Mechanisms Leading to Co-existence of Gas and Hydrate in Ocean Sediments

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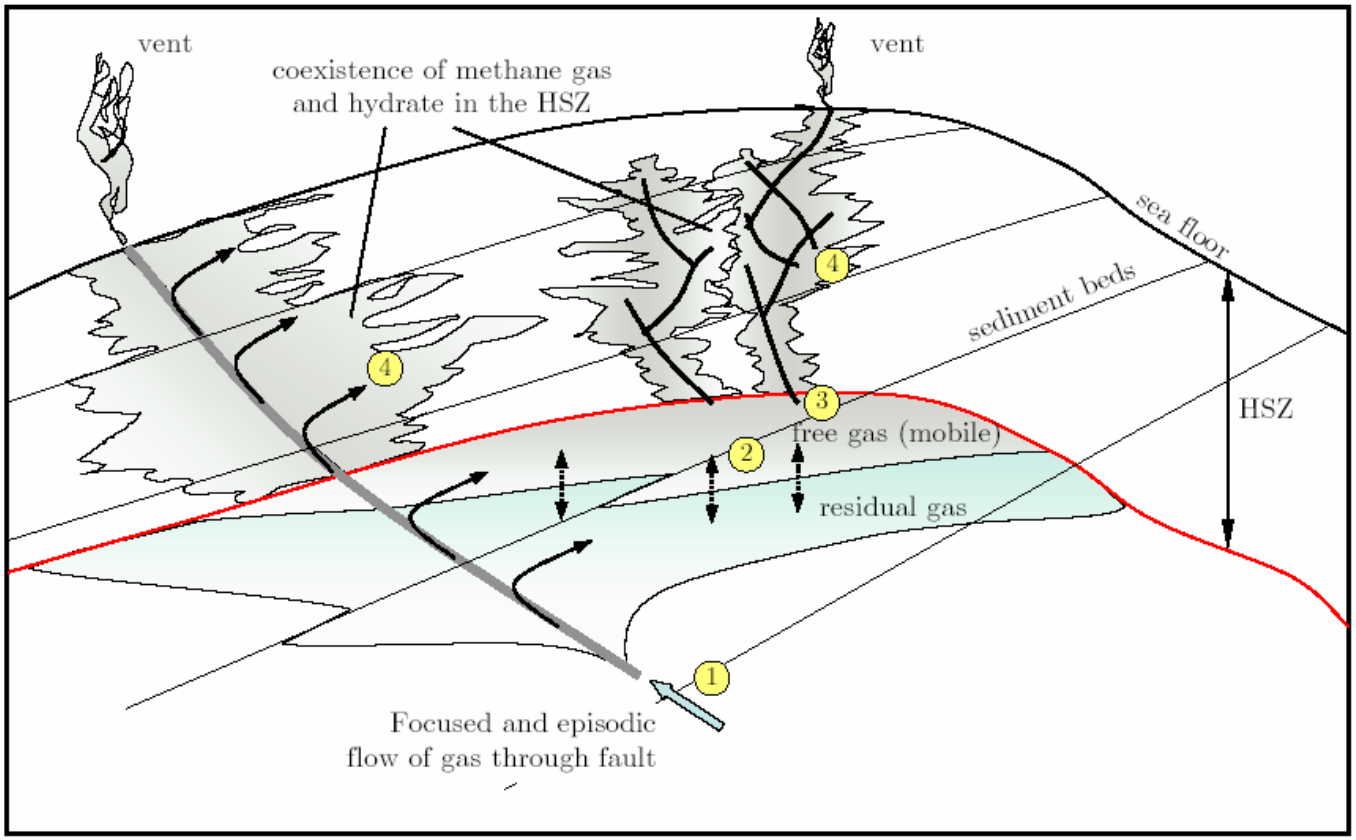
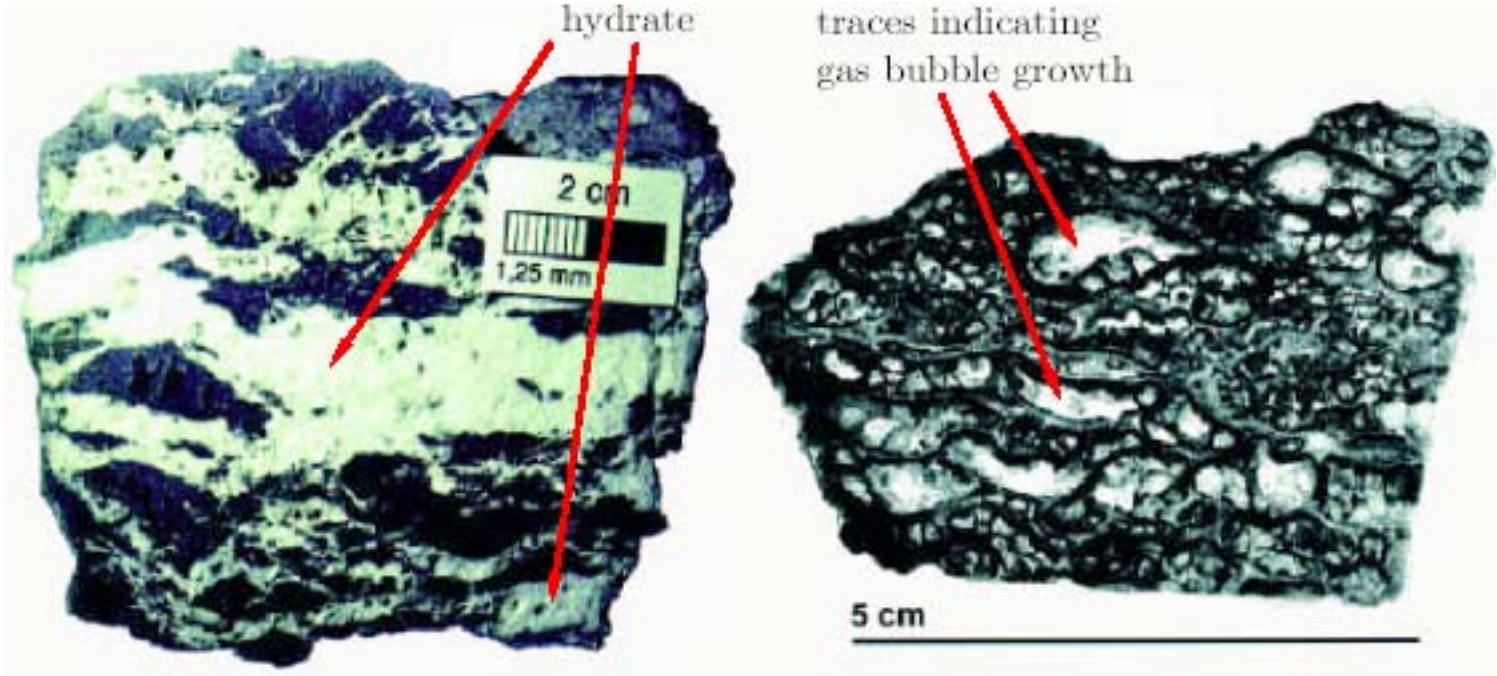
Observations and Ruminations



- Hydrate, gas and water co-exist within HSZ
- Methane transport within HSZ does not occur solely as dissolved species in aqueous phase

- Some proposed explanations for co-existence
  - kinetics of hydrate formation;
  - regional geotherms;
  - hypersaline brines as a result of hydrate formation;
  - fast, focused flow of free gas through fractures and high-permeability conduits

More observations and ruminations



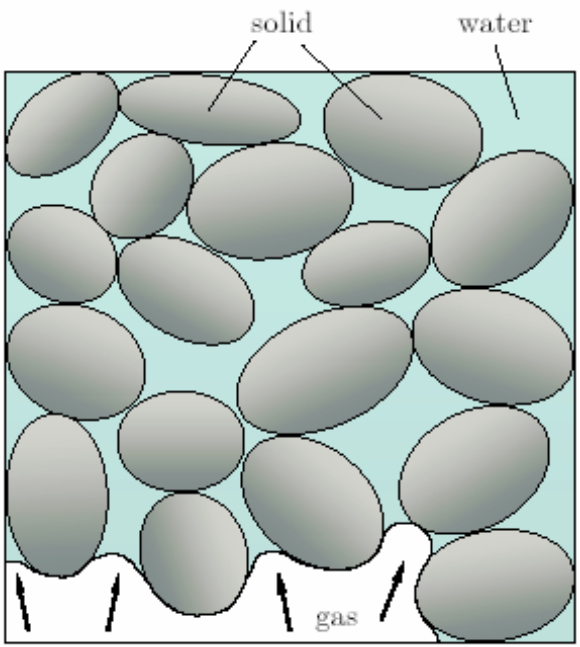
Hydrate fabric in ocean sediments.
L: hydrates occurring in discrete layers that are several millimeters or centimeters thick, generally parallel to bedding; the hydrate does not occupy the original pore space but, rather, has opened a fracture.
R: internal structure of the hydrate shows traces of gas bubbles, indicating that it is likely that hydrate precipitation was organized around the gas/water interface. [Suess et al., 1999]

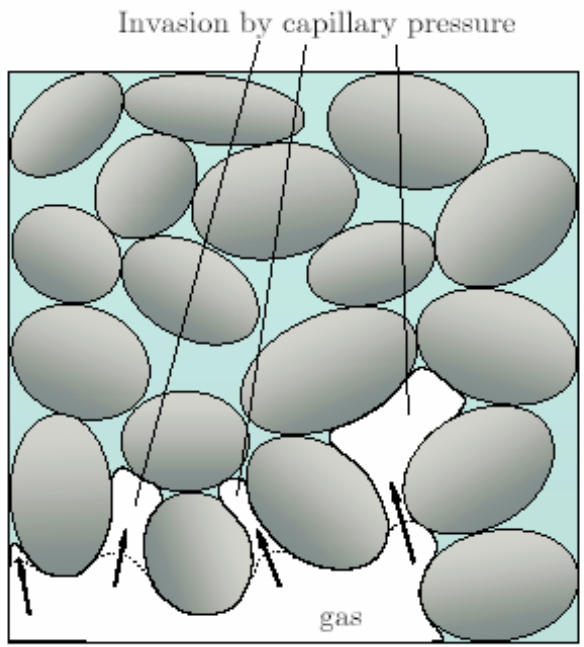
Our conjecture

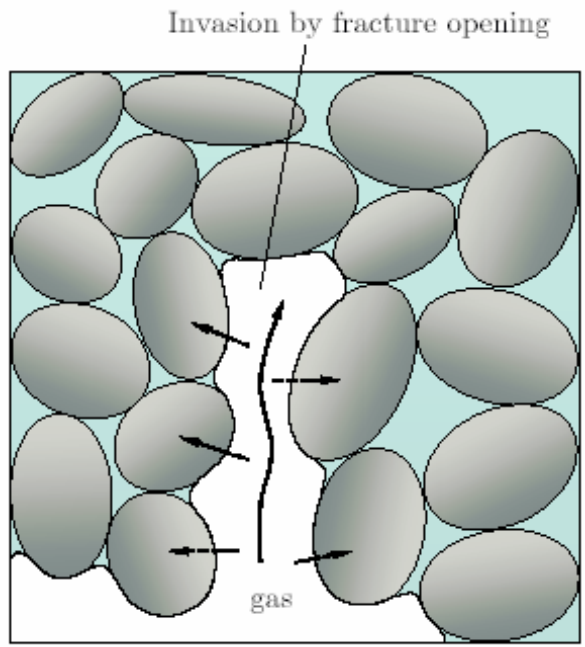
- Coupled multiphase flow/mechanics behavior leads to a characteristic distribution of hydrate that includes co-existence with gas, both laterally and vertically within a sediment column.
- We will study this by developing
  - Grain scale models
  - Bed scale models

Research Objectives (1a)

- Understand the mechanisms that control the presence, migration, entrapment and destabilization of methane hydrates in ocean sediments
  - Grain scale models of drainage, imbibition and methane trapping
  - Grain and bed scale models of sediment fracturing

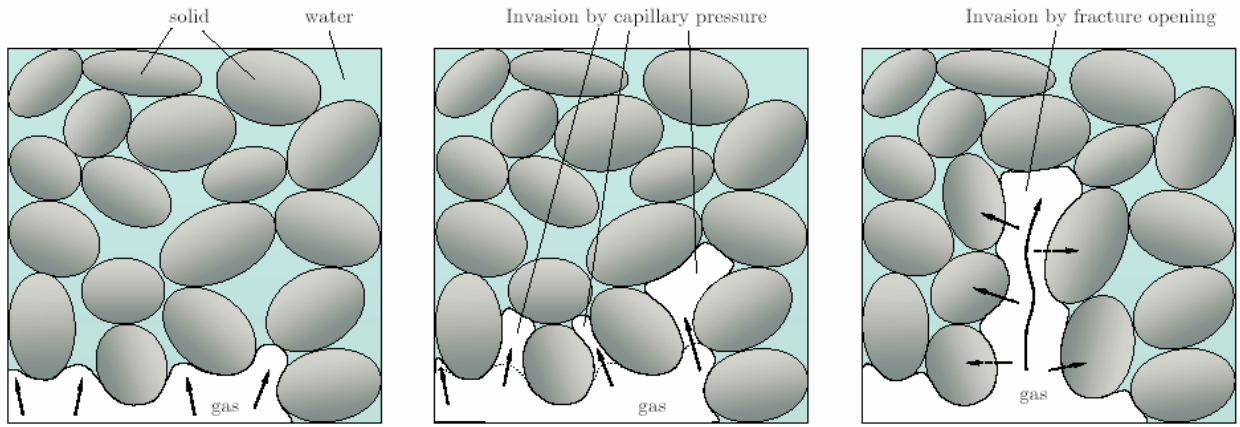


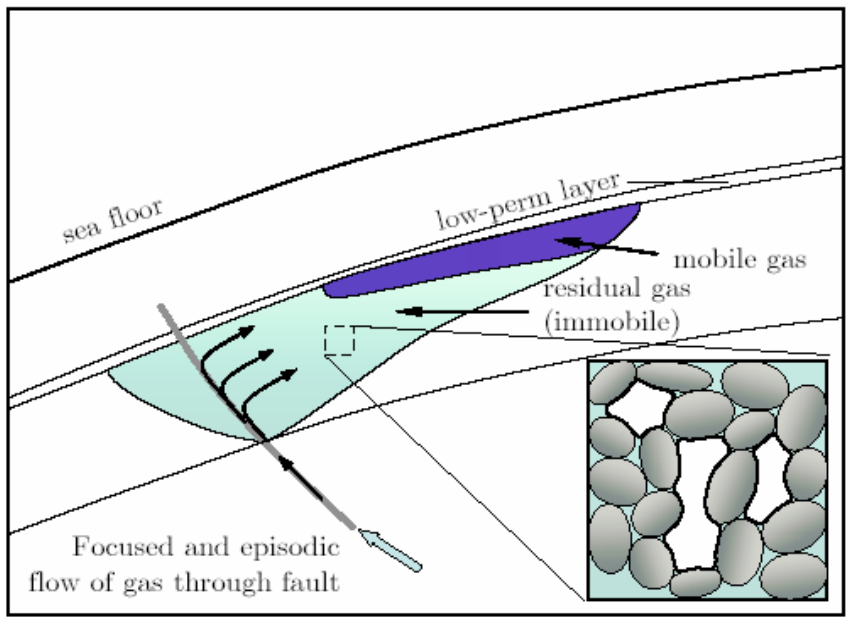


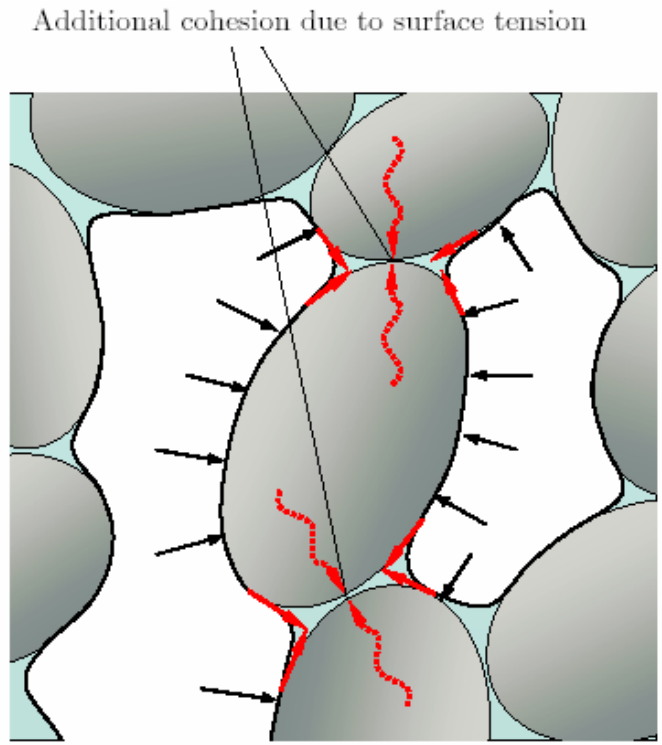


Research Objectives (1b)

- Grain scale models of drainage and methane trapping
- Grain and bed scale models of sediment fracturing

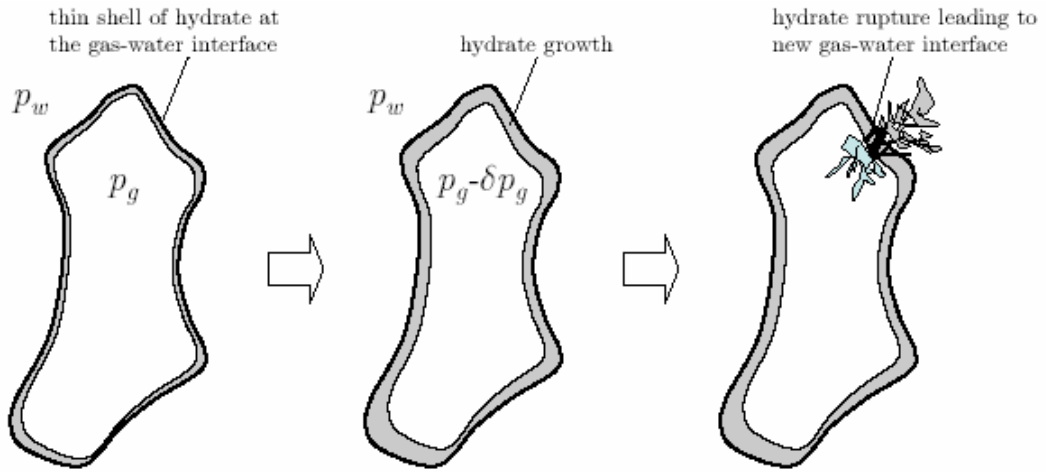


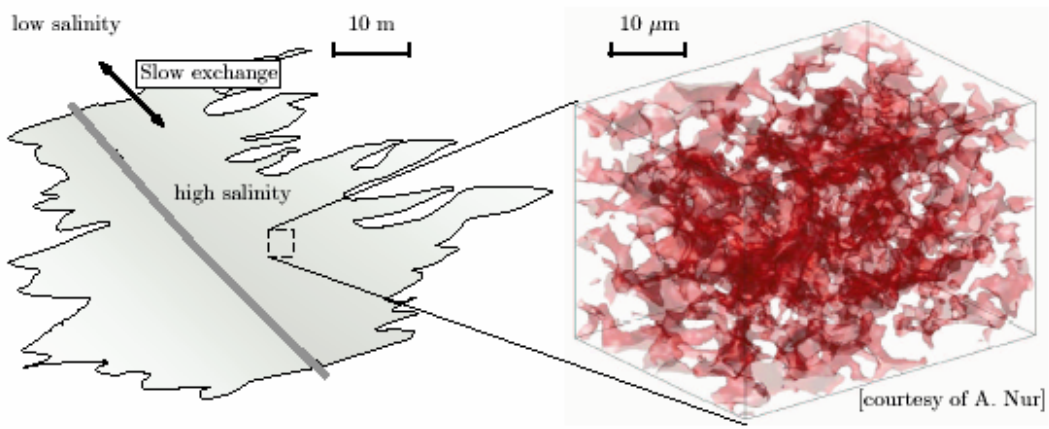




Research Objectives (2)

- Explain the co-existence of methane gas and methane hydrate within the HSZ
  - Increased salinity of pore water upon hydrate formation.
  - Availability of gas/water interface.

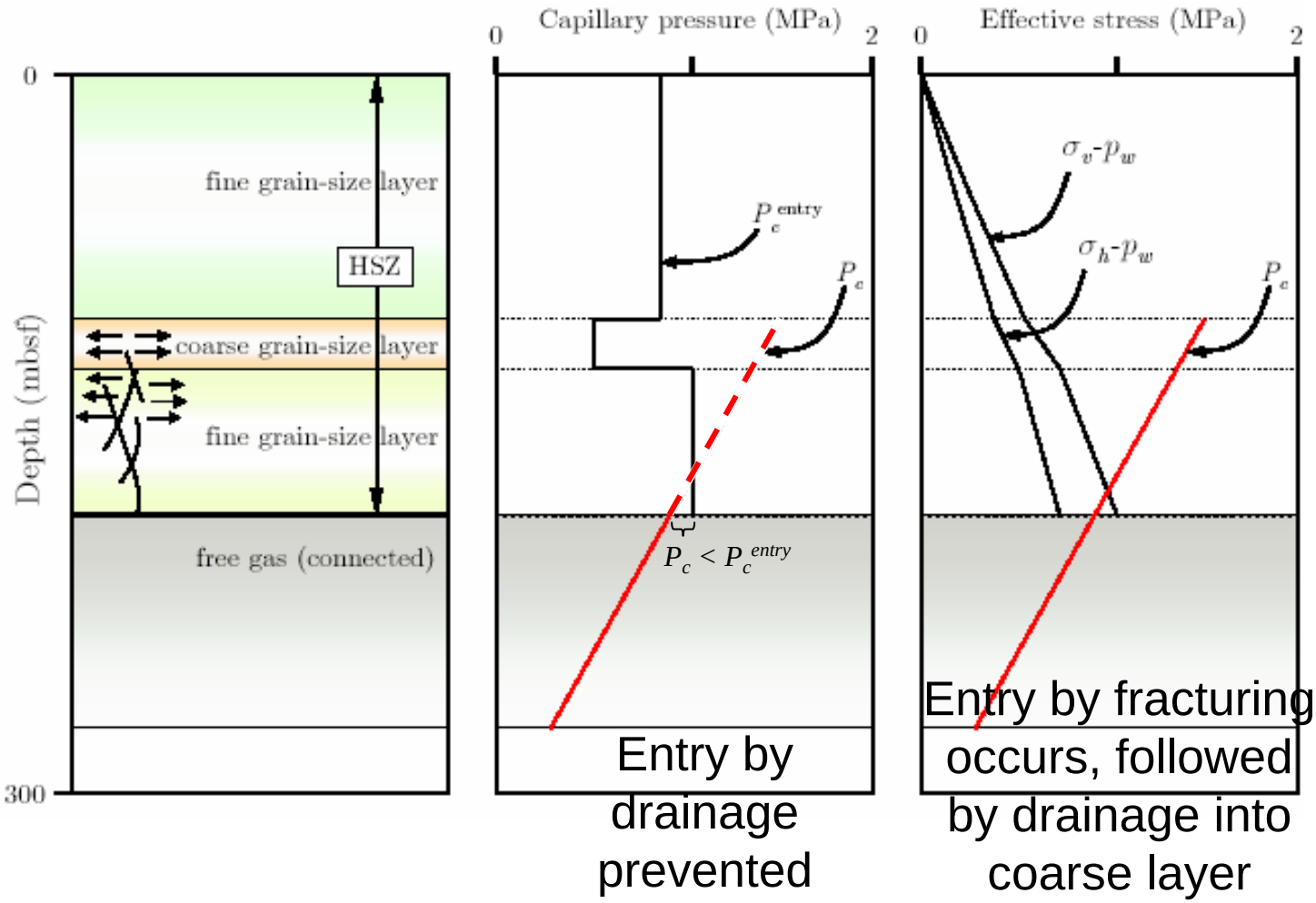




Water distribution in gas-invaded pore space

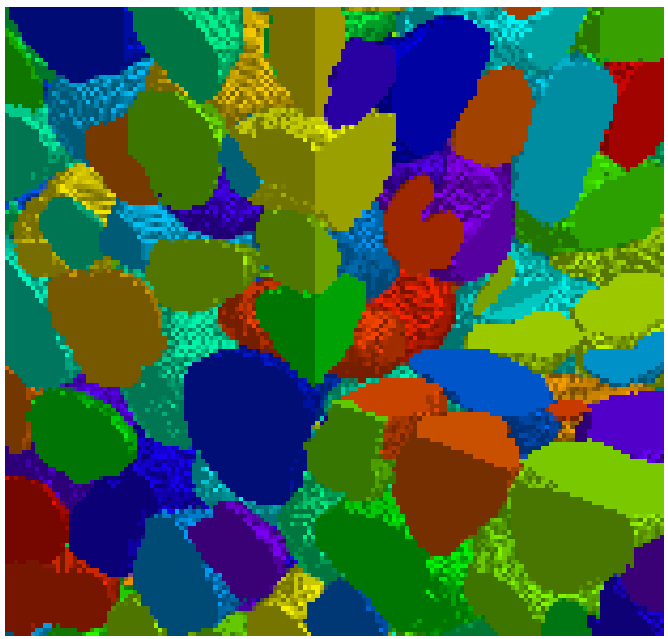
Research Objectives (3)

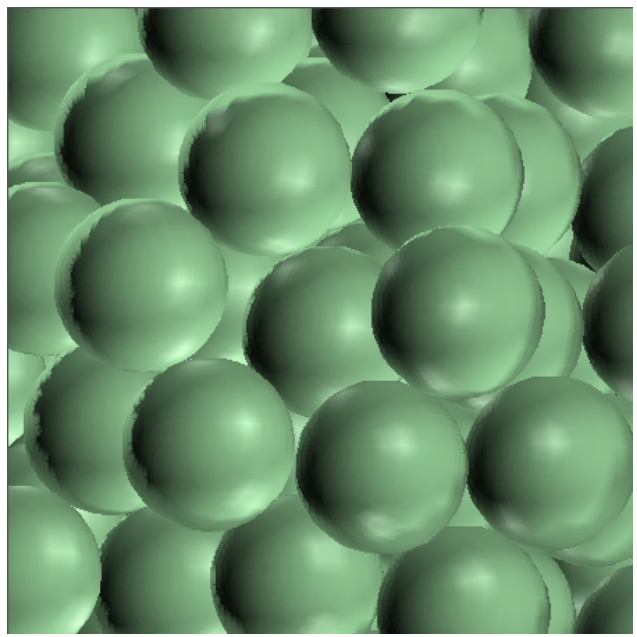
- Describe the dynamics within the HSZ, by means of numerical models



Methods

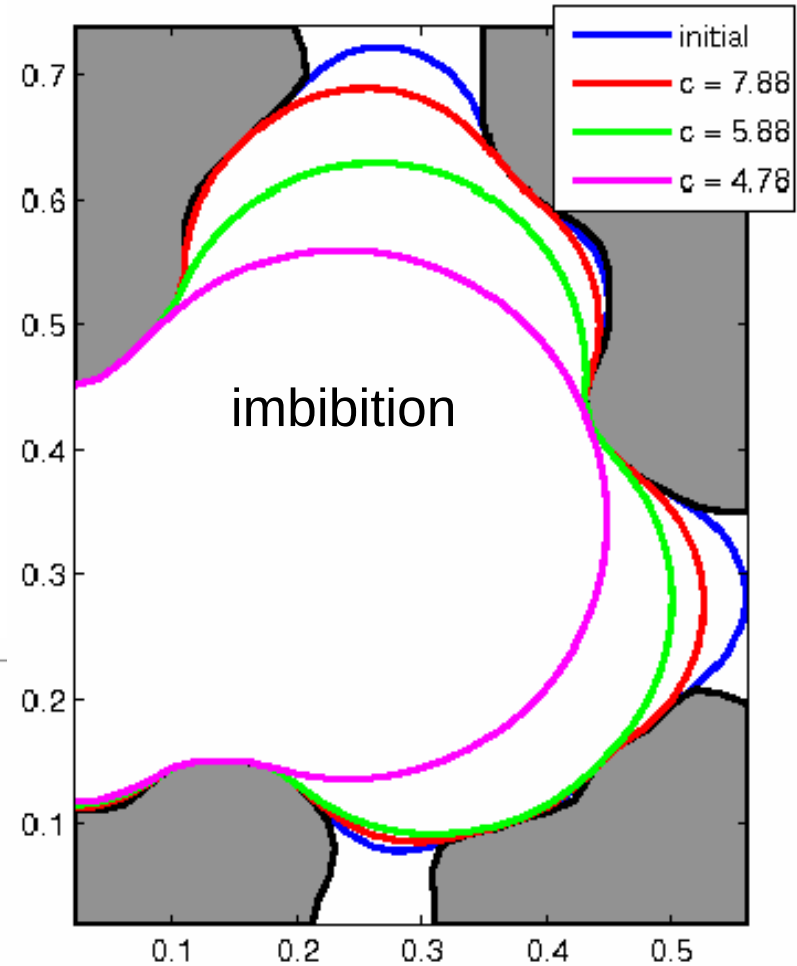
- Grain scale modeling of drainage and imbibition
  - Use dense random packings of spheres as model sediments

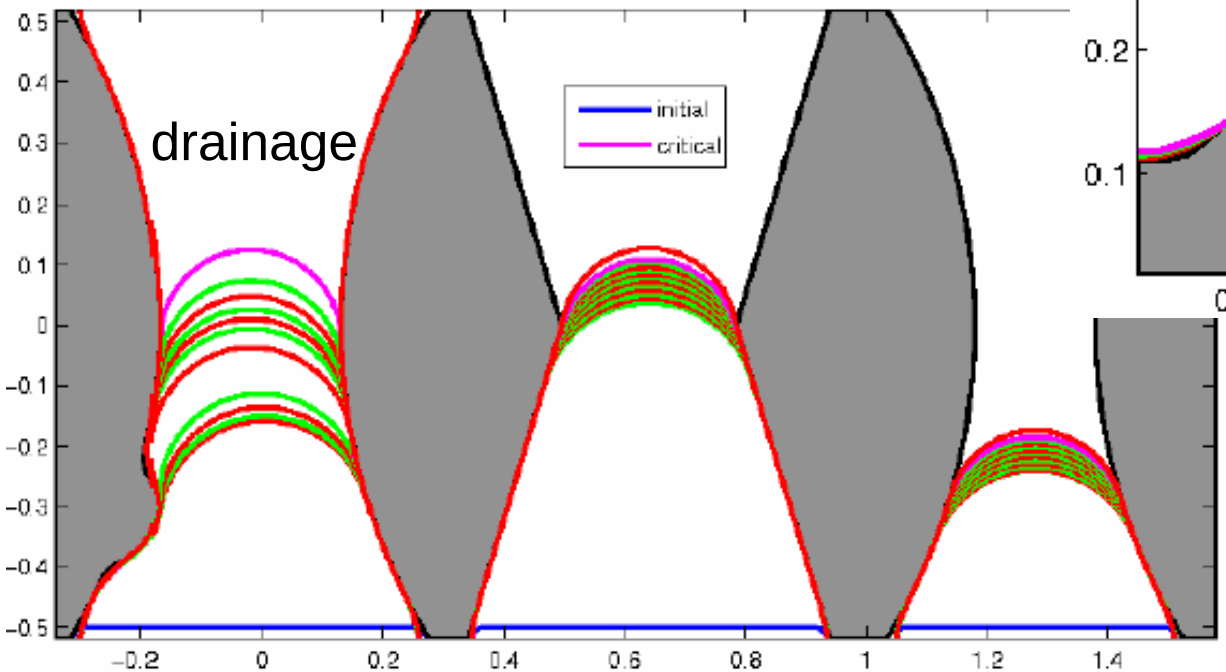




Methods

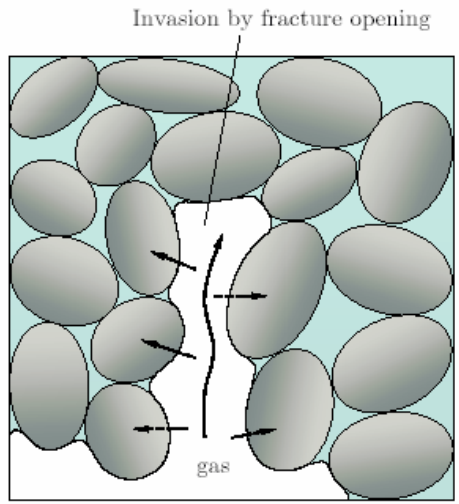
- Grain scale modeling of drainage and imbibition
  - Progressive quasi-static algorithm (Prodanovic and B., *JCIS* 2006; doi:10.1016/j.jcis.2006.08.048) for critical curvatures for pore-level events

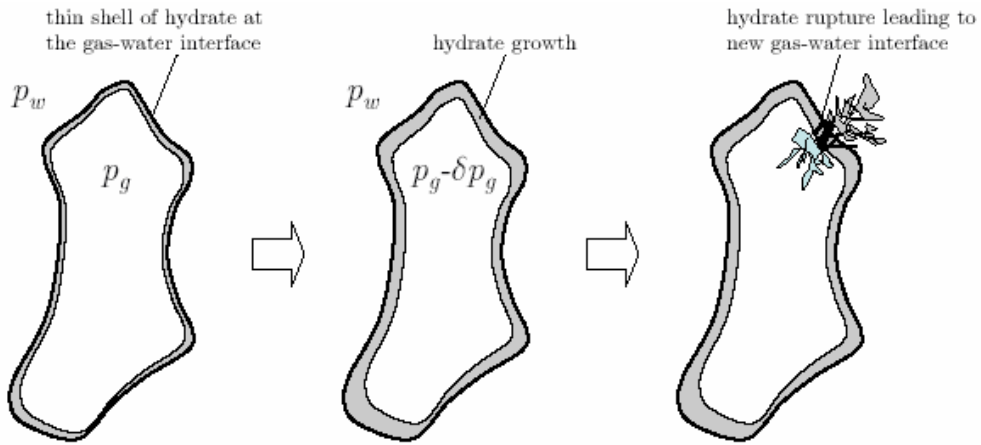


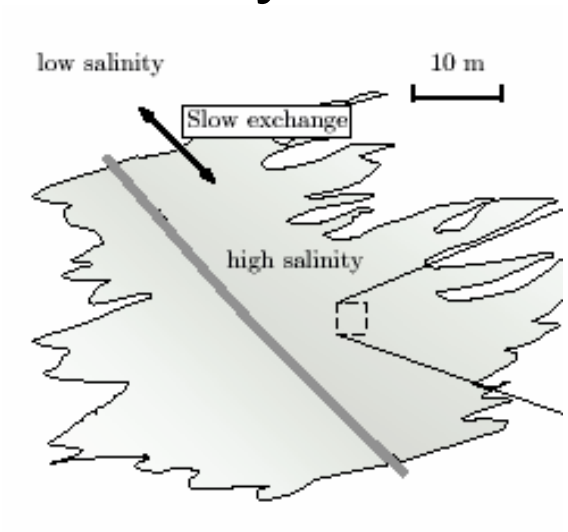


Methods

- Explicit model of hydrate growth at gas/water interface
  - Fracture/sediment boundary
  - Pore space
  - Salinity increase

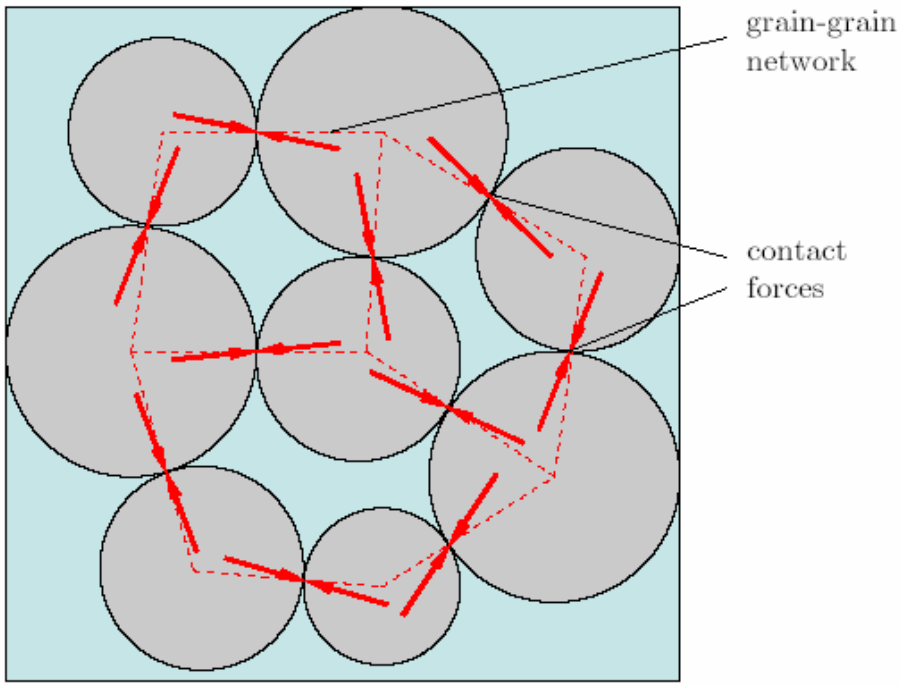


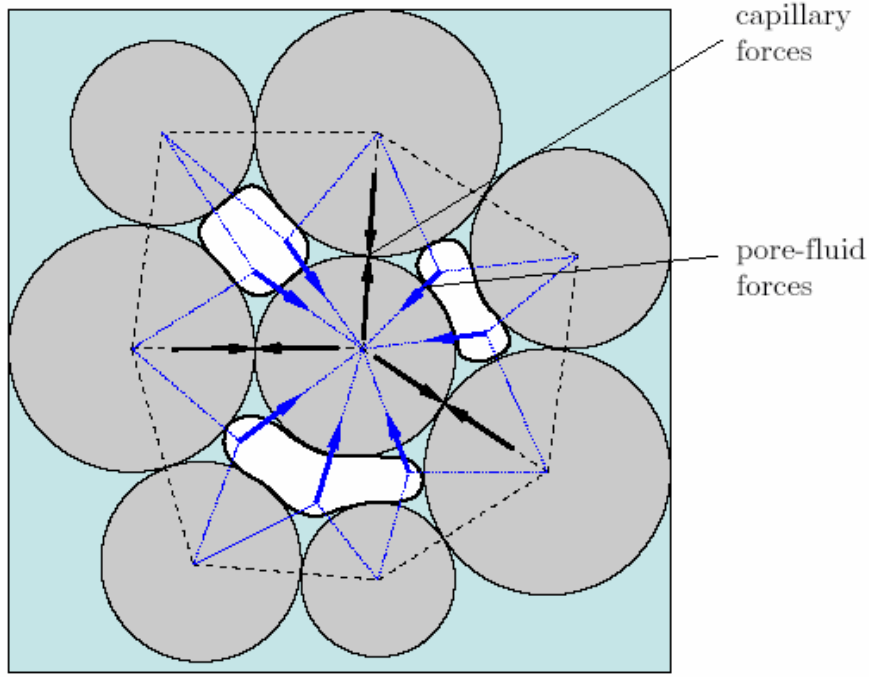




Methods

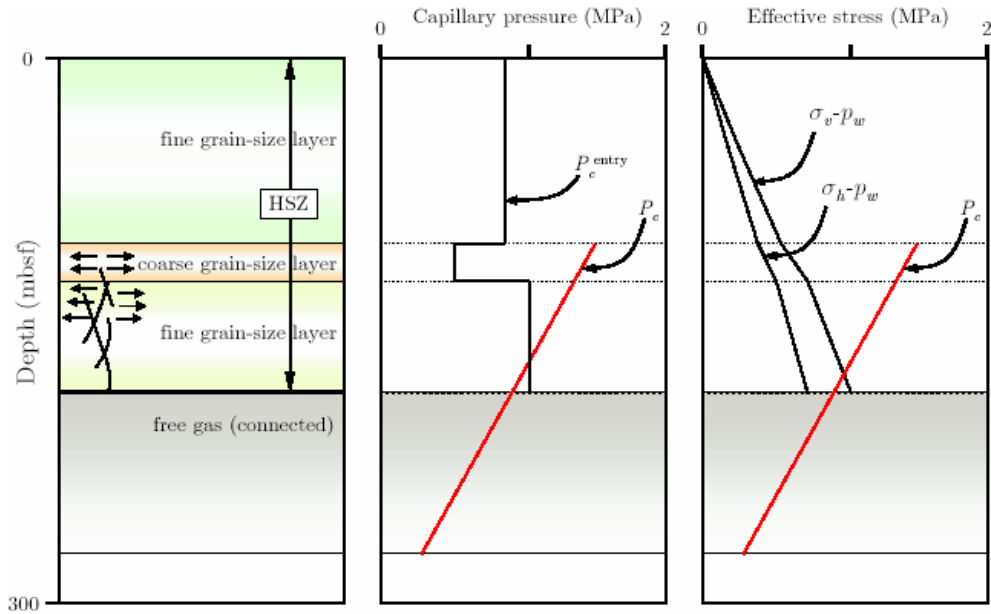
- Grain scale modeling of mechanics
  - PFC3D (commercial discrete element method code)
  - Add effect of 2nd fluid phase
  - Criteria for opening a fracture





Methods

- Bed scale “threshold + leakage” model
  - Incorporate grain scale understanding in quasi-1D vertical leaky conduit
  - Thresholds to vertical movement (into or through HSZ)
    - Capillary entry pressure
    - Sediment fracture pressure
  - Thresholds to horizontal movement (into beds)
    - Leakage rate ~ $P_c(z)$



Model validation

- Observations reported in literature
- New measurements by other researchers
  - Grain size distributions
  - Salinity variations