UNIVERSITY OF BERGEN
Department of Physics and Technology

Methane production from CO_2 injection in hydrates - CO_2 and CH_4 hydrate formation at pore scale

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CO_2 for EOR as CCUS, Rice University, October 4-6th 2015

Gas hydrate as energy source

- Vast amount of energy stored in natural gas hydrates
- Location
  - Permafrost regions
  - Deep sea continental shelves
- Production mechanisms
  - Pressure depletion
  - Thermal stimulation
  - Inhibitor injection
  - CO_2 injection

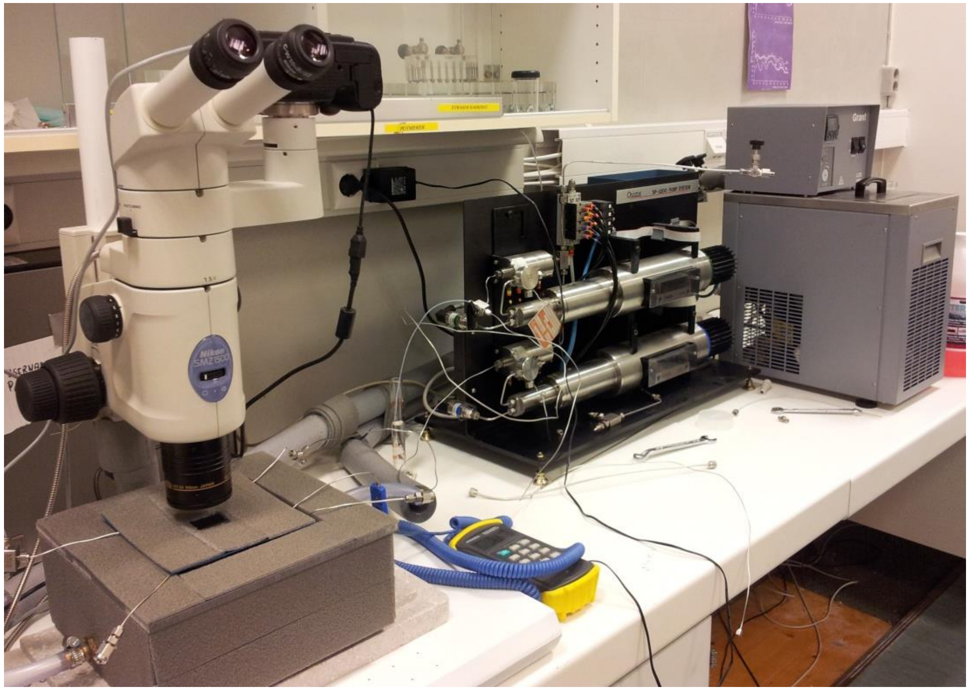
Source: http://www.theenergycollective.com/sbattaglia/200361/methane-hydrate-future-of-energy

Motivation

- Develop a new methodology to repeatedly form CO_2 and CH_4 hydrates in high pressure 2D porous medium
- Visualize and identify pore-level hydrate growth mechanisms
- Quantify hydrate growth rates in pore structures at reservoir conditions
- Provide an improved framework for fundamental studies of sediment-hosted gas hydrates

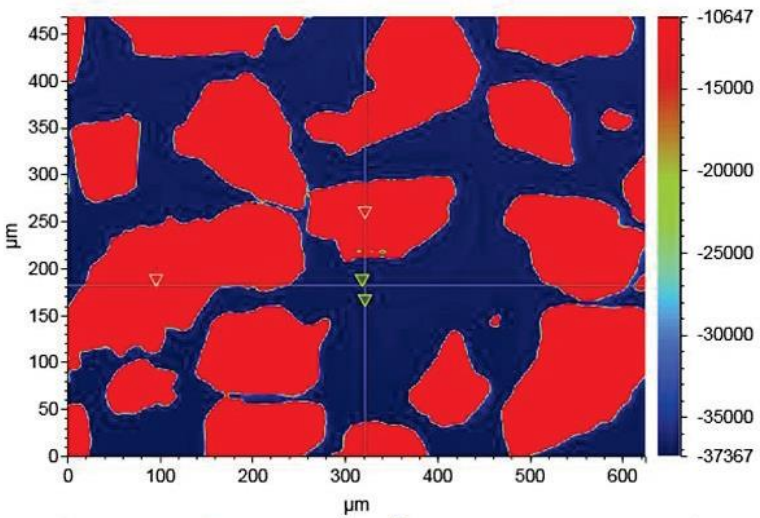
Laboratory setup

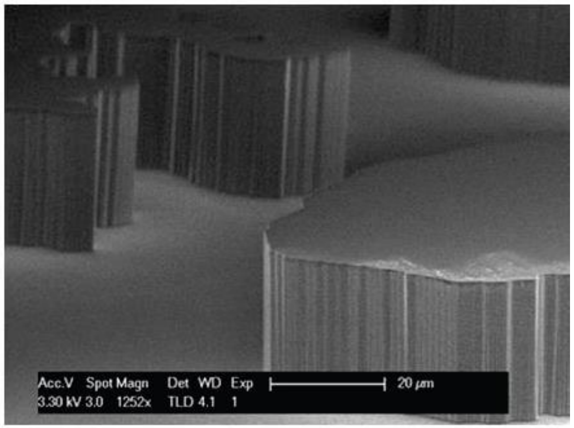
- High pressure
  - Quizix SP-5200 pump system
- Low temperature
  - Double chamber cooling system
- Dynamic imaging
  - Nikon SMZ 1500 microscope body / Nikon D7100 camera
- Porous medium
  - HP silicon micromodel

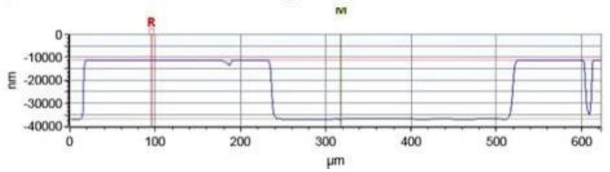


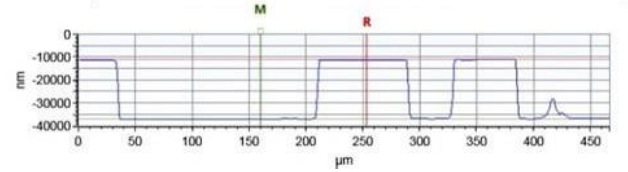
HP Etched-silicon micromodel

- Based on Berea sandstone
- DRIE etching technique (depth 25 µm)
- Accurate and well-defined pore geometry
- High coordination number (>4)
- Net pressure 10 MPa (1450 psi)

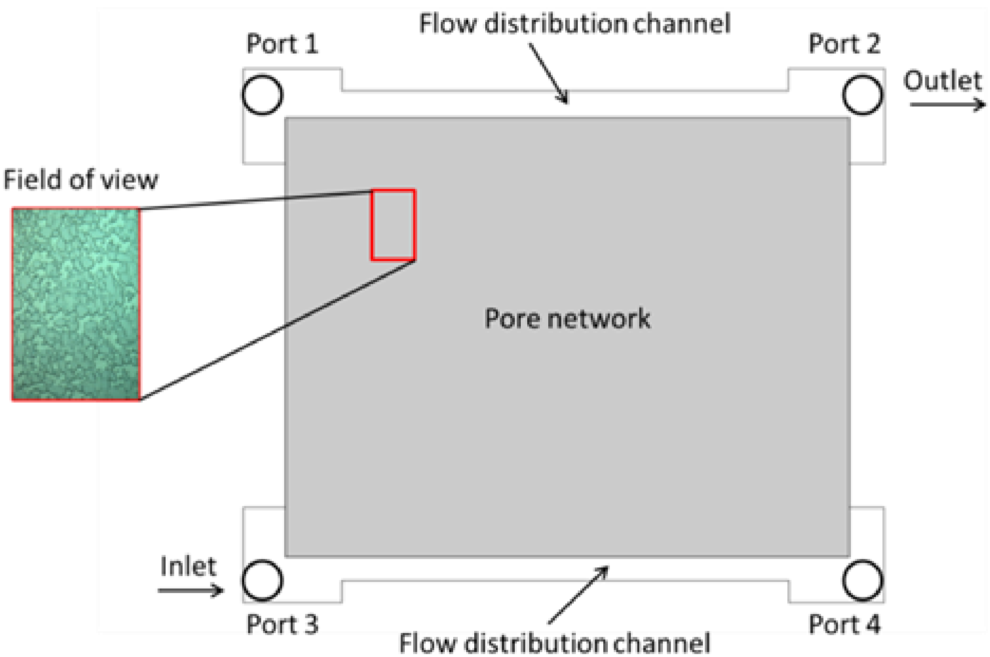


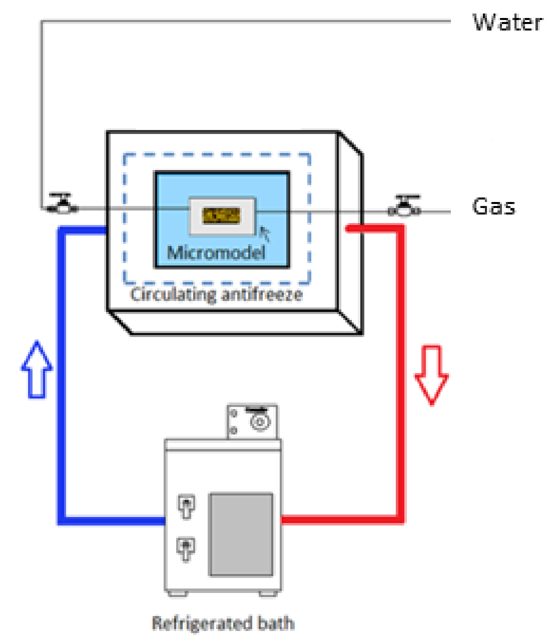






System description



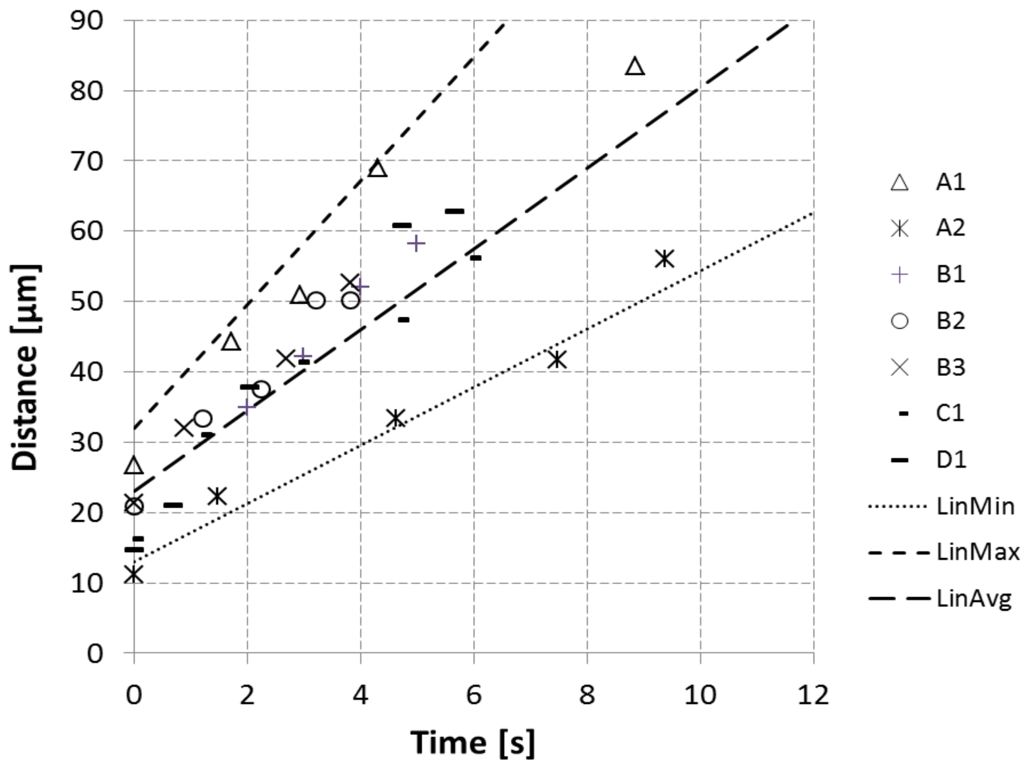


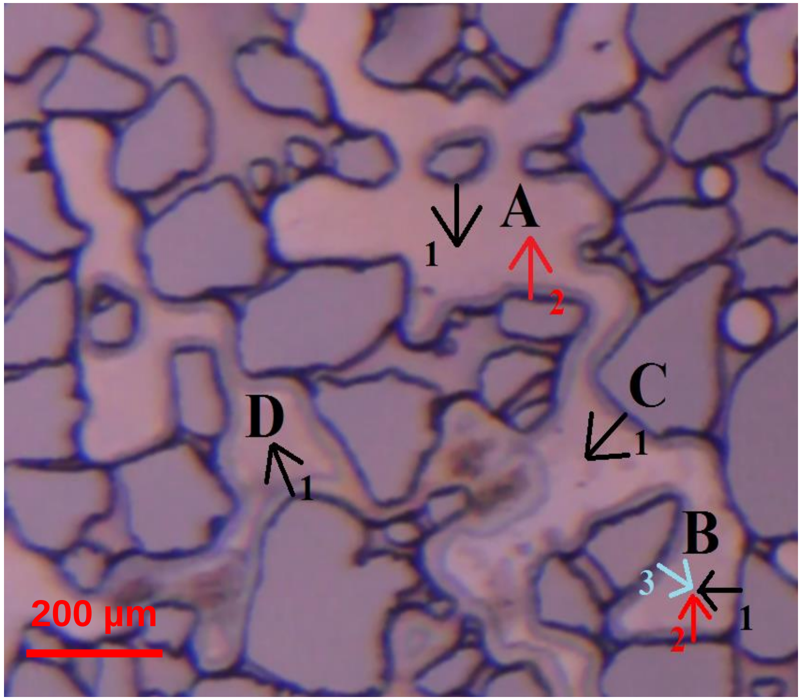
5 cm

Hydrate formation

Guest Molecule	$T_{Initiation}$ [°C]	P [MPa]	Cycle	Induction time	Agitation
CO_2	0.5	5.8	Primary	11 days	Pressure pulse
CH_4	0.5	8.0	Primary	9 days	Pressure pulse
CH_4	4.4	8.0	Secondary	2 hrs	Temp +/-

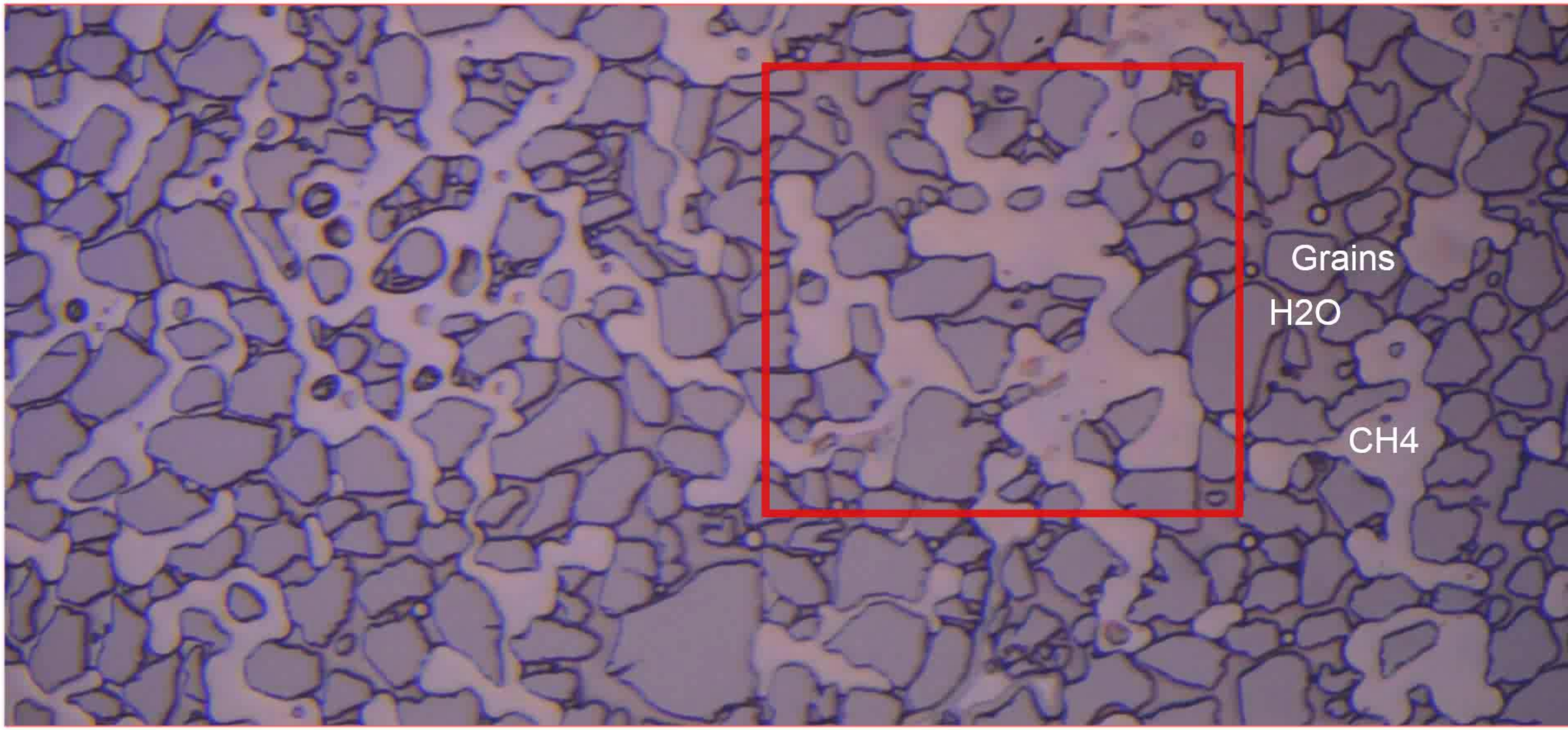
Hydrate growth rates





Dynamic hydrate distribution

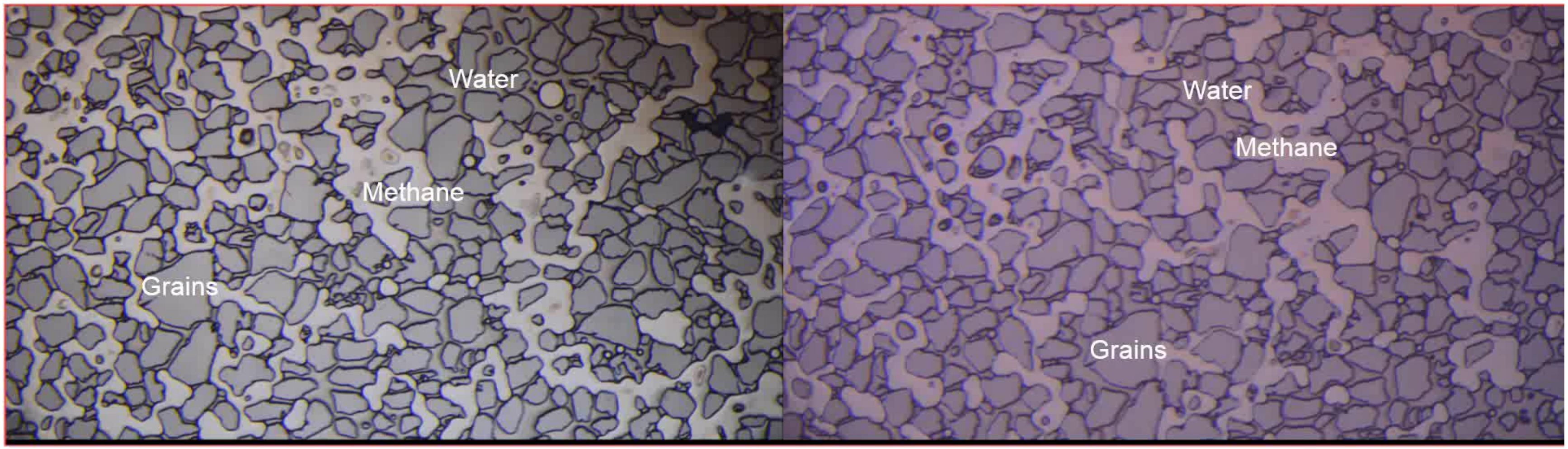
Secondary Methane Hydrate Formation P=8 MPa, T=4.4C



Formation in gas-filled pores: Area 1/Figure 7 in article. Speed: 100%

Degree of subcooling

Secondary Methane Hydrate formation (P = 8 MPa), 100% Speed



5.1 Degree C

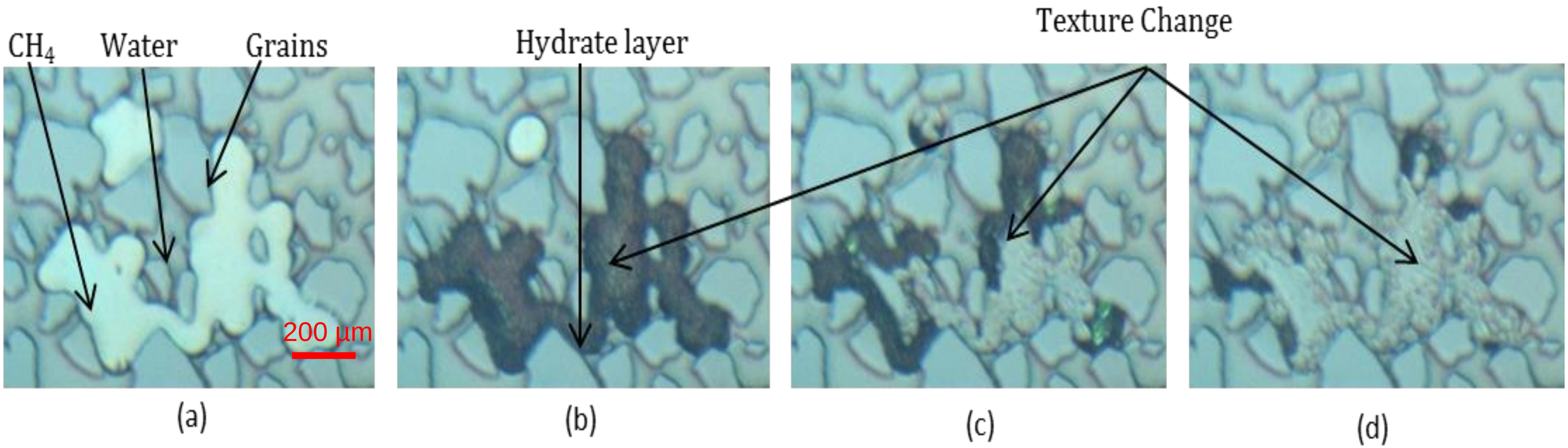
4.4 Degree C

Hydrates start forming in gas-filled pores, on the interface between gas and a water film coating the surfaces.

The newly formed hydrate surface acts as a growth site for further formation, resulting in a continous formation through clusters of gas-filled pores.

Hydrate growth is faster along the pore walls than towards the center of the pore.

Hydrate rearrangement



- Rearrangement into crystalline hydrate structure
- No hydrate formation in water-saturated pores

Conclusions

- HP silicon micromodel enables high spatial resolution imaging of CO_2 and CH_4 hydrate growth in realistic and well-defined pore structures
- Hydrate formation rate depends on local accessibility of water and gas and degree of subcooling. The average CH_4 hydrate growth rate (at 4.4°C):
  - Alongside the pore wall ~500 μm/s
  - Towards pore center ~7 μm/s

Conclusions

- Hydrate growth pattern is strongly coupled to the local fluid distribution and fluid connectivity within the pore network.
  - (1) A thin hydrate film growing widespread on the water/gas interfaces
  - (2) A thicker hydrate layer progressing along the pore wall and toward the pore center
  - (3) Rearrangement from agglomerated polycrystalline to crystalline hydrate structure occurring over several hours

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Additional