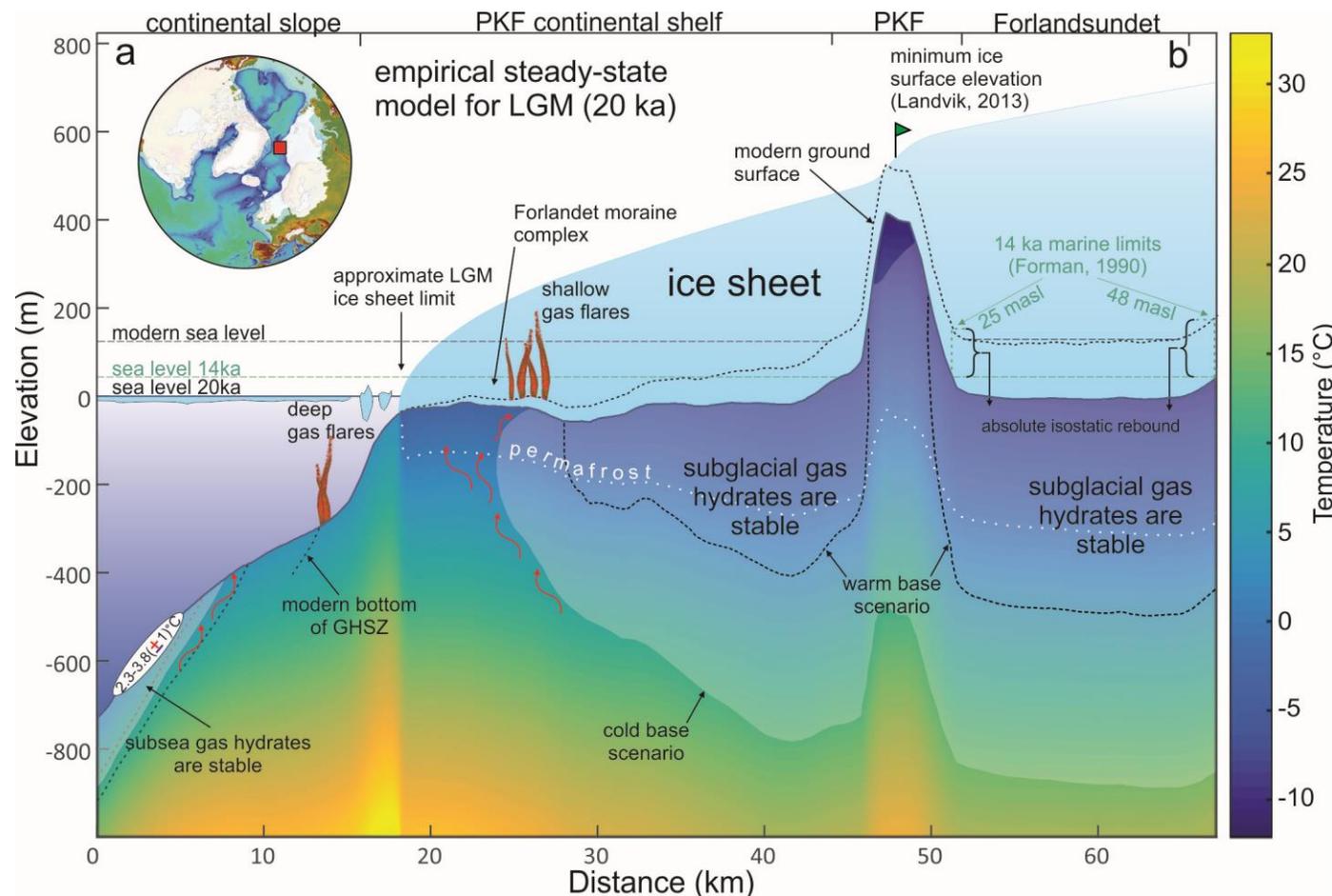
Vadakkepuliambatta et al., 2013

Incorporating environmental changes and hydrate stability

Steady-state

Assumes the system is in equilibrium

Ice sheets can support very thick gas hydrate stability zone within the sediments



Portnov et al., 2016

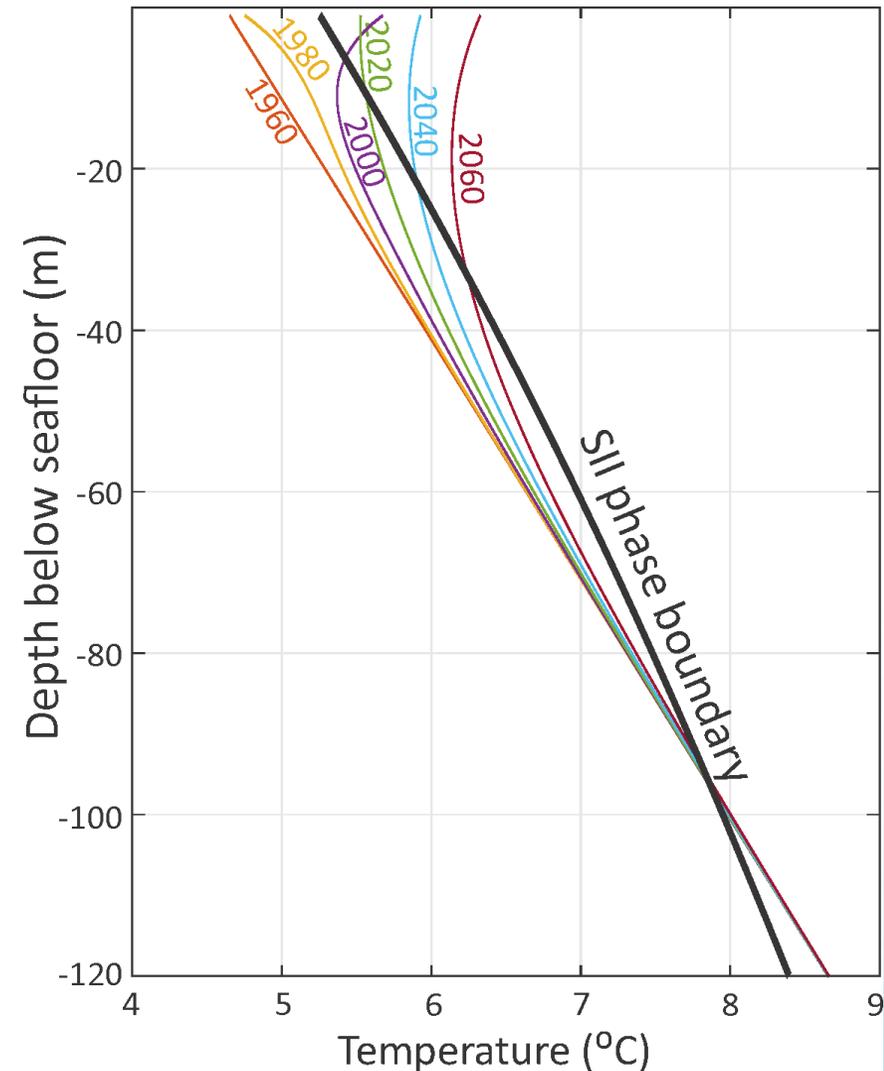
Incorporating environmental changes and hydrate stability

Dynamic / Transient

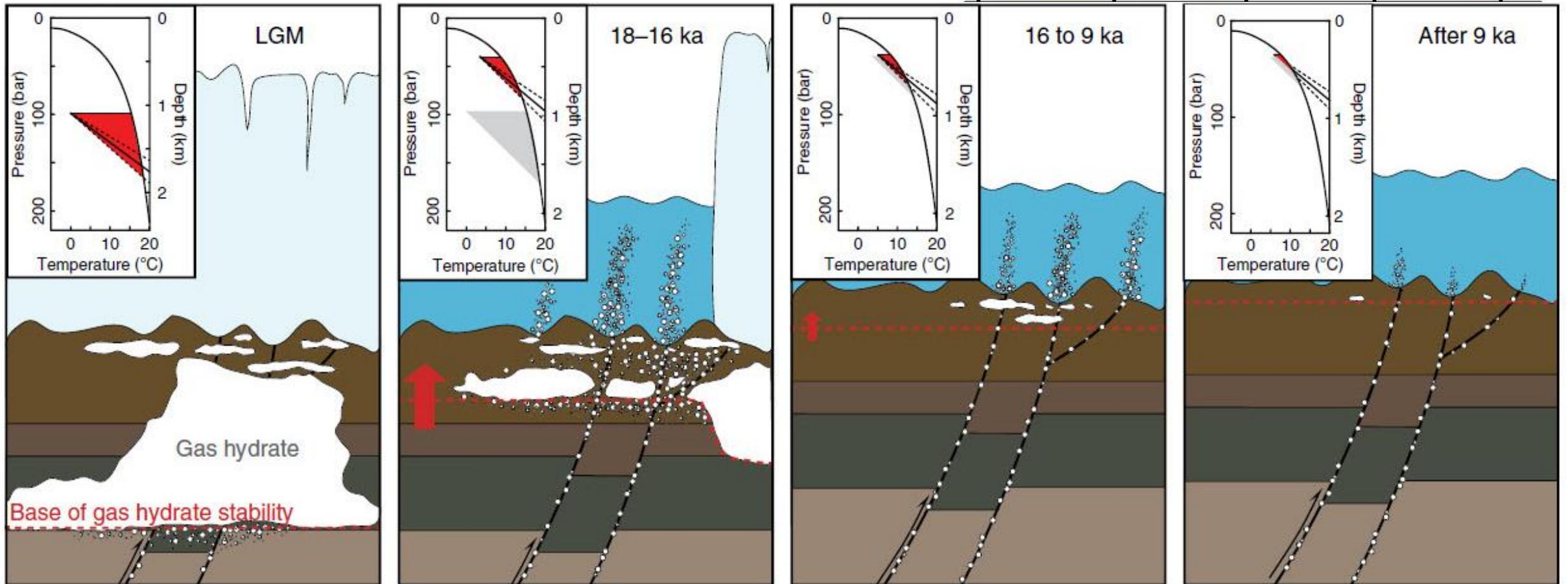
Incorporates temporal variation of parameters.
Can estimate variation in hydrate stability over short/geologic time-scales.

$$\frac{\partial T}{\partial t} = K * \frac{\partial^2 T_p}{\partial z^2}$$

K is diffusivity of sediments
t is time
z is depth
T_p is temperature in the past
T is temperature at time 't'

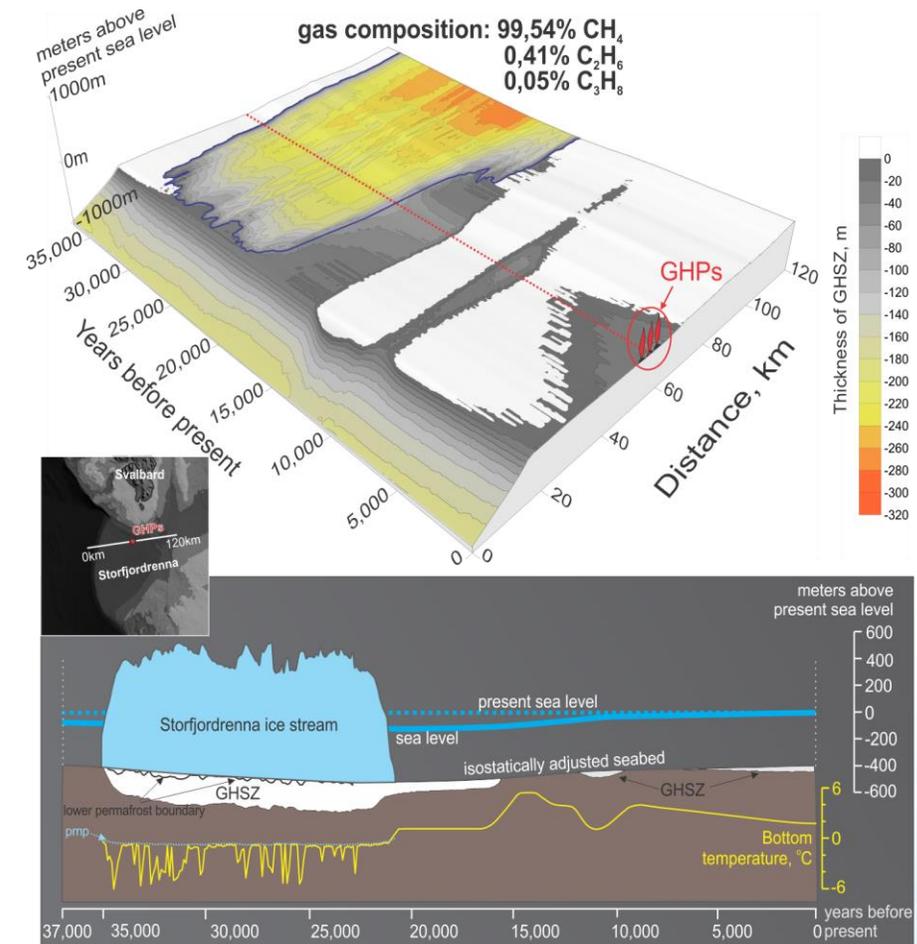
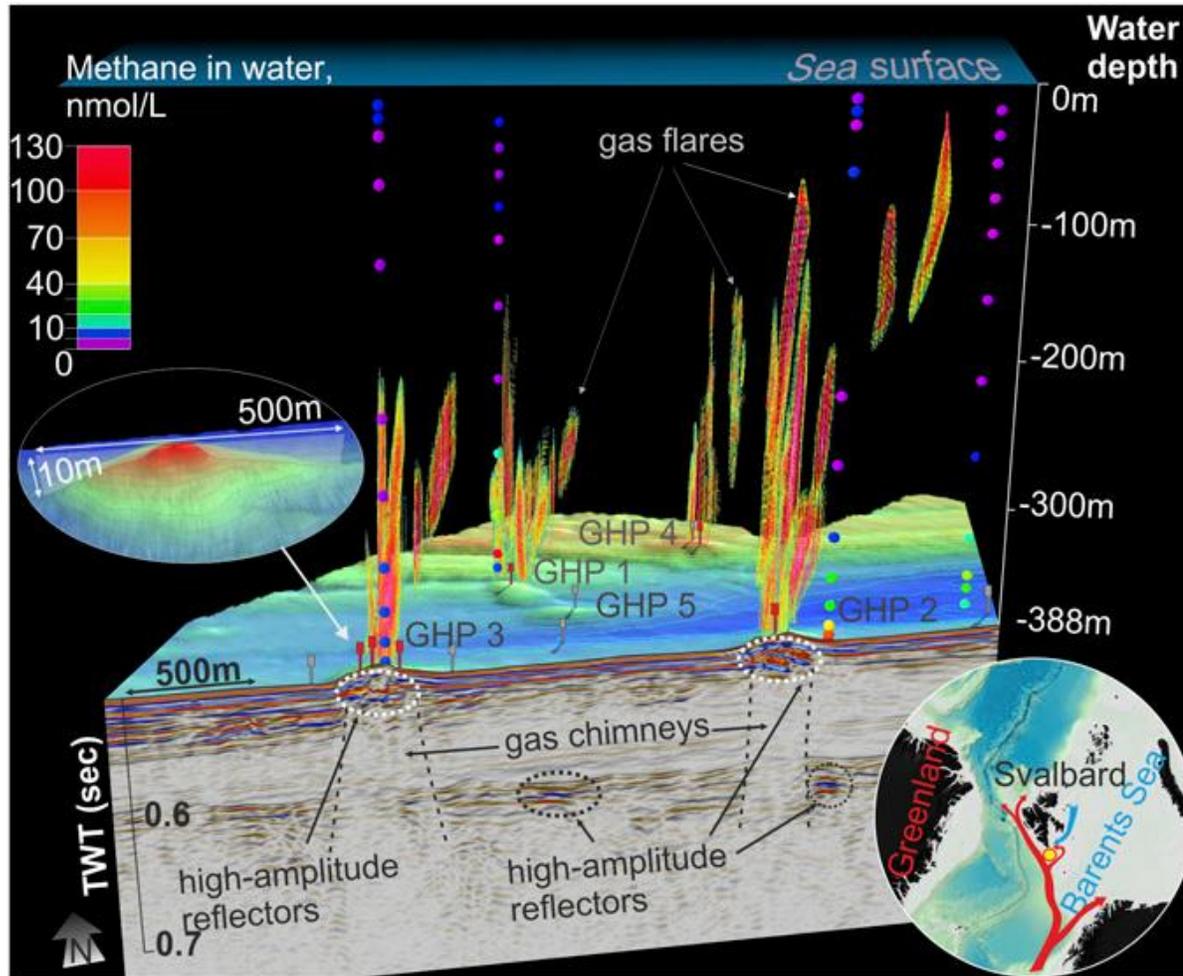


Carbonate accretions show evidence for massive methane release after icesheet retreat



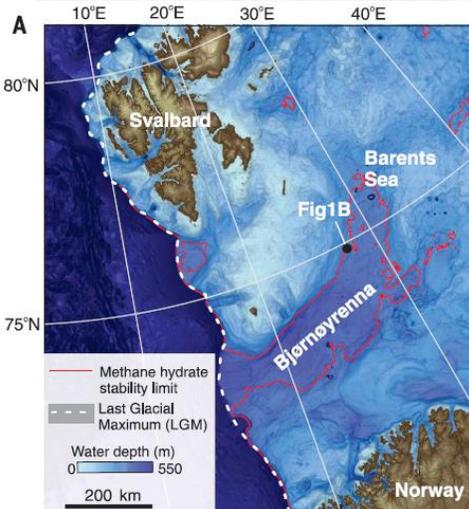
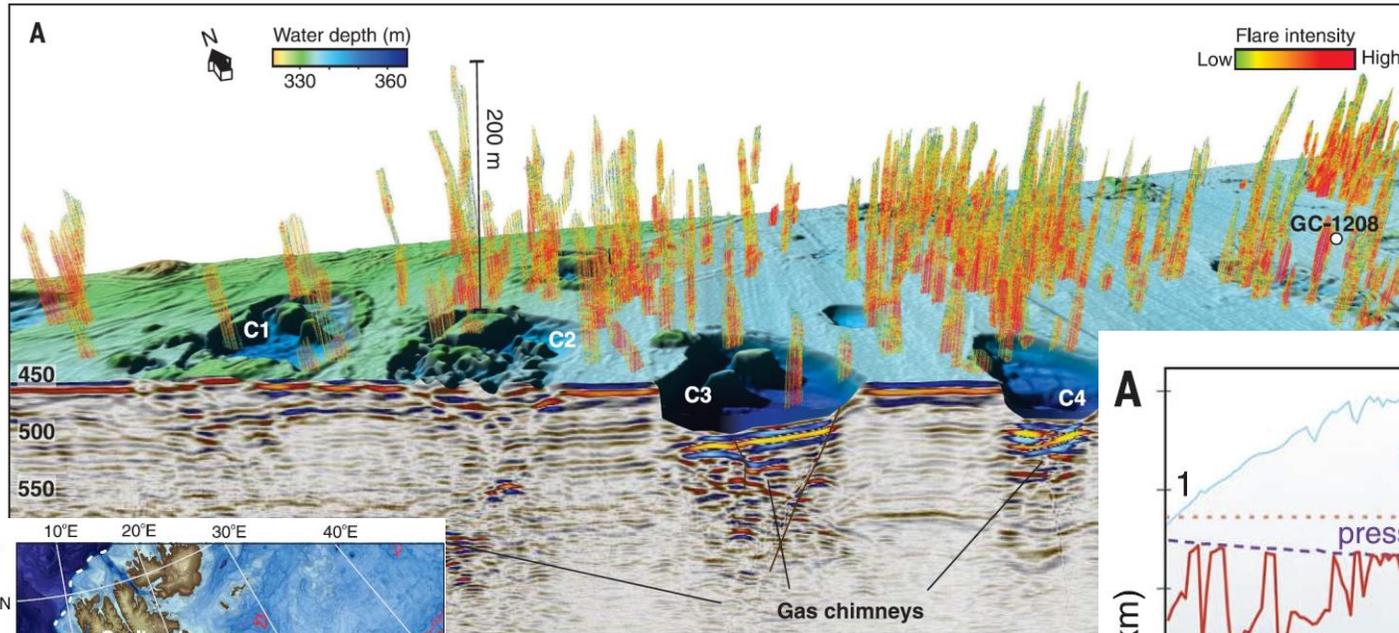
Crémière et al., 2016

Gas hydrate pingos in the Barents Sea

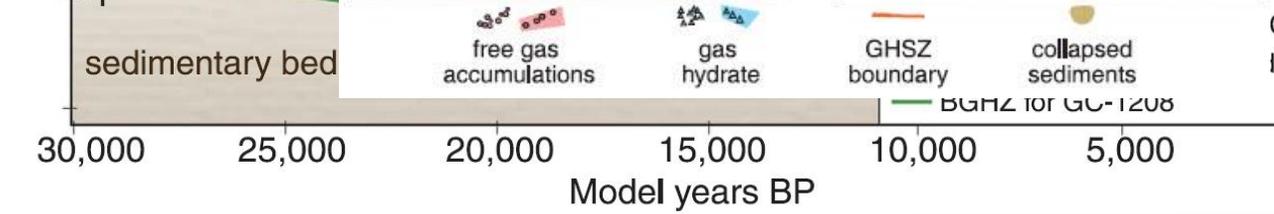
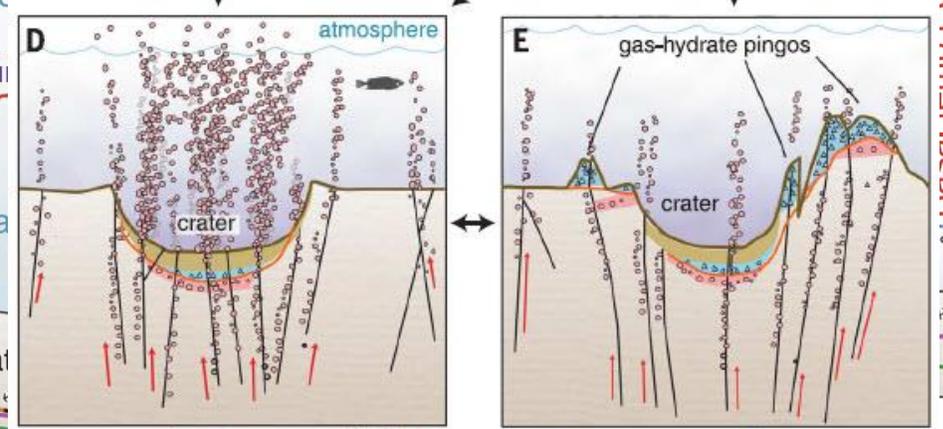
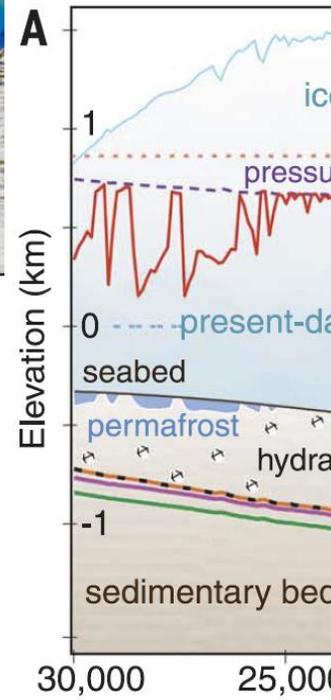
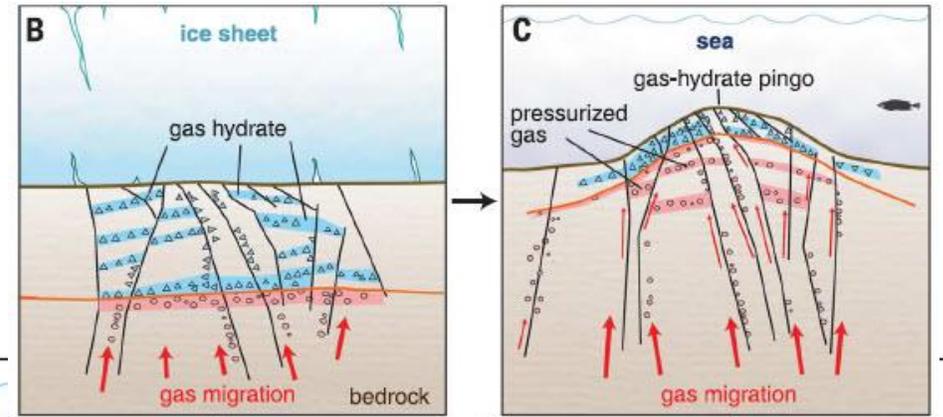


Serov et al., 2017

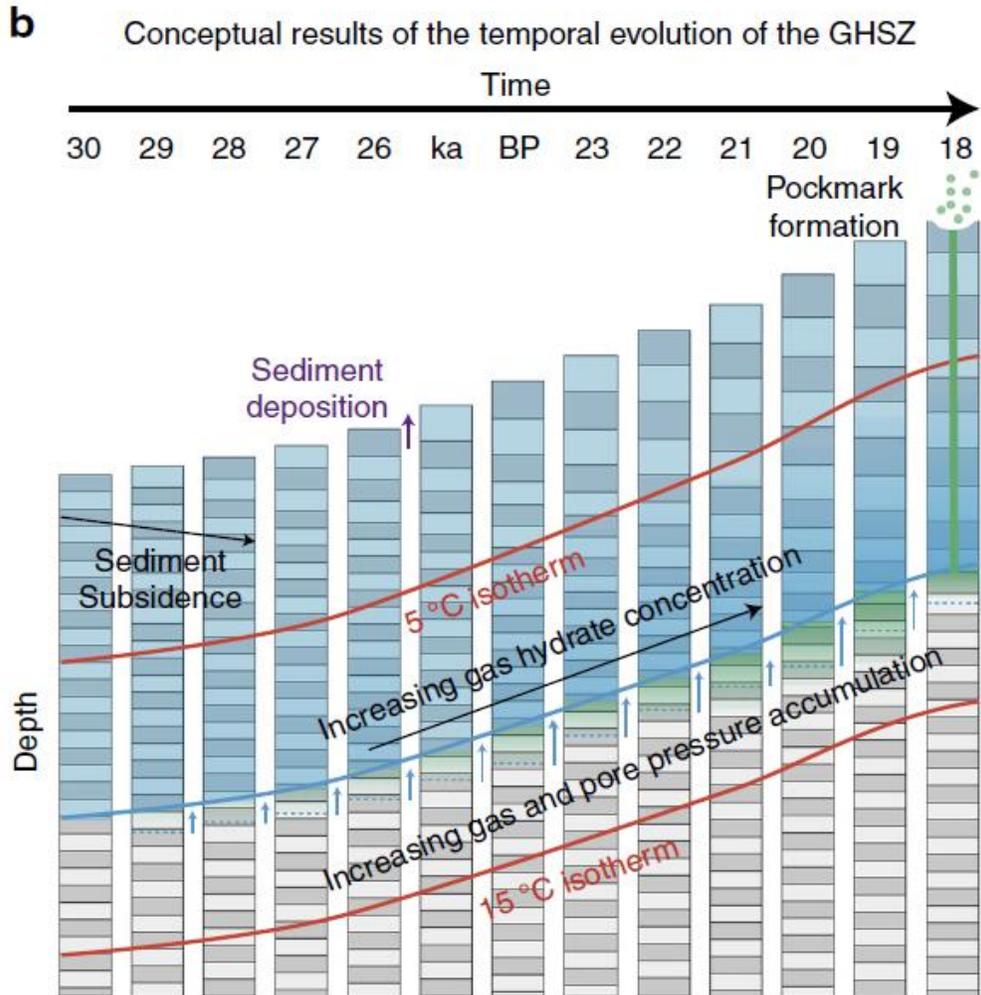
Hydrate dissociation after icesheet retreat generated large depressions on the seafloor



Andreassen et al., 2017

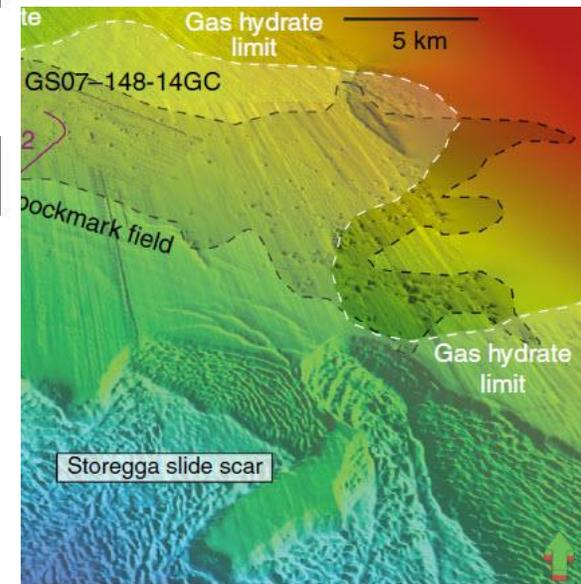
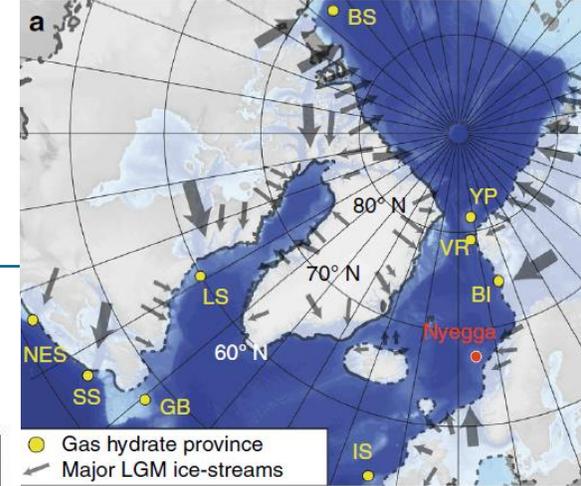
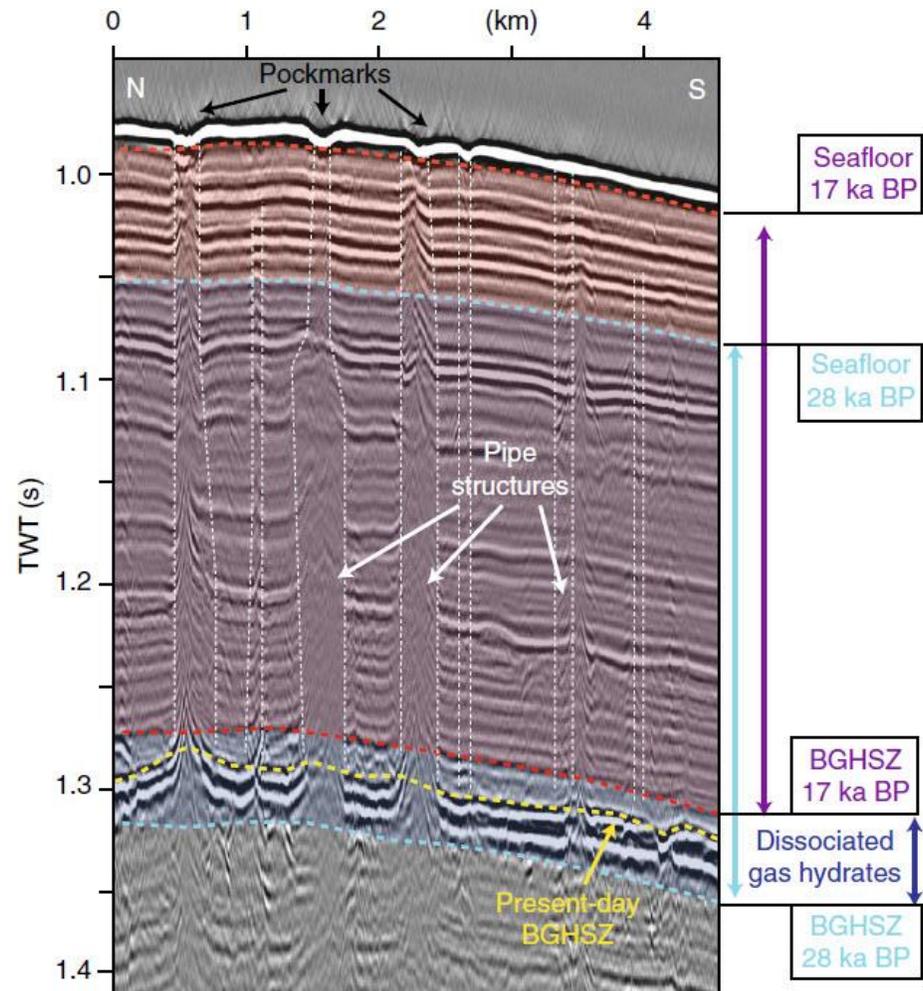


High sedimentation rate shift the base of hydrate stability

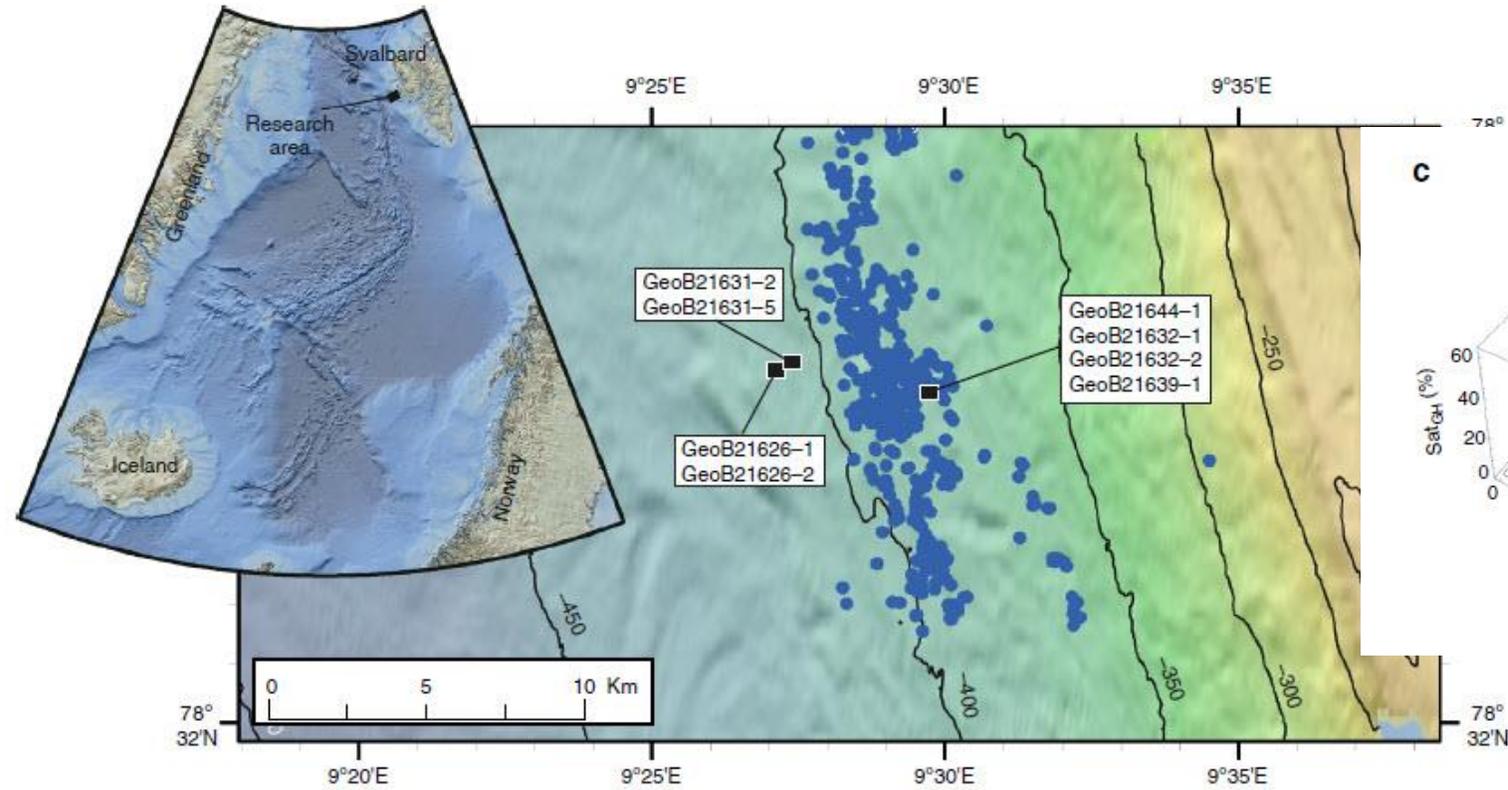


Karstens et al., 2018

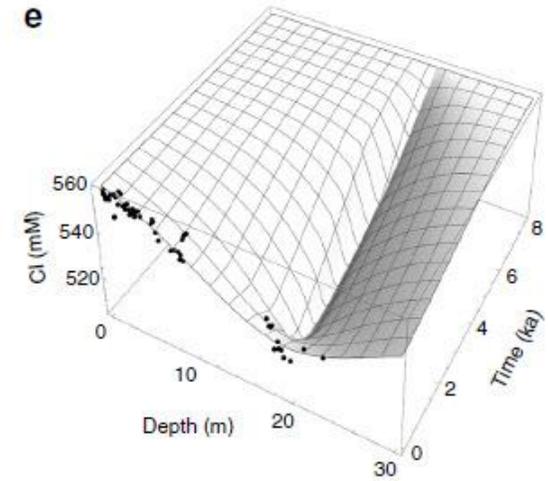
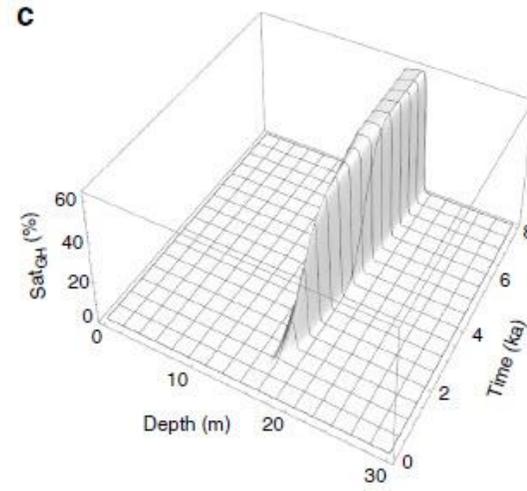
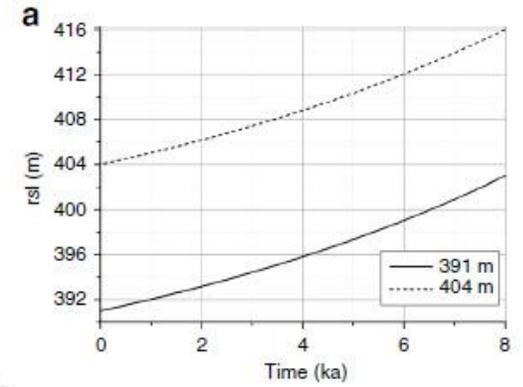
CAGE – Centre for Arctic Gas Hydrate, Environment and Climate



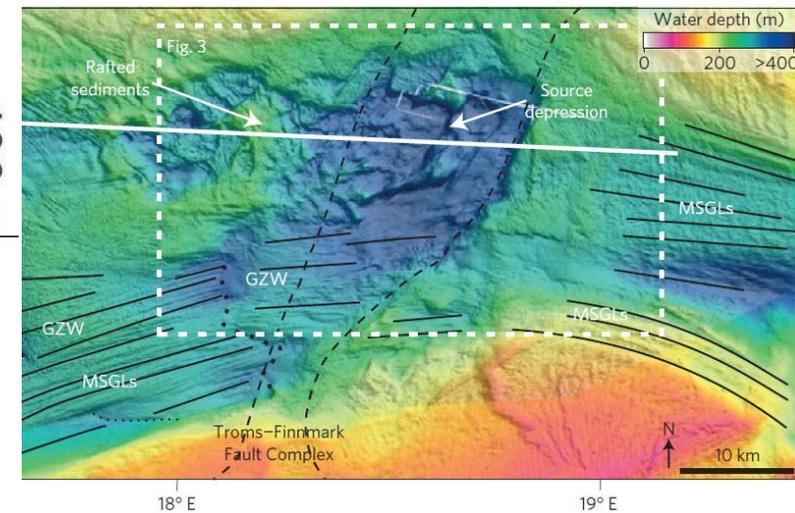
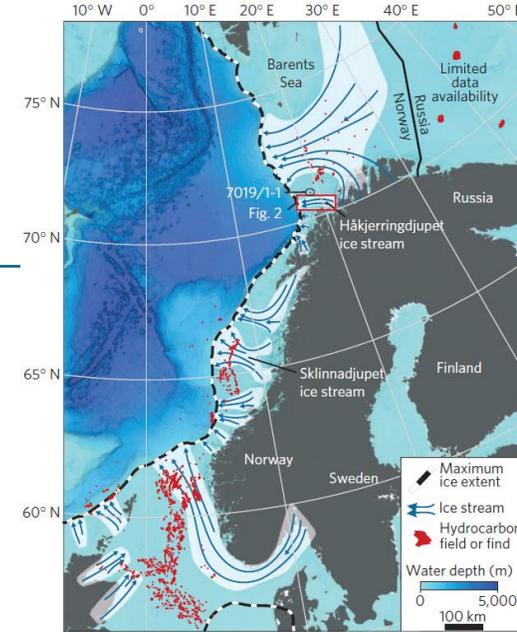
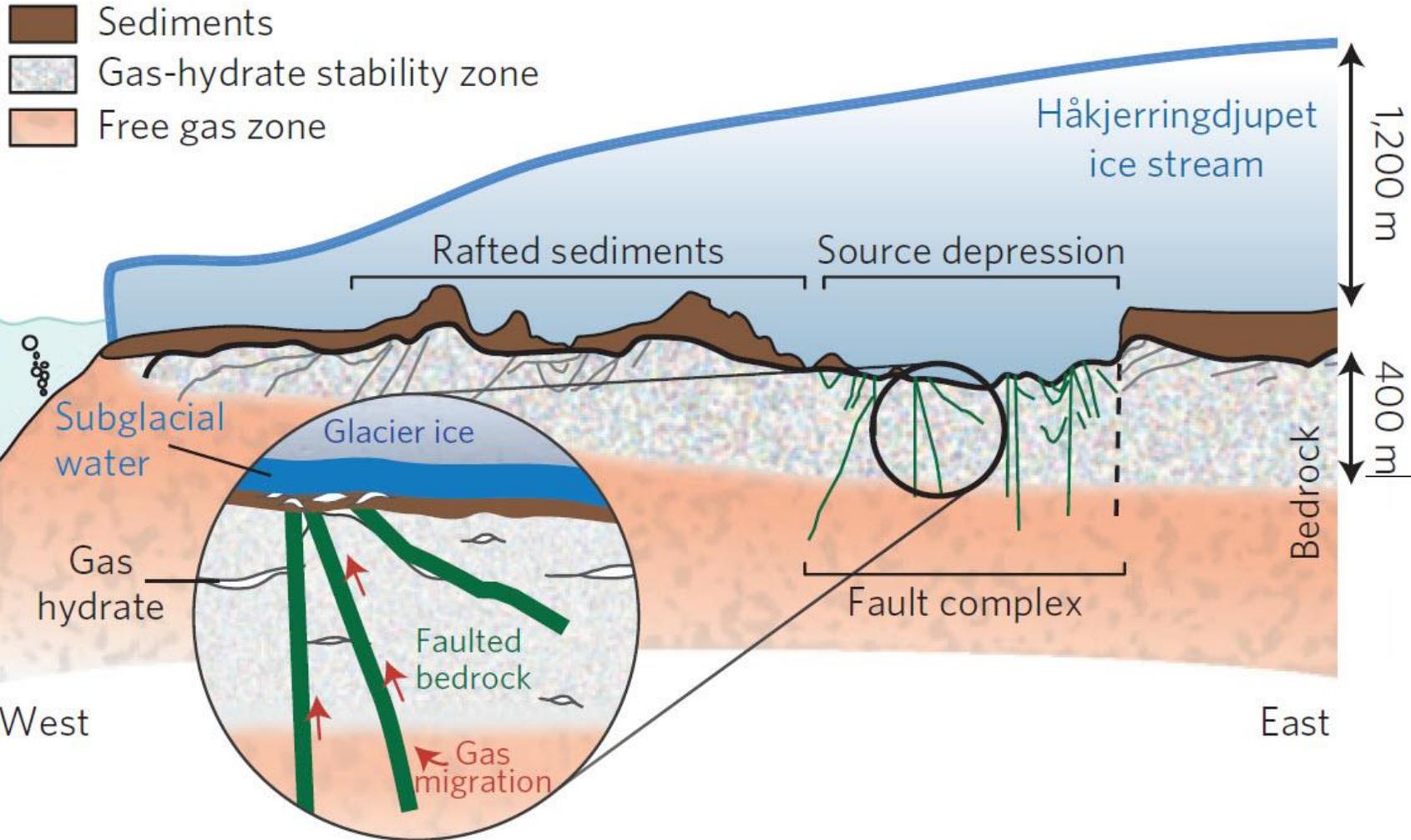
Glacial uplift is still affecting the hydrate stability in the Norwegian Margin



Wallmann et al., 2018



Hydrate 'sticky-spots' under ice regulating ice stream flow

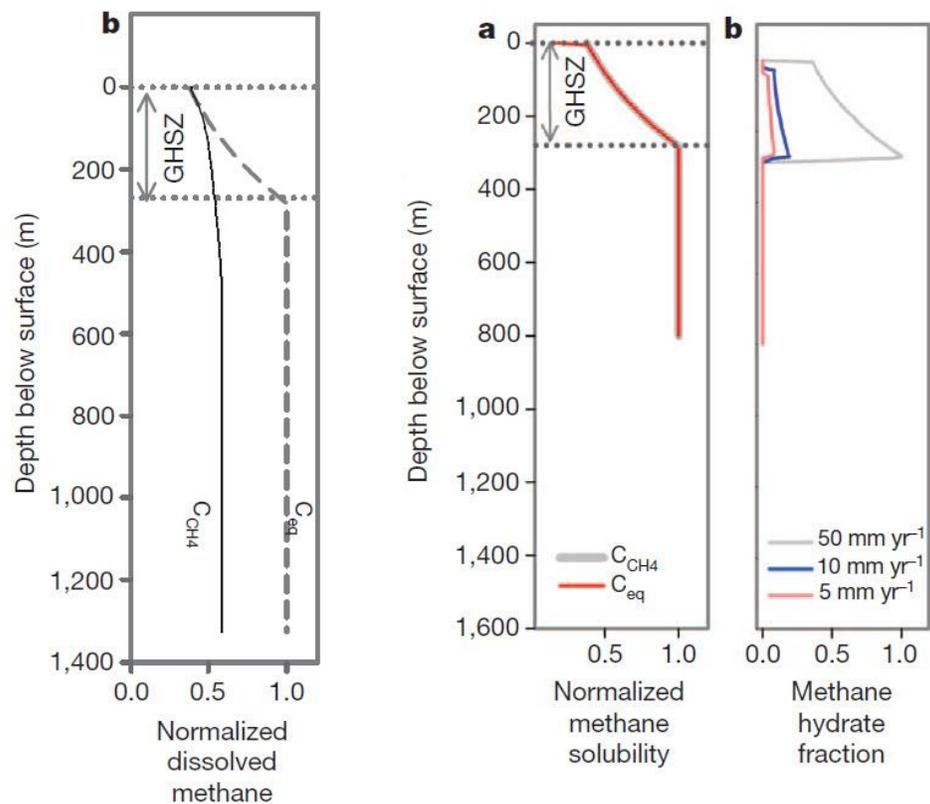


Winsborrow et al., 2016

Implications



Antarctica

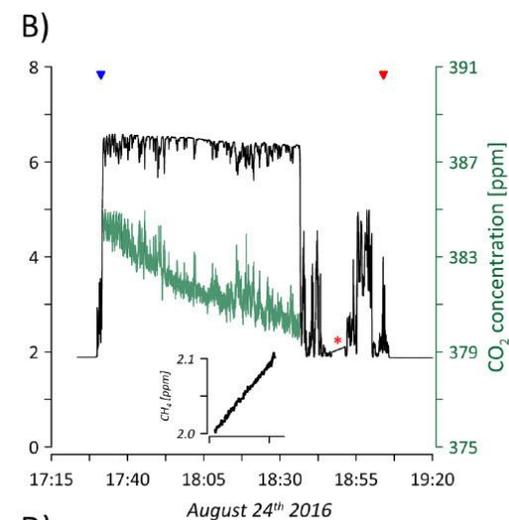
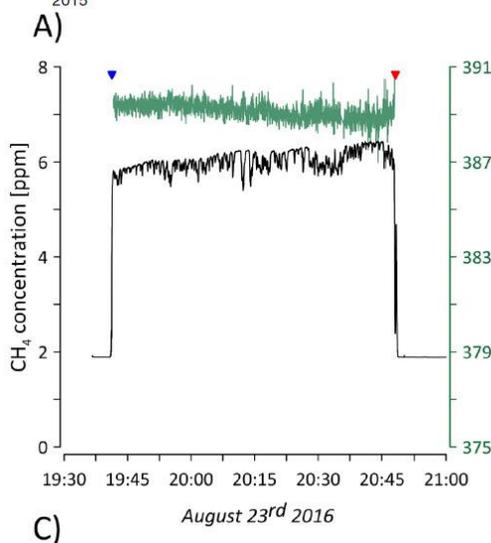
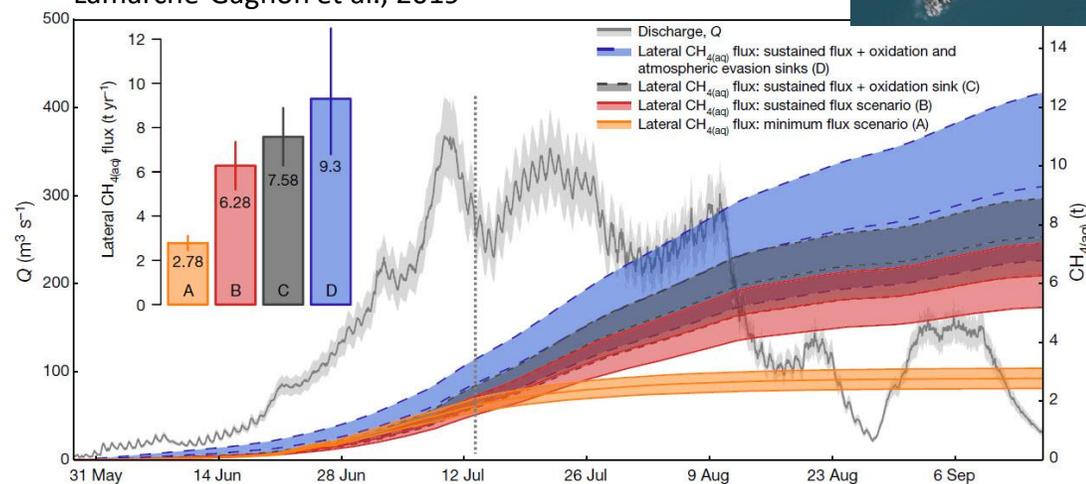


Wadham et al., 2012

Greenland



Lamarche-Gagnon et al., 2019



Christiansen and Jørgensen, 2018

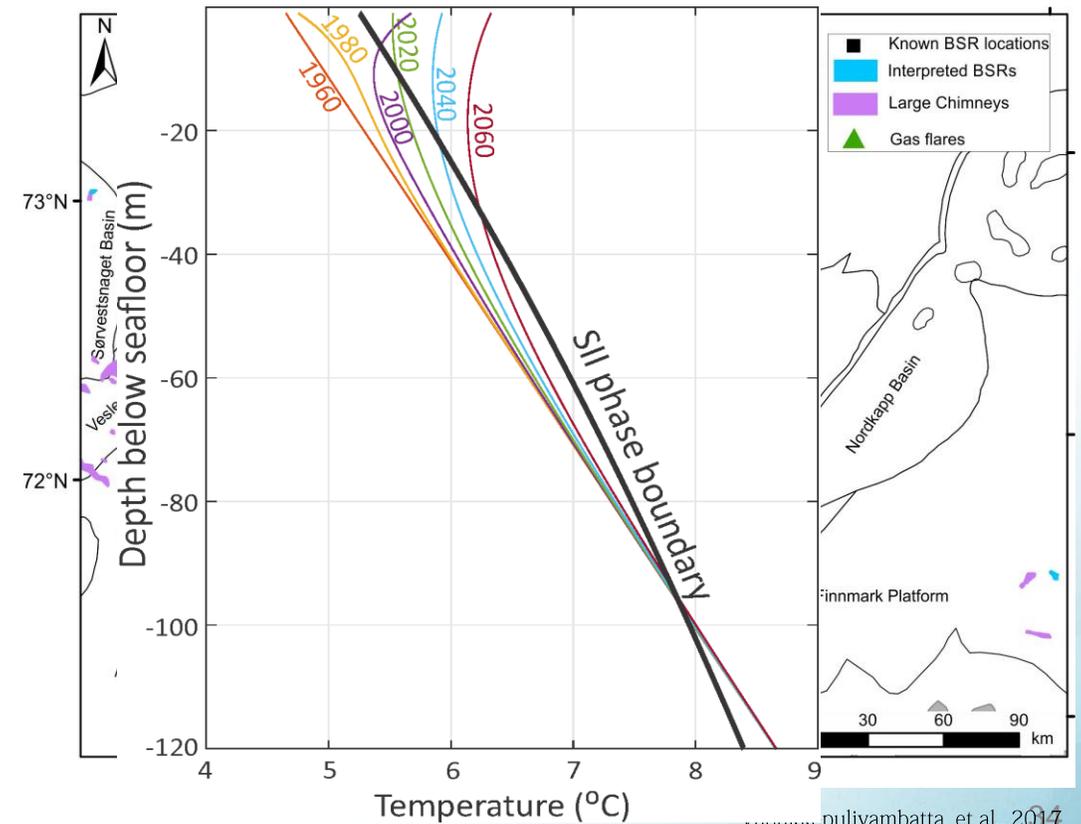
Challenges in understanding hydrate evolution under glaciers

Methane source

Initial conditions

Sediment availability and its properties

Quantification



Summary

- Icesheets support a thick gas hydrate stability zone.
- Deglaciation events are often accompanied by large-scale hydrate dissociation.
- Uplift, sealevel, and ocean temperatures control the hydrate evolution after icesheet retreat.
- Accelerating icesheet melt in Antarctica and Greenland may release large amounts of methane.