# Detection and Production of Methane Hydrate
# Phase 2

**Rice University &**

**University of Houston**

**George J. Hirasaki, *Lead PI***

**CONTRACT NO. DE-FC26-05NT42960**

**NETL Project Manager: Kelly Rose**

**Presentation to US DOE NETL**

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# Objective

- This proposal seeks to understand regional differences in gas hydrate systems from the perspective of as an energy resource, geohazard, and long-term climate influence. Specifically, we want to:
  - 1) collect data and conceptual models that targets causes of gas hydrate variance,
  - 2) construct numerical models that explain and predict regional-scale gas hydrate differences in 2- and 3-dimensions with minimal “free parameters”,
  - 3) simulate hydrocarbon production from various gas hydrate systems to establish promising resource characteristics,
  - 4) perturb different gas hydrate systems to assess potential impacts of hot fluids on seafloor stability and well stability, and
  - 5) develop geophysical approaches that enable remote quantification of gas hydrate heterogeneities so that they can be characterized with minimial costly drilling.

# Expected Benefits

- An understanding of the factors responsible for difference the distributions of methane hydrate
  - Compilation of data from specific sites
  - Models to explain regional difference in hydrate distributions
  - Strategy for production from hydrate accumulations
  - Sensitivity of seafloor and wellbore stability to temperature pertubations
  - Seismic interpretation methods for differences in hydrate accumulations

# Project Organization Structure
## Rice University, Lead Organization
## George Hirasaki, Project Manager

- Rice University
  - Hirasaki & Chapman
    - Gaurav Bhatnager
    - New PhD student
  - Jerry Dickens
    - Glen Snyder (faculty)
    - New PhD student
  - Brandon Dugan
    - New PhD student
  - Colin Zelt
    - Priyank Jaiswal
- University of Houston
  - Kishore Mohanty
    - New PhD student

# Project Organization

1) Carbon In/Outputs – Jerry Dickens, Glen Snyder, Rice Ph.D. student [$181,962 DOE, $65,575 cost-share]
2) Hydrate Accumulation Models – George Hirasaki, Walter Chapman, Gaurav Bhatnager (Ph.D. candidate), Rice Ph.D. student [$430,996 DOE, $115,788 cost-share]
3) Production Strategy Analysis – Kishore Mohanty, UofH Ph.D. student [$214,165 DOE, $76,294 cost-share]
4) Seafloor & Borehole Stability – Brandon Dugan, Rice Ph.D. student [$215,917 DOE, $58,107 cost-share]
5) Geophysical Imaging – Colin Zelt, Priyank Jaiswal (Ph.D. candidate) [$213,236 DOE, $84,000 cost-share]

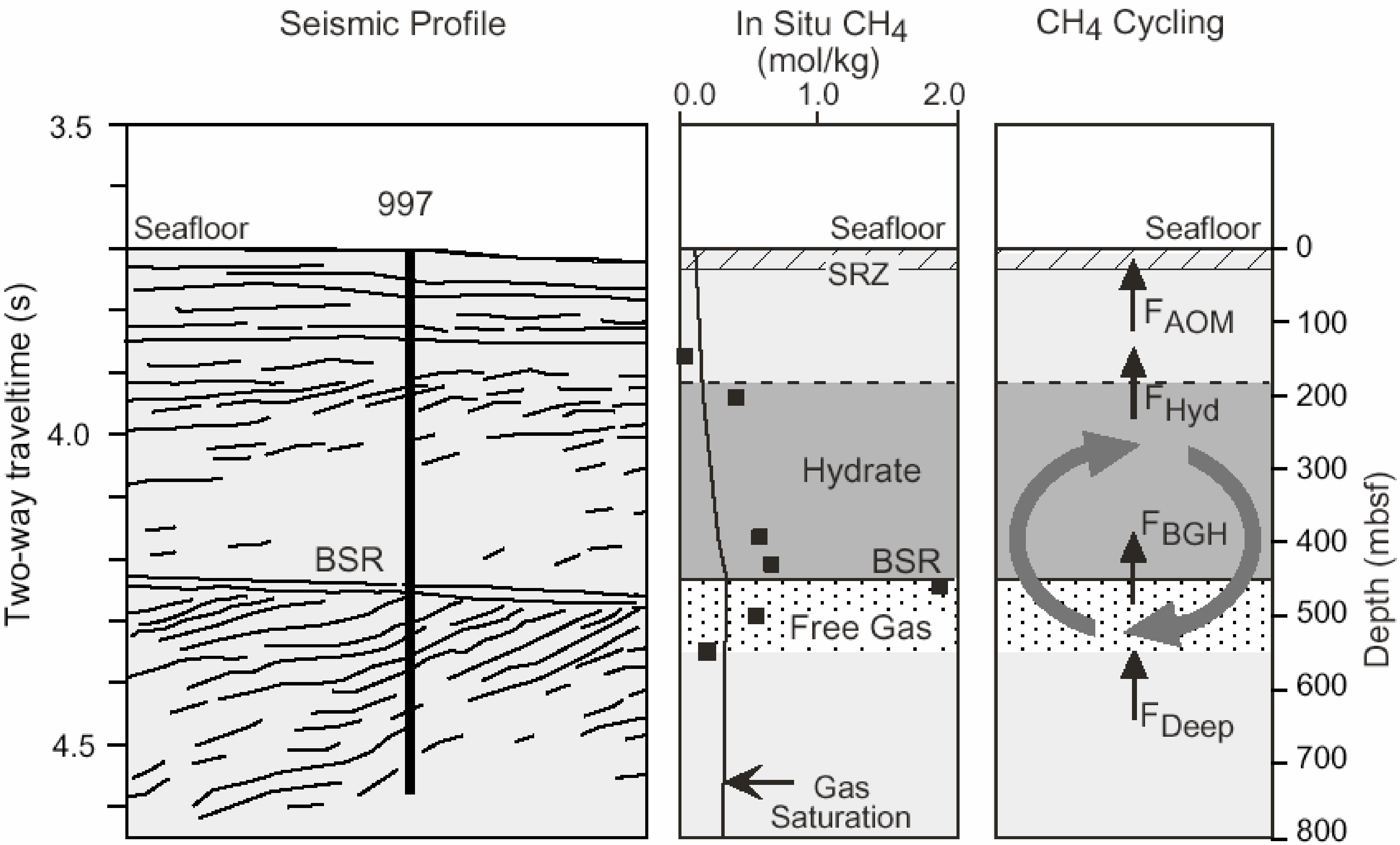
# Tasks

- **Task 1: Carbon Inputs and Outputs to Gas Hydrate Systems**
  - Gerald Dickens, Glen Snyder +*new PhD student*
- **Task 2: Numerical Models for Quantification of Hydrate and Free Gas Accumulations**
  - George Hirasaki & Walter Chapman**,** *Gaurav Bathnager* + *new PhD student*
- **Task 3: Analysis of Production Strategy**
  - Kishore Mohanty (UH) +*new PhD student (UH)*
- **Task 4: Seafloor and Borehole Stability**
  - Brandon Dugan + *new PhD student*
- **Task 5: Geophysical Imaging of Gas Hydrate and Free Gas Accumulations**
  - Colin Zelt, *Priyank Jaiswal*

# Task 1: Carbon Inputs and Outputs to Gas Hydrate Systems

- **Jerry Dickens, Glen Snyder, & Rice Ph.D. student**
- **$181,962 DOE**
- **$65,575 cost-share**
- ***1. Complete iodine cycling*.**
- ***2. Authigenic minerals***

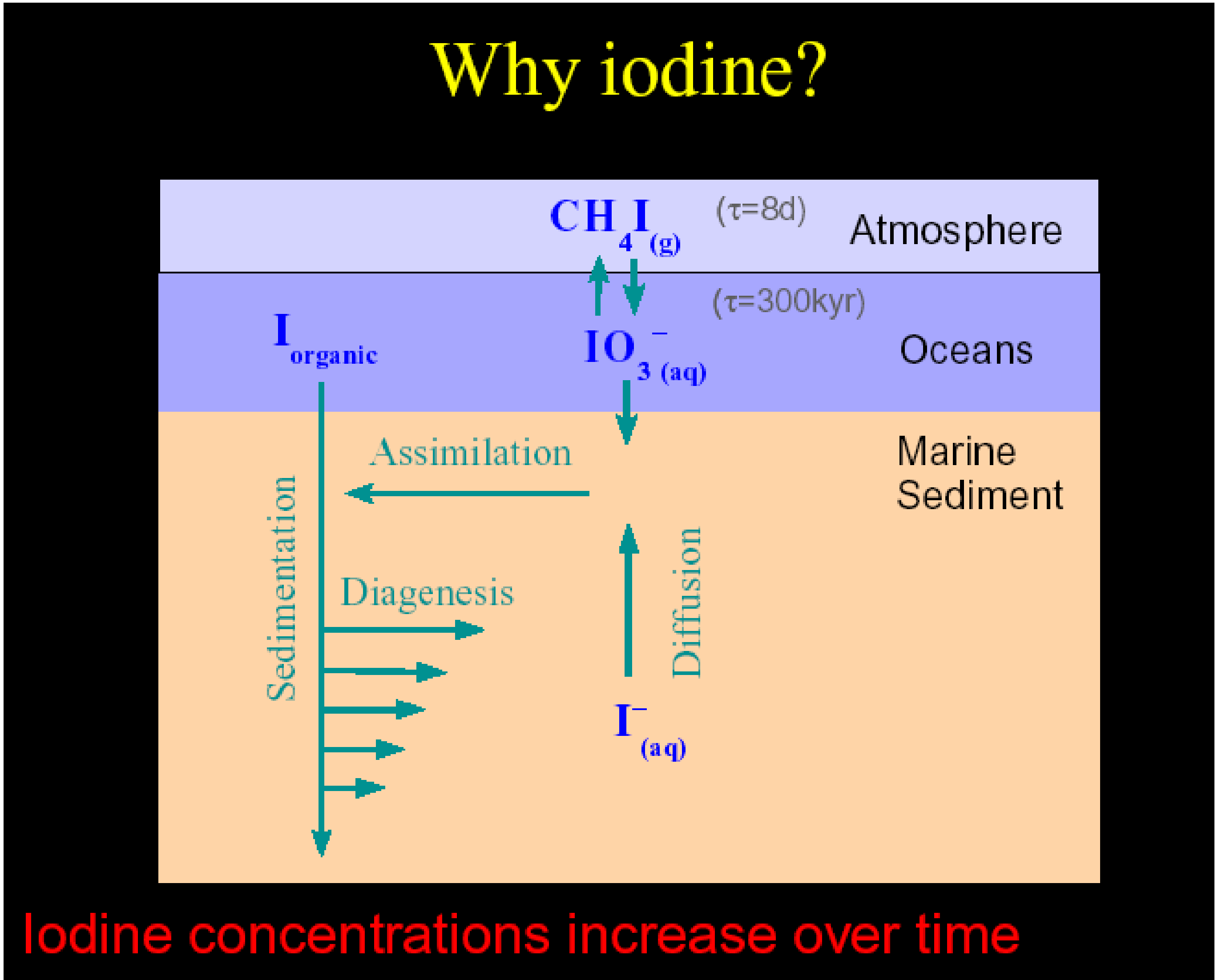
# Carbon Inputs and Outputs



# Carbon Inputs and Outputs

## 1) Iodine and carbon systems

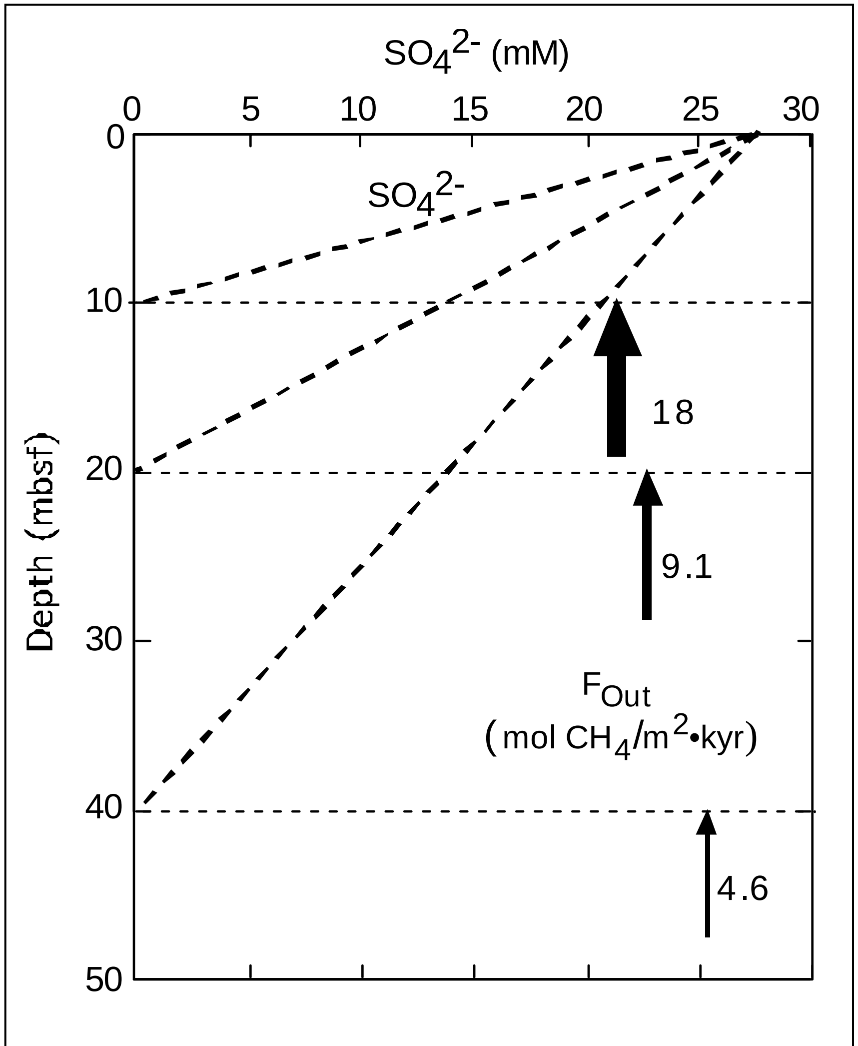
### - organic carbon flux over time



# Carbon Inputs and Outputs

## 2) Authigenic mineralization

### - characterize hydrocarbon flux

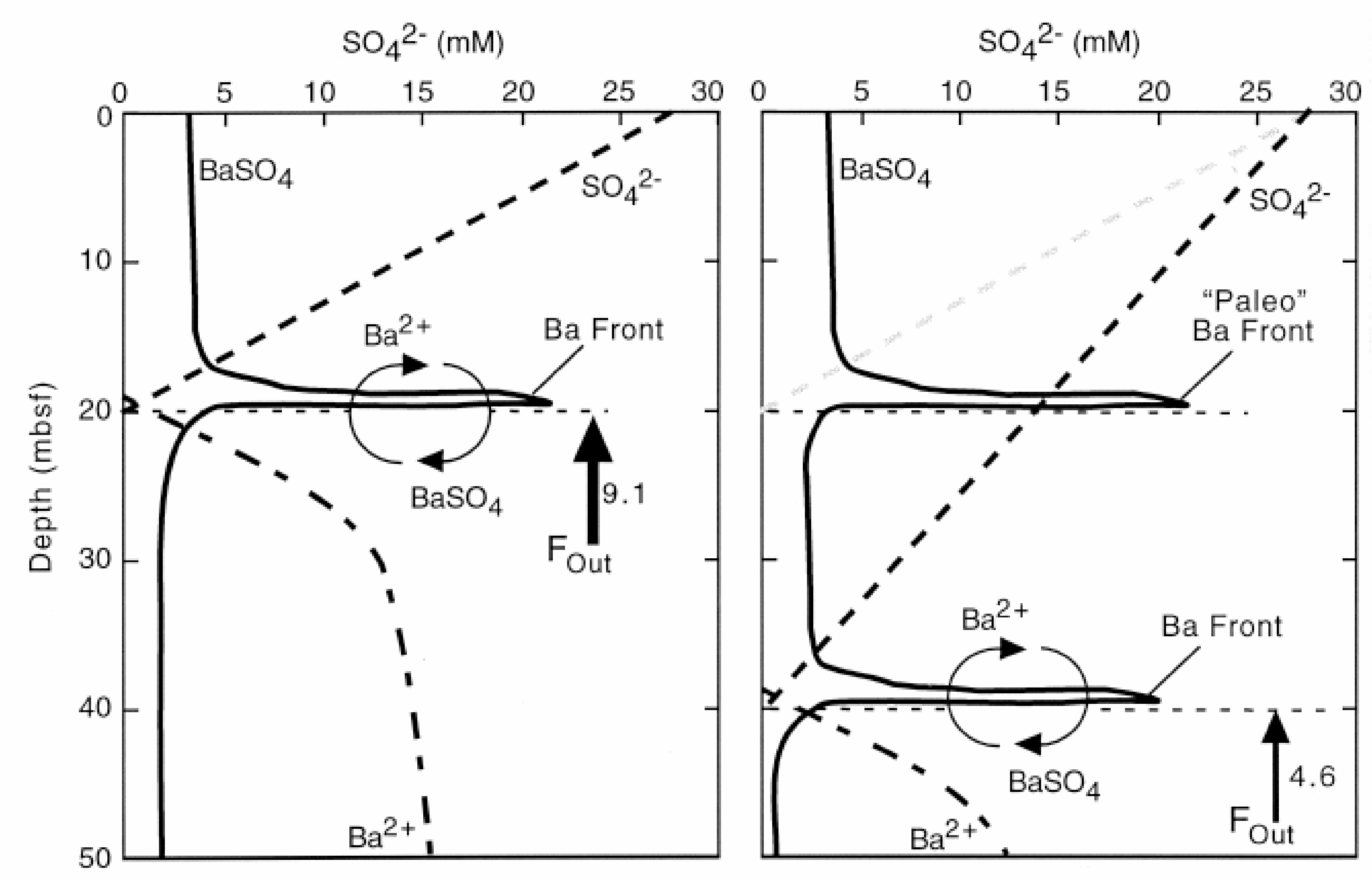



$CH_4 + SO_4^{2-}$ --->
$HCO_3^- + HS^- + H_2O$

Source: *Borowski et al., Geology, 1996*

# Carbon Inputs and Outputs

## 2) Authigenic mineralization

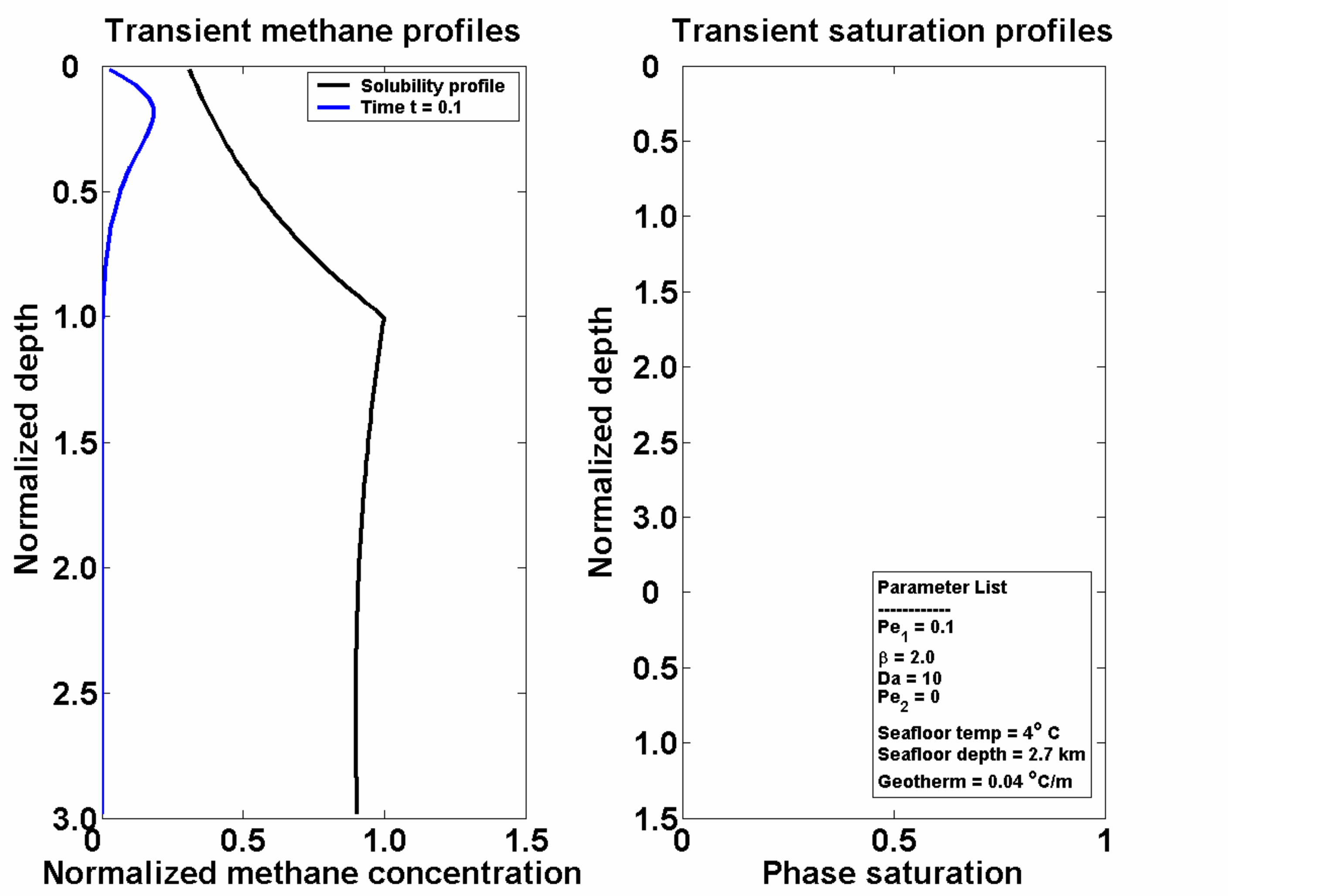



Source: *Dickens, GCA, 2001*

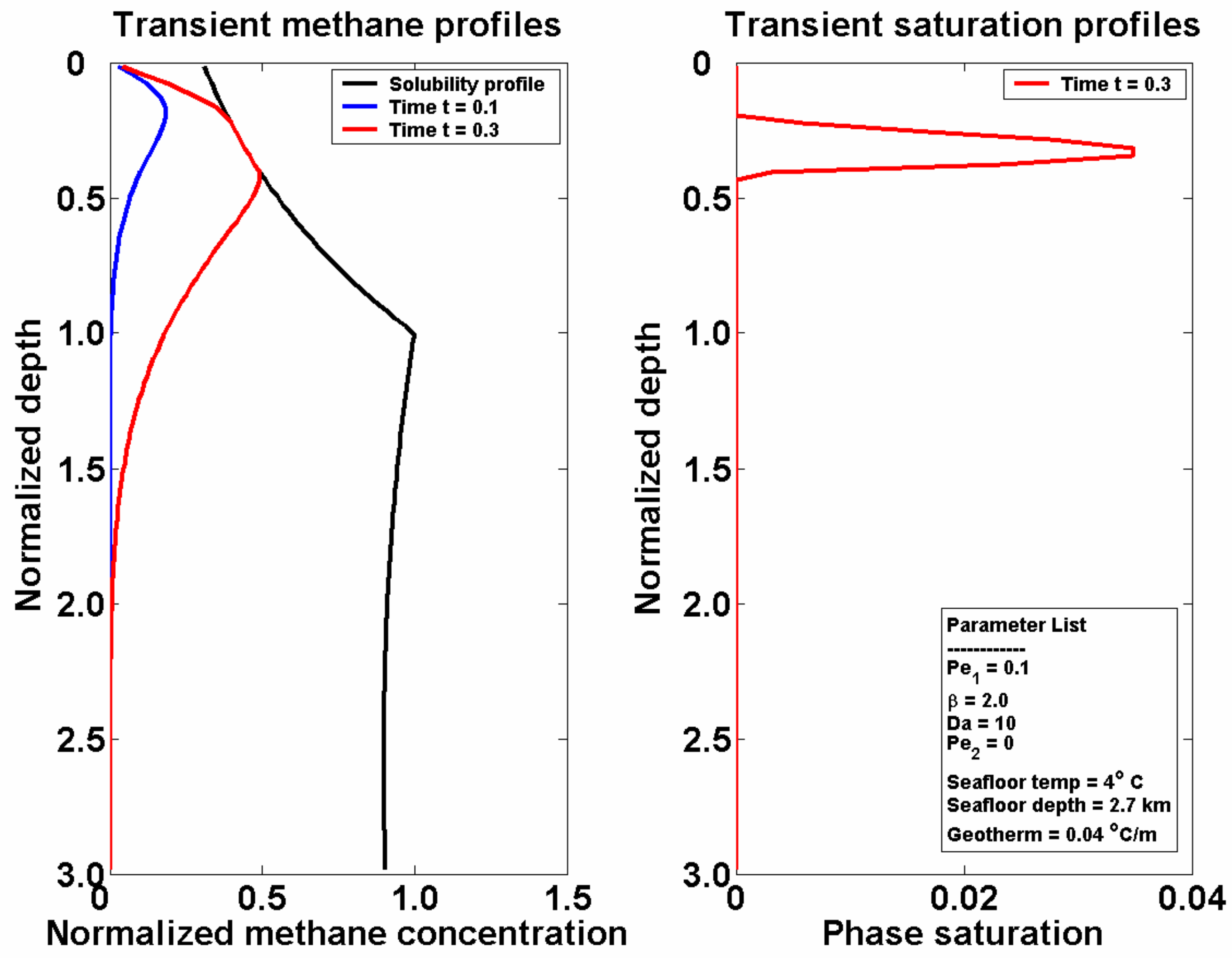
# Task 2: Numerical Models for Quantification of Hydrate and Free Gas Accumulations

- ***1: Model development***.
- ***2: Conditions for existence of gas hydrate***
- ***3: Compositional effect on BSR***
- ***4: Amplitude Attenuation and chaotic zones due to hydrate distribution***
- ***5: Processes leading to overpressure***
- ***6: Concentrated hydrate and free gas***
- ***7: Focused free gas, heat and salinity***
- ***8: Sulfate profile as indicator of methane flux***

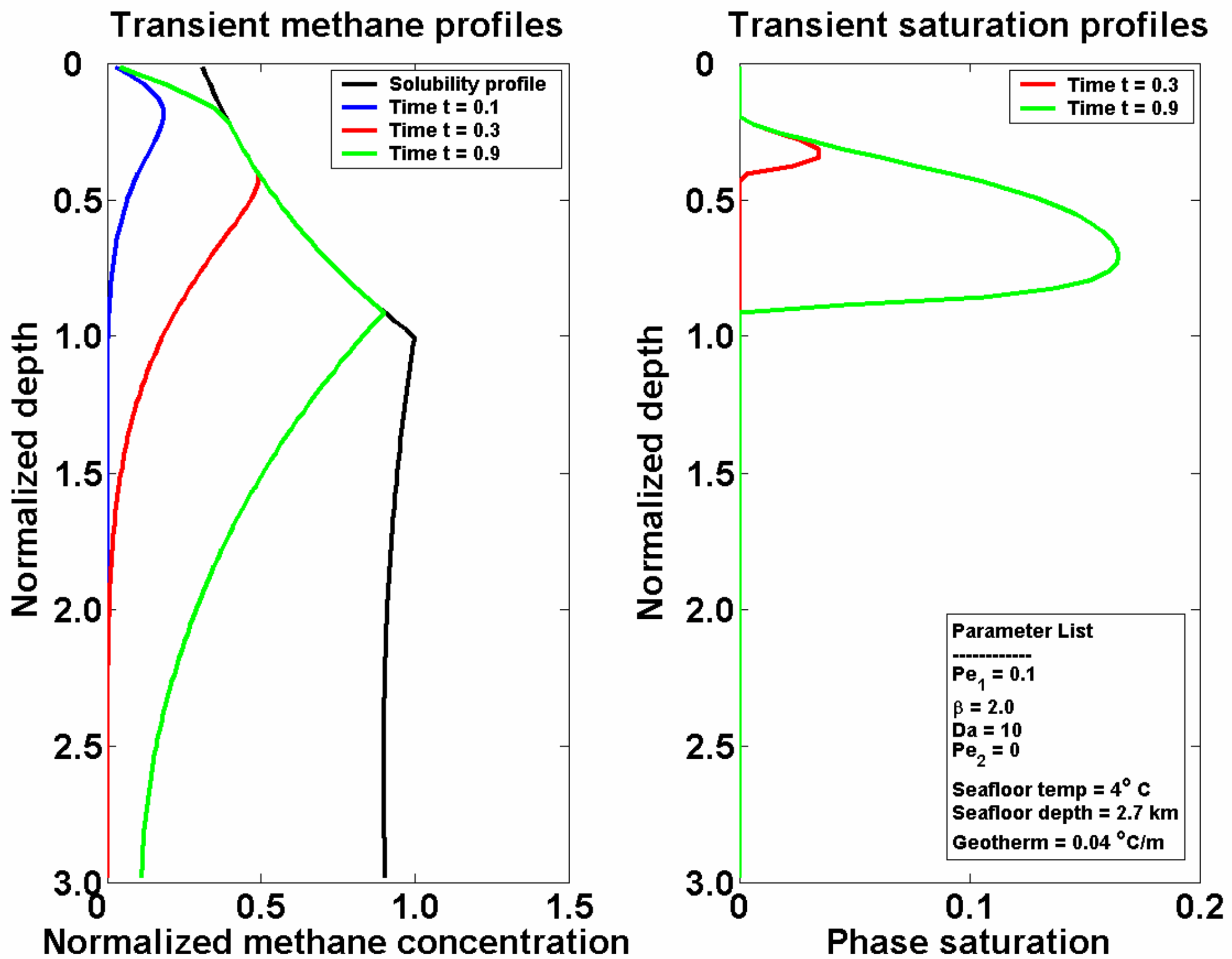
# Hydrate accumulation with underlying free gas



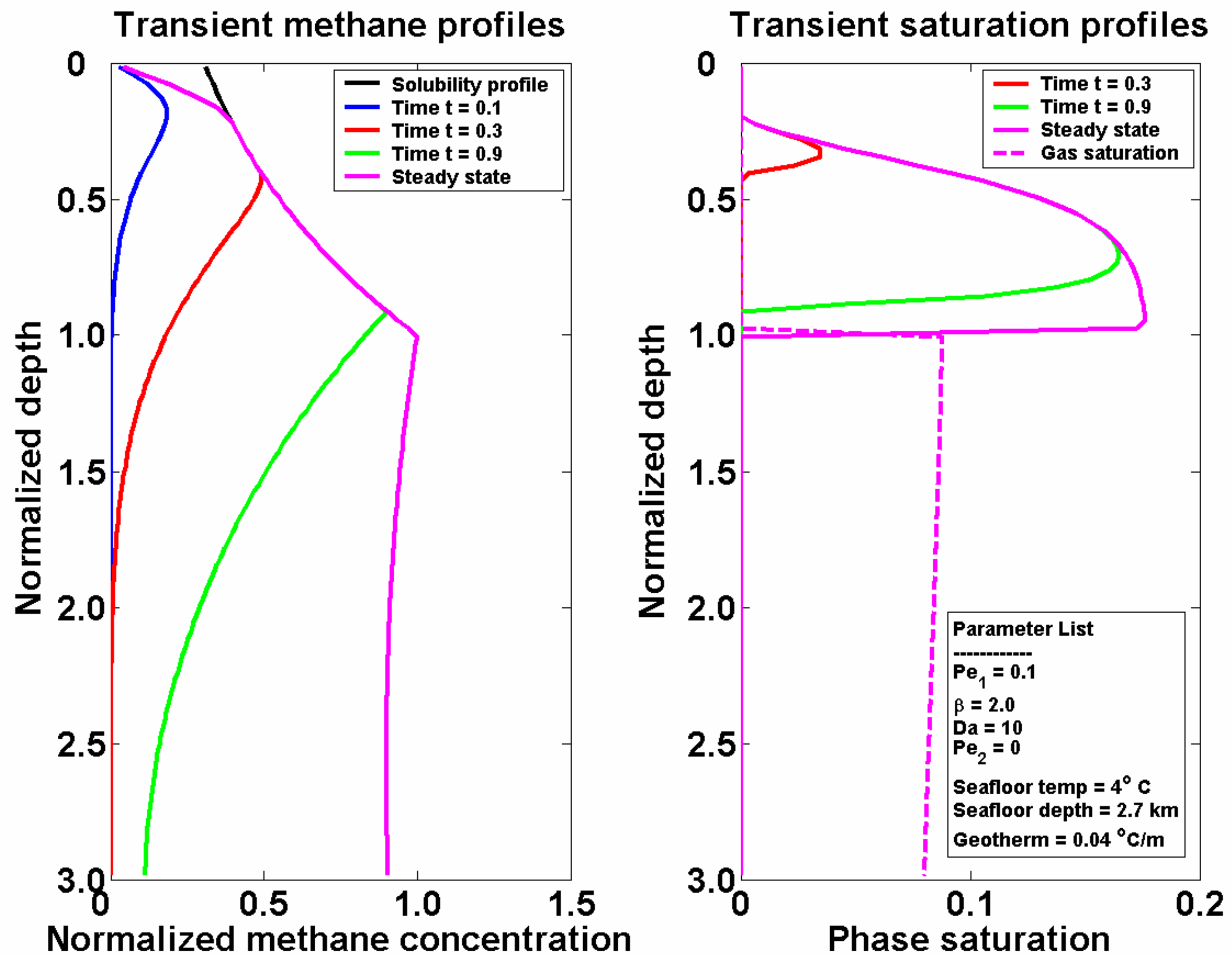
# Hydrate accumulation with underlying free gas



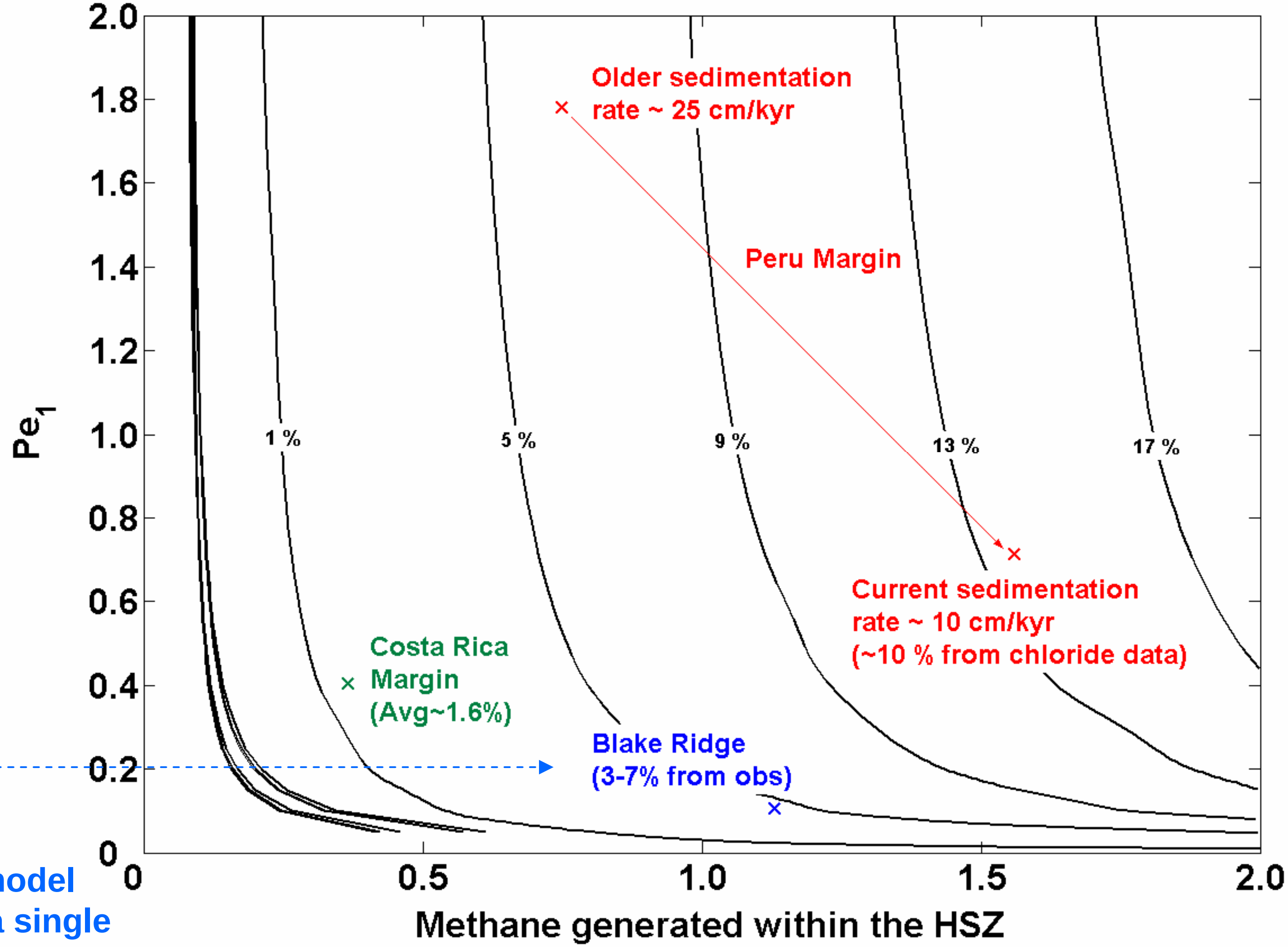
# Hydrate accumulation with underlying free gas



# Hydrate accumulation with underlying free gas

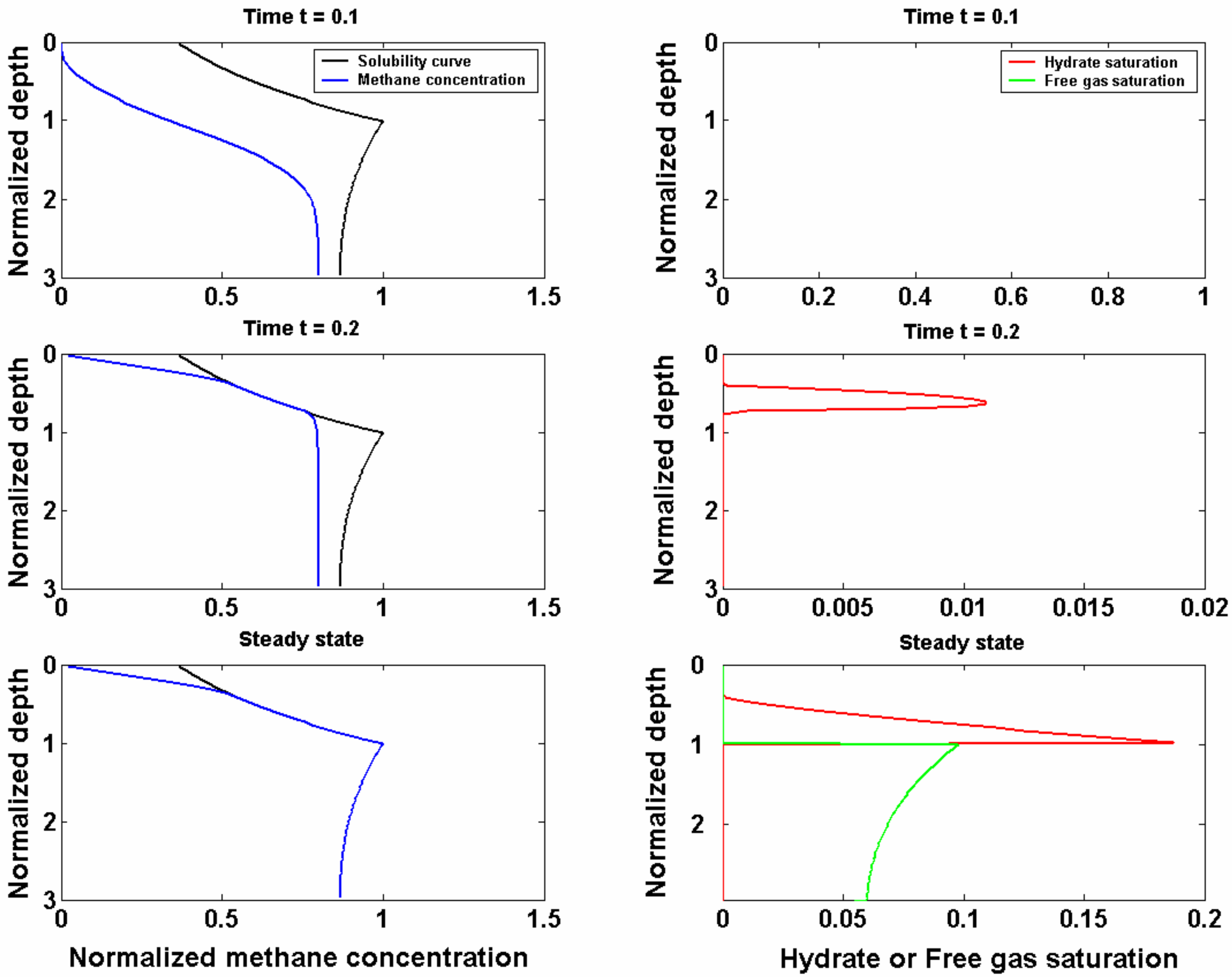


# Hydrate saturations averaged over HSZ (biogenic sites)




Buffett's model becomes a single point on this plot

# Hydrate formation from deeper sources

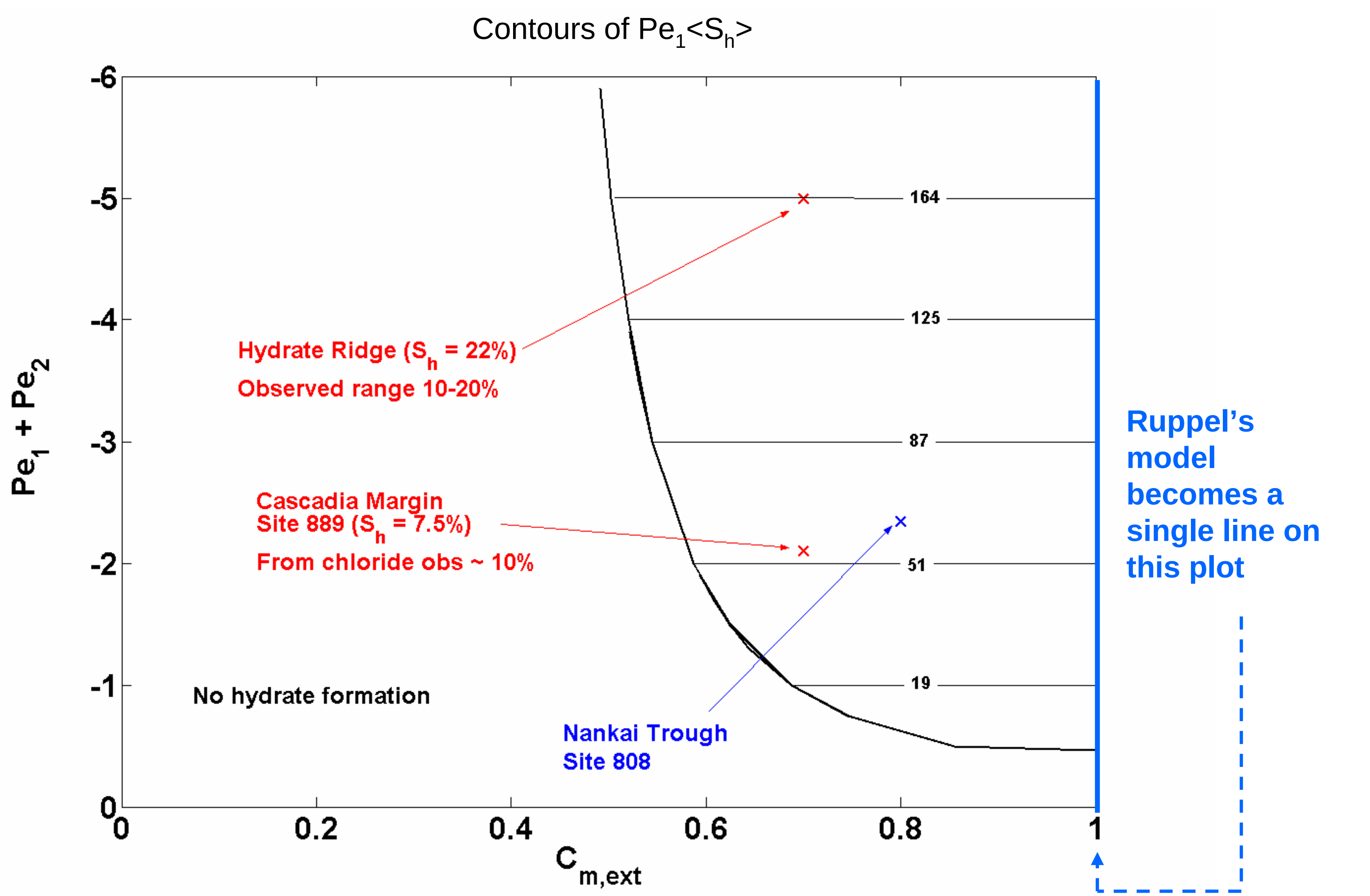



$$Pe_2 = \frac{U_{f,ext} L_t}{D_m}$$

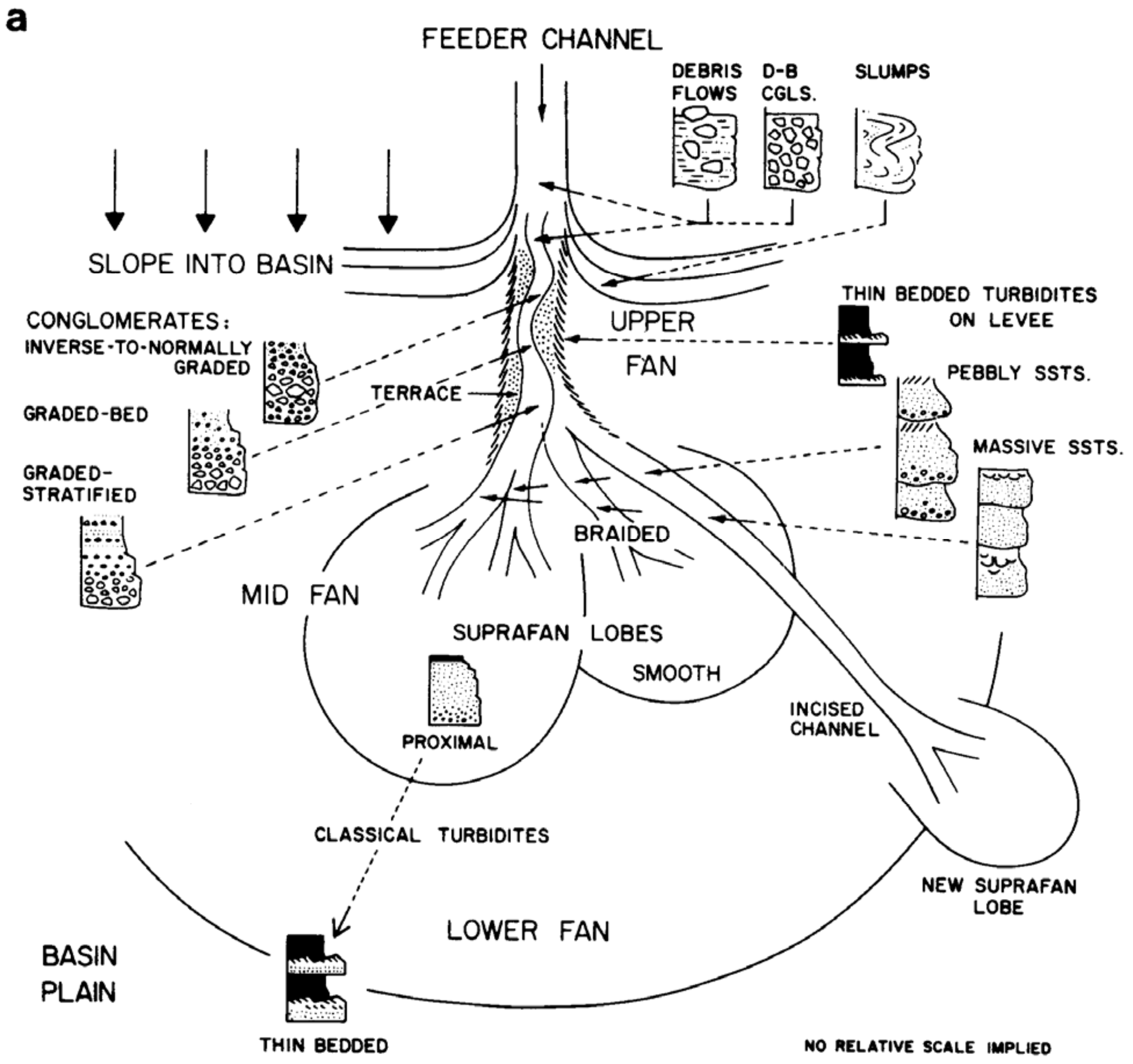
Parameter List

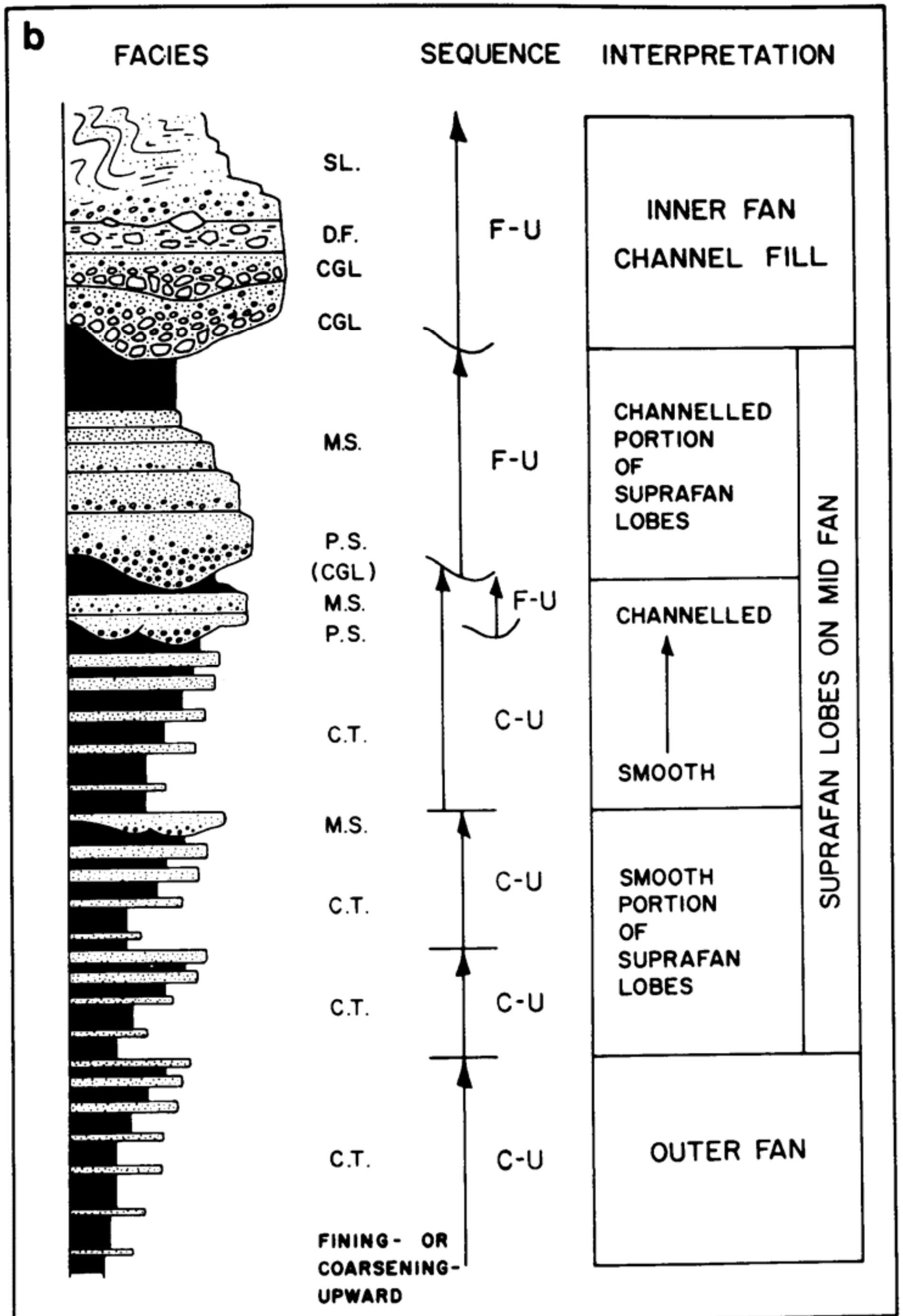
$Pe_1 = 0.1$
$Pe_2 = -2.0$
$C_{m,ext} = 0.8$

# Hydrate saturations from deeper sources



# A submarine fan model (Bjorlykke 1989)

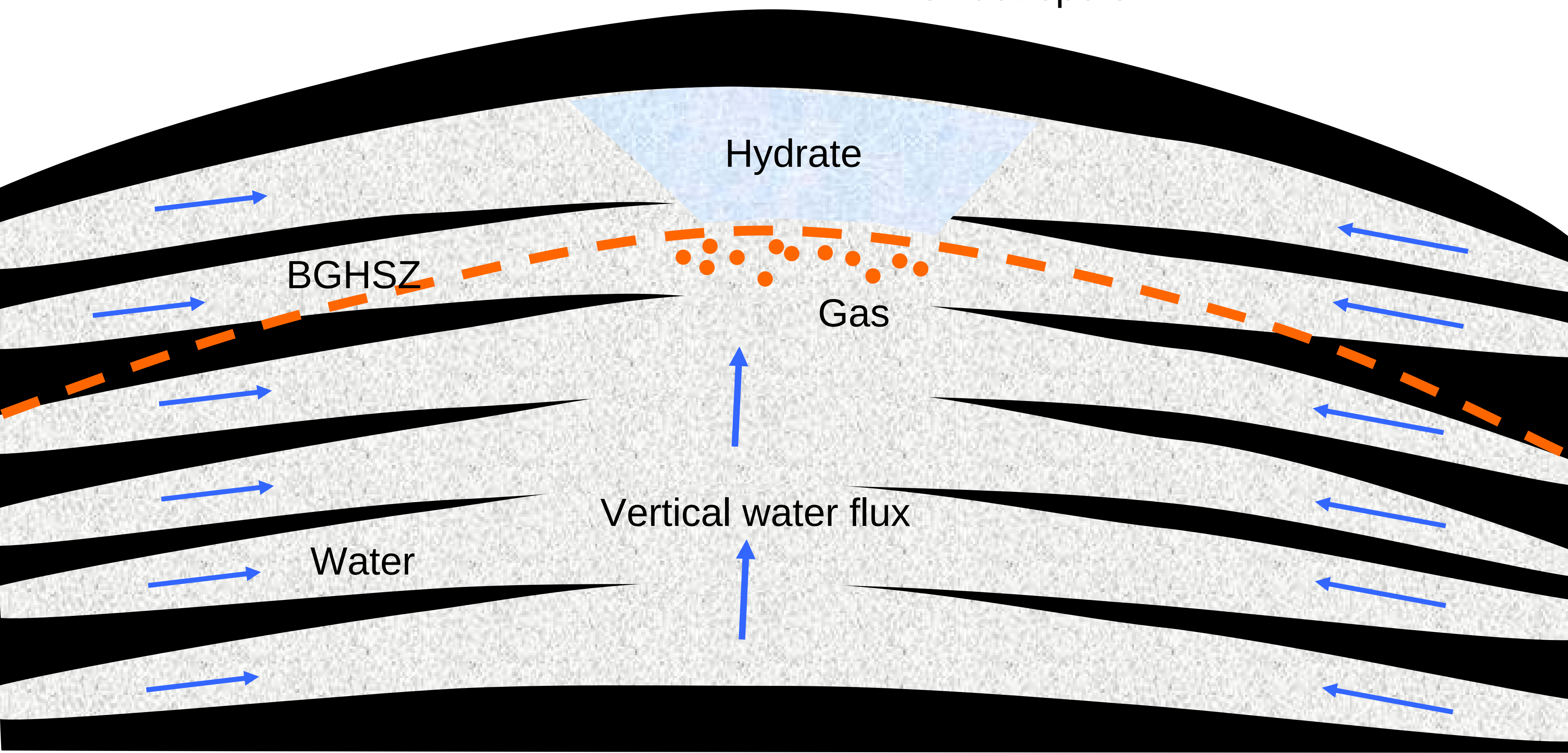




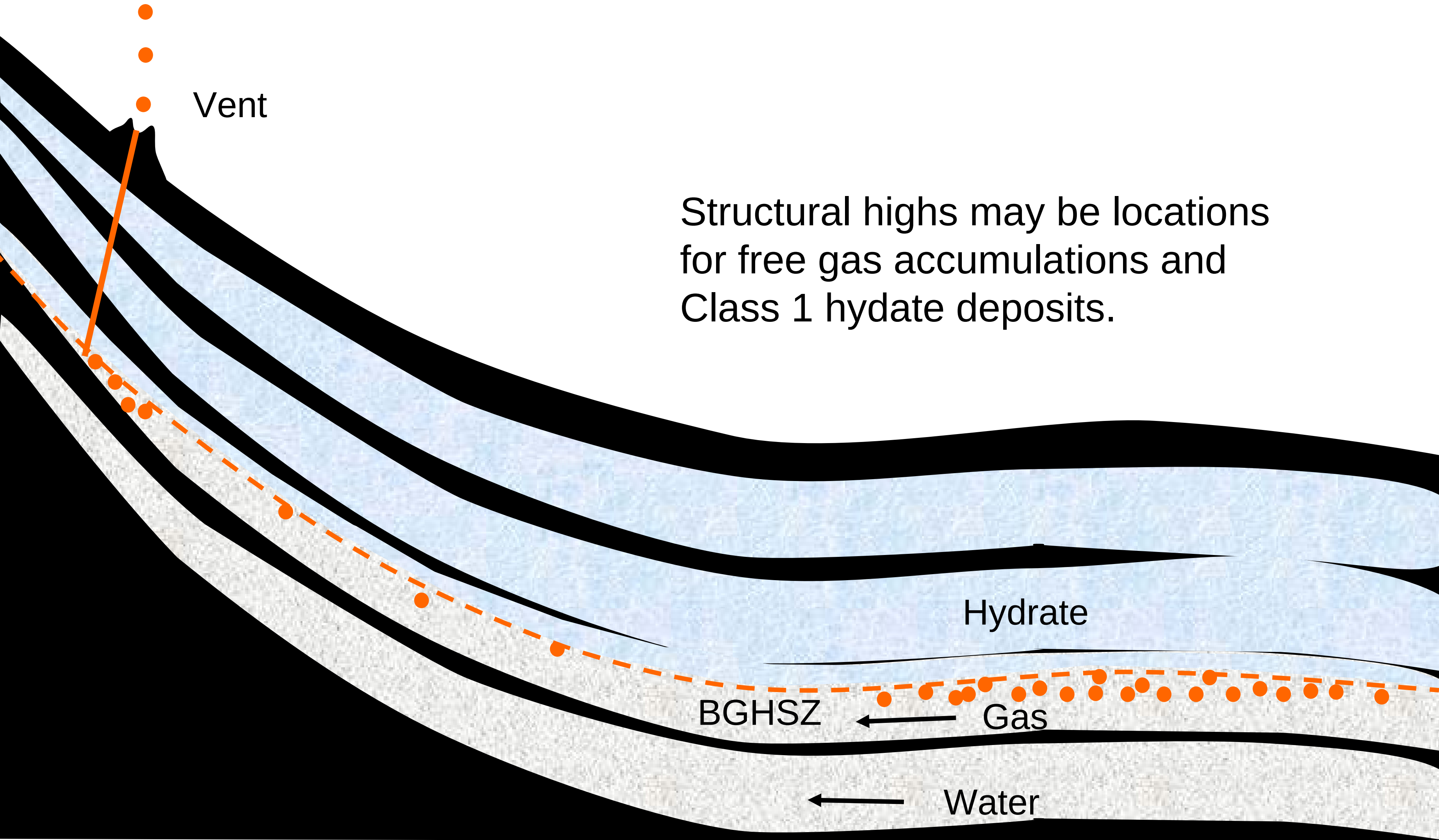

**Vertical sequence through a submarine fan (Bjorlykke 1989)**

# Transverse cross section across turbidite fan

Dewatering of shales and vertical migration where shales are eroded by turbidity currents are possible sweet-spots.



# Longitudinal cross section across turbidite fan



# Attributes Favoring Economic Hydrate Deposits

- **Local upward water flux expected for compacting turbidite fan system**
  - **Shales will dewater during compaction; source rock for biogenic methane**
  - **Location with thick, continuous shales will have water flowing parallel with bedding**
  - **Vertical flow between sands possible where turbidity currents erode clay layer**
  - **Vertical flow regions are possible hydrate sweet-spots in permeable sands**

# Attributes Favoring Economic Hydrate Deposits

- **Crest or channels of submarine turbidite fans**
  - **Continuous sands, fining upward separated by shale layer**
  - **Erosion of shale due to turbidity flows gives vertical groundwater flow paths for hydrate accumulation**
  - **Anticline structure favor accumulation of free gas along nose; Class 1 deposit**
  - **Upstructure along nose, free gas will accumulate and GHSZ will thin until instability results in chimney or vent for escape of free gas and water**

# Attributes Favoring Economic Hydrate Deposits

- **Isopach maps of thickness of GHSZ**
  - **Local thinning (steeper temperature gradient) may be due to increased vertical fluid flux**
  - **Excessive thinning implies chimney with shallow GHSZ**
  - **Moderate thinning implies moderately greater fluid flux and possible higher hydrate saturations – sweep-spot!**

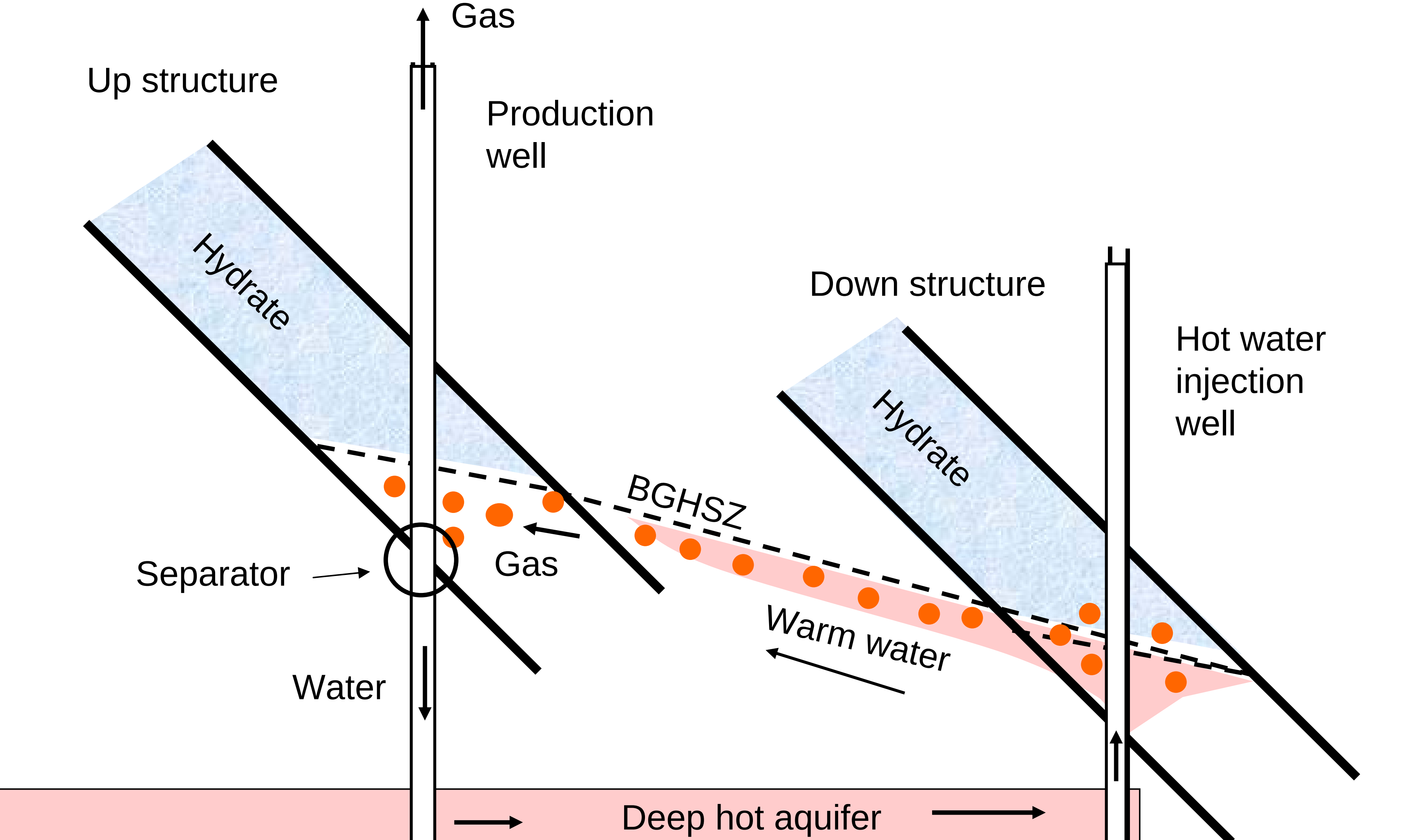
# Task 3: Analysis of Production Strategy

- ***1:*** **Pore-scale Model for Petrophysical and Thermophysical Parameters.**
- ***2:*** **Evaluation of Production Strategy**

# Attributes Favoring Economic Hydrate Deposits

- **Structure map of sands and its intersection with BGHSZ**
  - **Dip direction of BGHSZ may indicate natural migration direction of free gas**
  - **Depth contours will indicate possible locations for free gas structural traps**
  - **Dip direction will suggest direction for production and heat injection wells**

# Production of Class 2 Hydrate Deposit



# Task 4: Seafloor and Borehole Stability

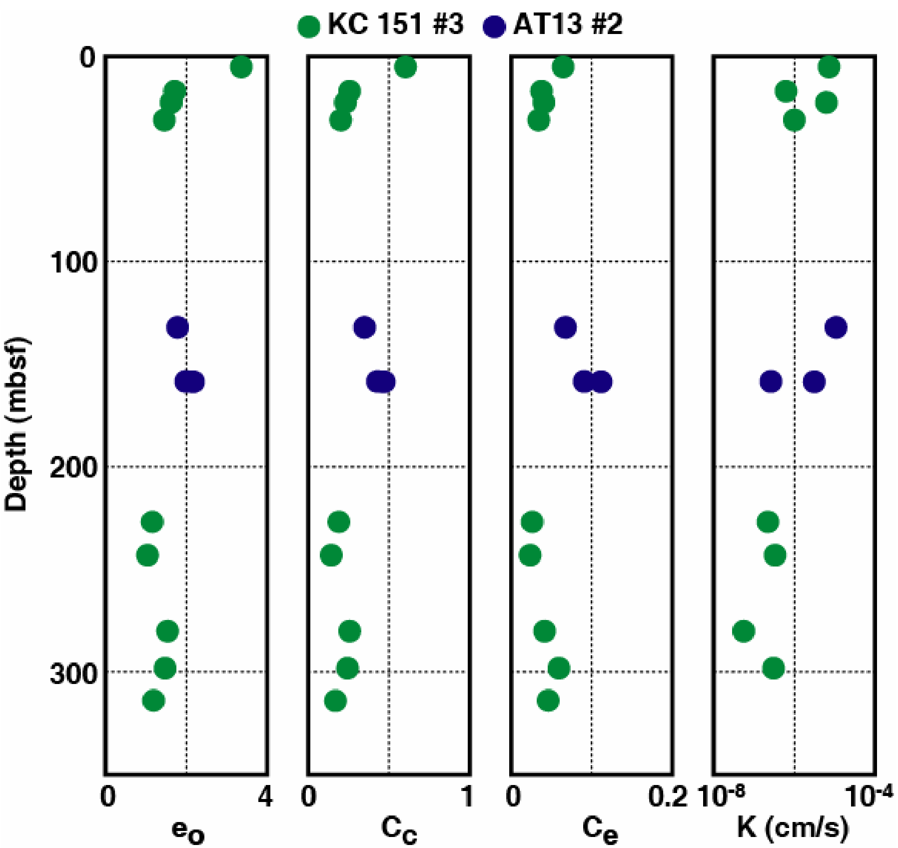
**Problems/Risks**

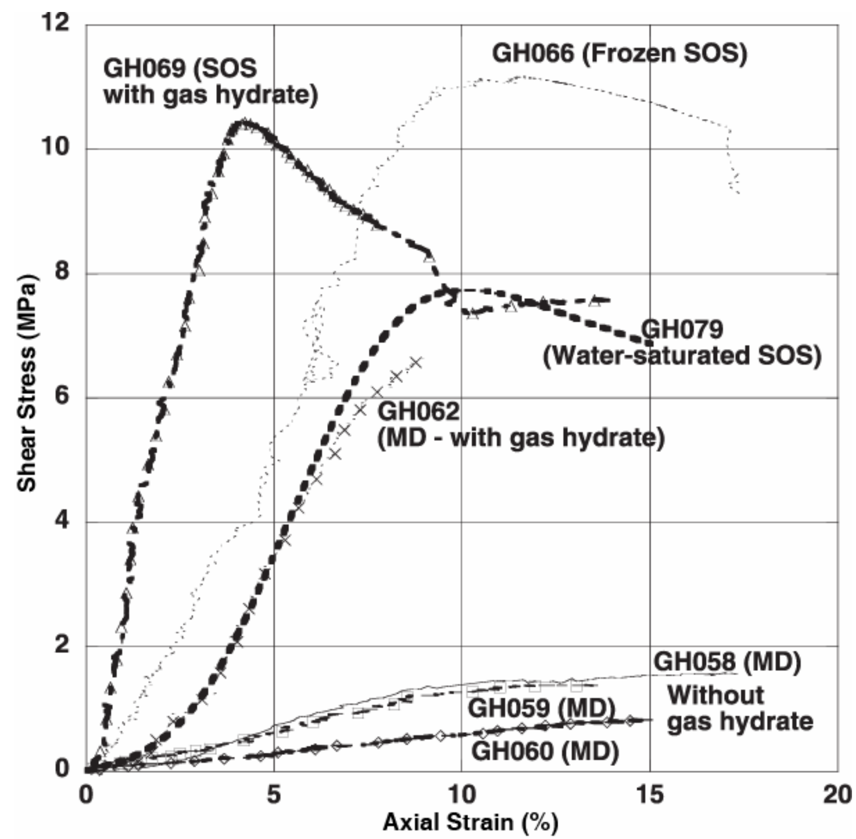
1) Up-scaling
   - lab to field extrapolation (space and time)
2) Sample Disturbance
   - limited to samples collected for geotech work
   - impacts of pressure/temperature cycles on specimens with hydrate

# Seafloor and Borehole Stability

- experiments on natural sediments w/ and w/o hydrate

- integrate lab work with existing field data

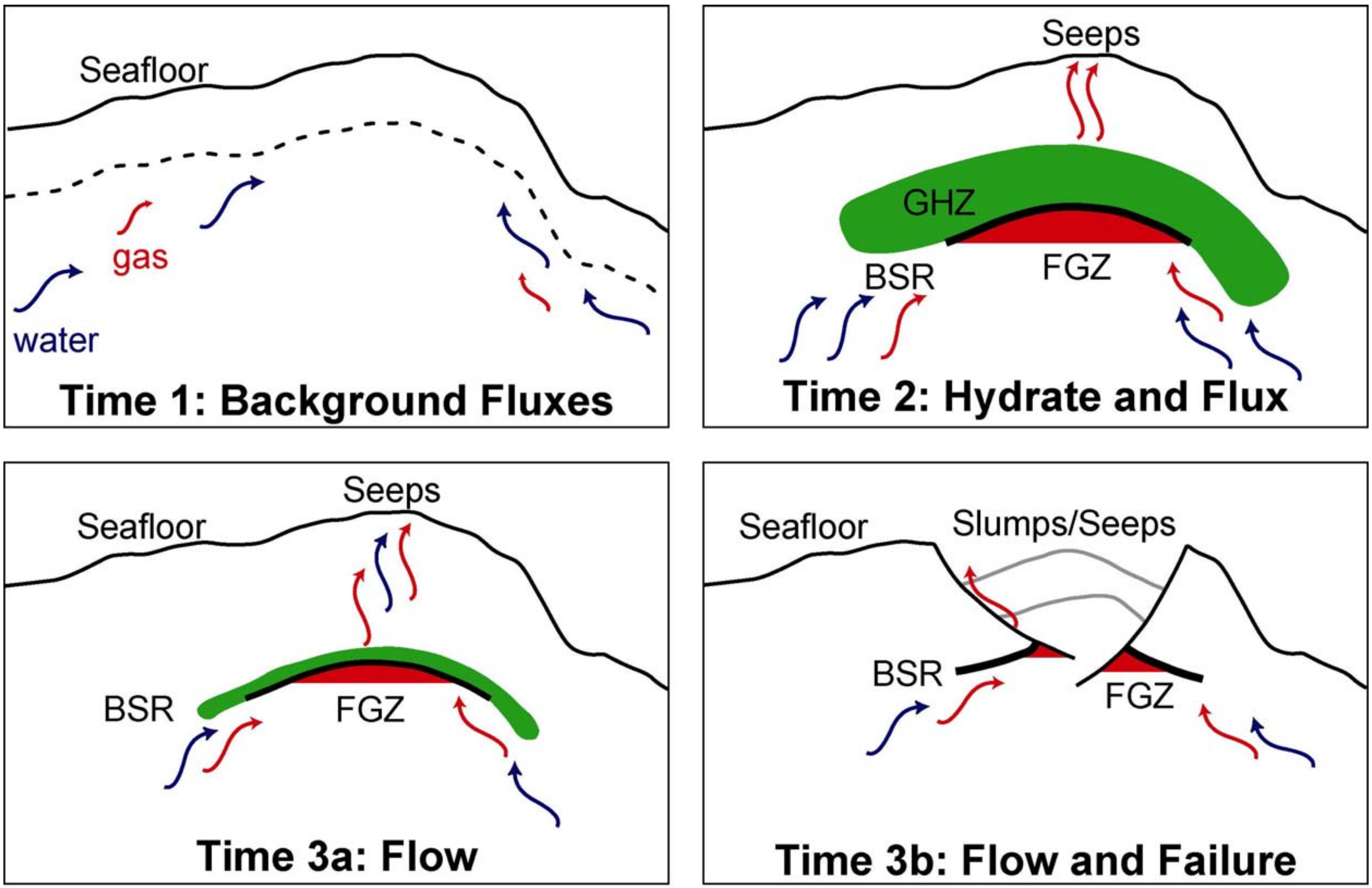



Winters et al. (2004)

# Seafloor and Borehole Stability

**- deformation and failure processes coupled with geologic models and production simulators**

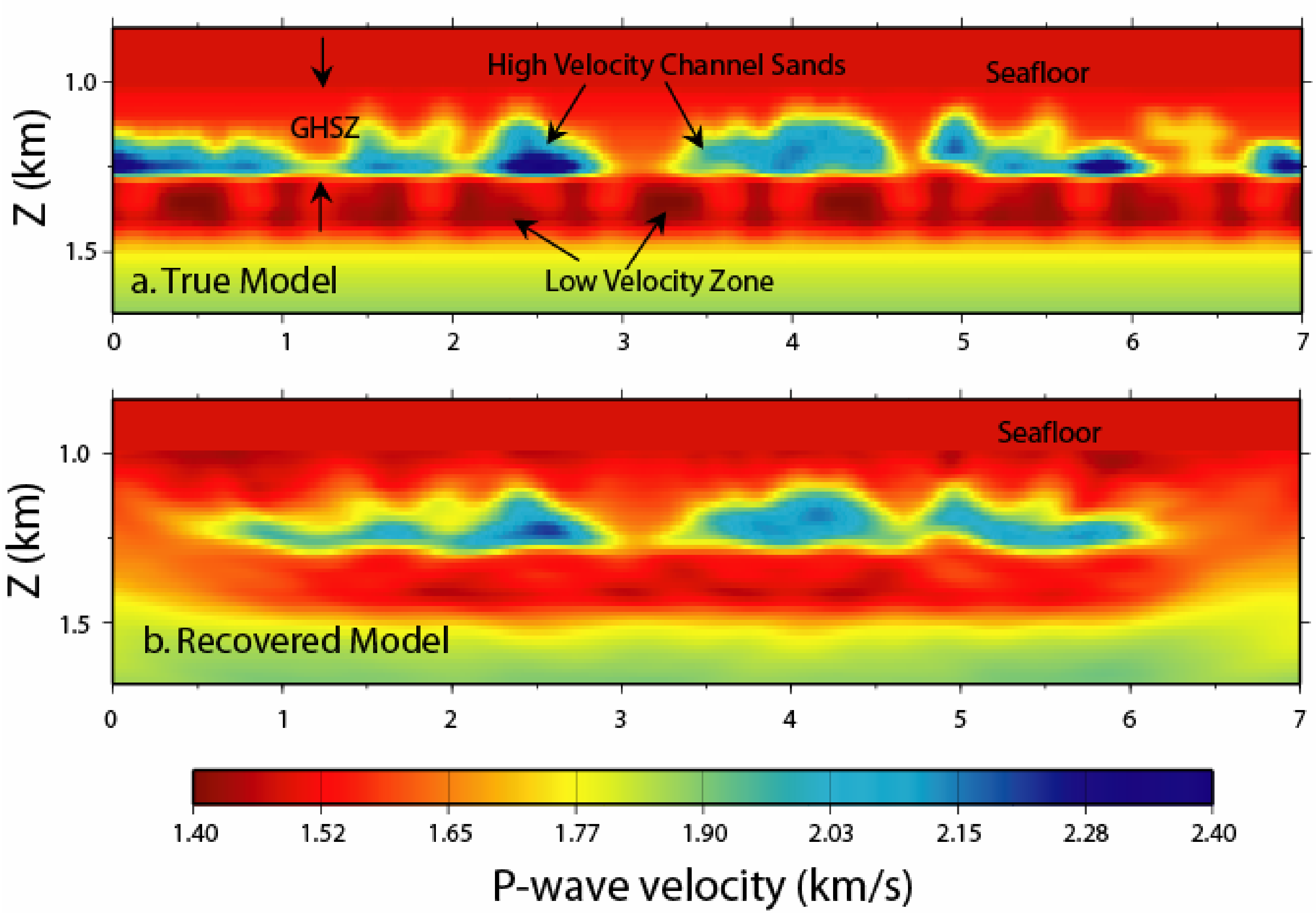


# Task 5: Geophysical Imaging of Gas Hydrate and Free Gas Accumulations

- 1: Preliminary processing and inversion of seismic data.
- 2: Final 1-D elastic and 2-D acoustic waveform inversion.
- 3: Rock physics modeling.

# Geophysical Imaging

## Waveform inversion with all attributes of the seismic data (amplitude, phase, frequency, and arrival time)



# Geophysical Imaging

- (a) Channel stratigraphy constructed after K-G basin (India) interpretations.
    - The channel axis form pathways for fluid migration thus accumulating gas-hydrates.
    - Base of hydrate stability zone coincides with base of channel systems.
    - Free-gas dispersed in the underlying sediments
    - Gas-hydrates and free-gas respectively increase and decrease the P-wave velocities of their host sediments.

- (b) recovered using waveform inversion applied on synthetic seismic data simulated from (a)
    - Synthetic data had broad bandwidth (1-21 Hz; low frequencies are critical for good recovery) and high signal to noise ratio.

- Waveform inversion utilizes all attributes of the seismic data (amplitude, phase, frequency, and arrival time to solve for velocity perturbations) as opposed to conventional seismic imaging.

# Geophysical Imaging

- Key Objectives
    - Develop a regional 2-D acoustic model
    - At selected locations develop 1-D elastic model
- Challenges
    - Finding a suitable seismic dataset
        - Broad frequency spectrum
        - High signal-to-noise ratio
    - Finding supplementary information
        - Cores
        - Well logs

# Milestones

| | |
|---|---|
| Year 1 | -$C_{org}$, sediment metal profiles<br>-2D/3D geologic GH model<br>-pore-scale models<br>-physical properties data collation<br>-link sed. database with models<br>-travel-time modeling of data<br>-preliminary processing of seismic data |
| Year 2 | -model authigenic minerals, $CH_4$ flux<br>-compositional capability to geologic GH model<br>-petrophysical/thermophysical props<br>-production strategy models<br>-complete sediment+hydrate database<br>-add sediment stability to models/simulators<br>-acoustic and elastic modeling |
| Year 3 | -sensitivity of models to heterogeniety<br>-identify conditions driving instability<br>-2D waveform inversion<br>-rock physics modeling |
| Year 4 | Integrate mineral profiles<br>Model seismic response of heterogeneous hydrate systems<br>Production strategy<br>Conditions for instability<br>Seismic inversion with improved rock physics |

# Budget

| | 2007 | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|---|
| DOE | $316,520 | $331,135 | $356,049 | $259,335 | $1,263,039 |
| Cost - Share | $130,349 | $112,029 | $114,882 | $118,711 | $475,971 |
| Total | $446,869 | $443,164 | $470,931 | $378,086 | $1,739,010 |

# Text for George to go with the slide

- The P-wave velocities of the synthetic model in (a) have been recovered in (b) using waveform inversion of synthetic seismic data. Waveform inversion utilizes all attributes of the seismic data (amplitude, phase, frequency, and arrival time to solve for velocity perturbations) as oppsoed to conventional seismic imaging.
- The model in (a) reflects a channel stratigraphy constructed after interpretations in the K-G basin. The axis of channels provide pathways for focused fluid migration thus becoming seats of gas-hydrate accumulation.  The net effect of the gas-hydrates is enhancement of the P-wave velocity of the channel axes. Free-gas dispersed in the underlying sediments decreases the P-wave velocities.