Gas Hydrate as a Potential Precursor for Some Shale Gas Deposits?*

Michael D. Max[1] and Arthur H. Johnson[1]

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[1]Hydrate Energy Int'l, Kenner, LA (artjohnson51@hotmail.com)

Abstract

Shale gas is a major energy resource with significant commercial potential. Understanding the paragenesis of the gas is a key to exploration because gas is unequally distributed in the shale host. Presently, the gas content is regarded as being directly related to the amount of local organic carbon that may constitute up to 8 to10% of the shale. This assumption implies that gas generation took place essentially after the shale became impermeable. However, when high local gas content is not directly related to organic carbon content, it is likely that gas generation and concentration may have a more complex history.

A means of sequestering gas produced early in the diagenetic history of the shale involves the formation of solid, mechanically strong gas hydrate grains, nodules, or veins in the still highly porous, muddy shales. Hydrate concentrates gas by compressing it by a factor of about 164 into its crystalline lattice. A great deal of natural gas is sequestered in gas hydrate. Modern gas hydrate concentrations of 5 to 10% are common in gas hydrate stability zones in fine-grained marine sediment sections as thick as 800 feet in continental slopes. Muddy sediments on modern continental margins are estimated to currently hold more gas worldwide than has been identified in all other hydrocarbon deposits. Without doubt, natural gas hydrates also formed in ancient sediments under suitable pressure and temperature conditions. In addition to gas that is locally produced, subjacent gas can also migrate from deeper source beds, which allows the hydrate-enriched muddy sediments to hold more gas than could be generated locally. If pressure - temperature conditions persisted during lithification of shale gas precursor, at least until packing of the clay minerals reduced permeability to a point that the gas released from hydrate by increasing temperature or decreasing pressure could not migrate easily, then a very large part of this gas would remain trapped in the shales as their further compaction proceeded. An implication for exploration is that high gas

concentrations may be the result of multiple gas concentration mechanisms acting in the shales. Gas hydrate tends to form preferentially is more siliceous beds and partings, such as lower organic content grey shales and more siliceous shales, whose economic potential is enhanced because these respond well to fracing.

Selected References

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Michael D. Max & Arthur H. Johnson,
Hydrate Energy International (**HEI**)

AAPG ACE 2012

www.hydrate-energy.com

Presenter's Notes:
Coalbed methane
Shale gas
Tight gas
Hydrate is the only one that depends on maintenance of supply

The Concept

- Shales deposited in deep enough water would have likely contained gas hydrate.
- Gas from hydrate may have remained in the shale during compaction
- However: Most gas shales were deposited in water too shallow for hydrates to have been present

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Shale Gas

- Shale gas is a major NG gas source
  - Original porosity
  - Adsorbed
  - Fractures
  - Tight, low permeability
- Gas values vary

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Shale Gas Paragenesis

- In-place digestion of organic material
  - By inference – after permeability closes
- Gas values should be related to organic material
  - However:

Zagorski & Emory (2011): The highest gas in place values in one of the two Marcellus Shale sweet spot areas are in a lower TOC regime

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Gas Variability Controls

- Is gas volume directly related to TOC?

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Gas Variability Controls

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- Is all the gas generated after significant compaction?

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Gas Variability Controls

- Is gas volume directly related to TOC?
- Is all the gas generated after significant compaction?
- Is there an early concentration mechanism?

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Is there a mechanism to concentrate gas prior to permeability closing?

- Natural Gas Hydrate (NGH) concentrates and retains gas early in diagenetic history

- Objective: Develop Hydrate Precursor Petroleum System to facilitate Exploration

- Introduce an additional predictor for potential sweet spots

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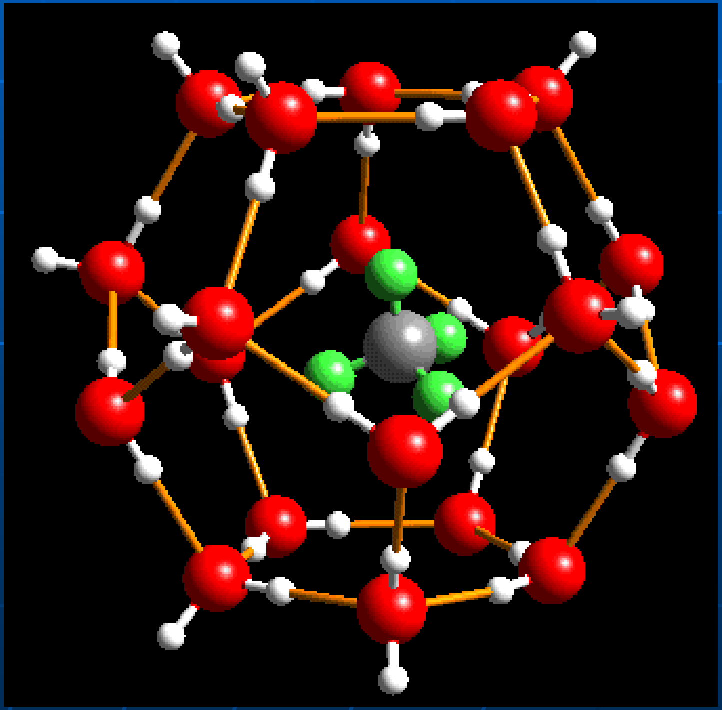
What is a Gas Hydrate?

- **Crystalline solid consisting of gas molecules, usually methane, each surrounded by a cage of water molecules**
  - One volume hydrate typically equivalent to 164 volumes methane gas
- **Stable at low Temperature and high Pressure**
- **Occur abundantly in nature**
  - Arctic regions and in marine sediments
  - 3-10% of bulk volume of some deepwater shales



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Early Hydrate Formation

- Not Directly Related to Local TOC
- Hydrate formation in shales can vary considerably
  - Disseminated
  - Fracture filling
  - Vent related
  - Near surface large masses
- Can sweet spots reflect original hydrate concentrations?

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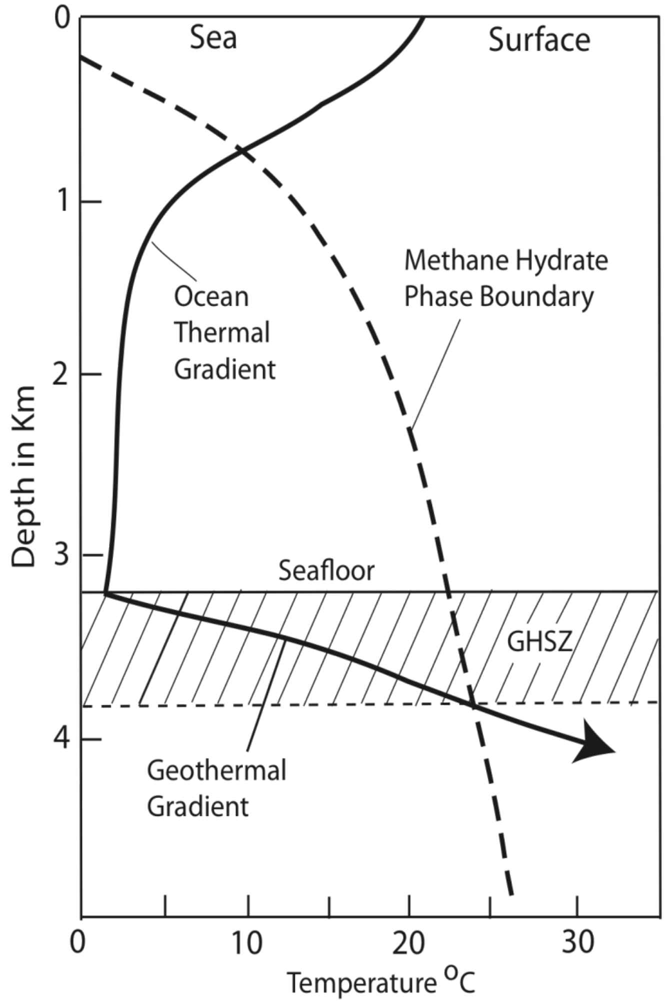
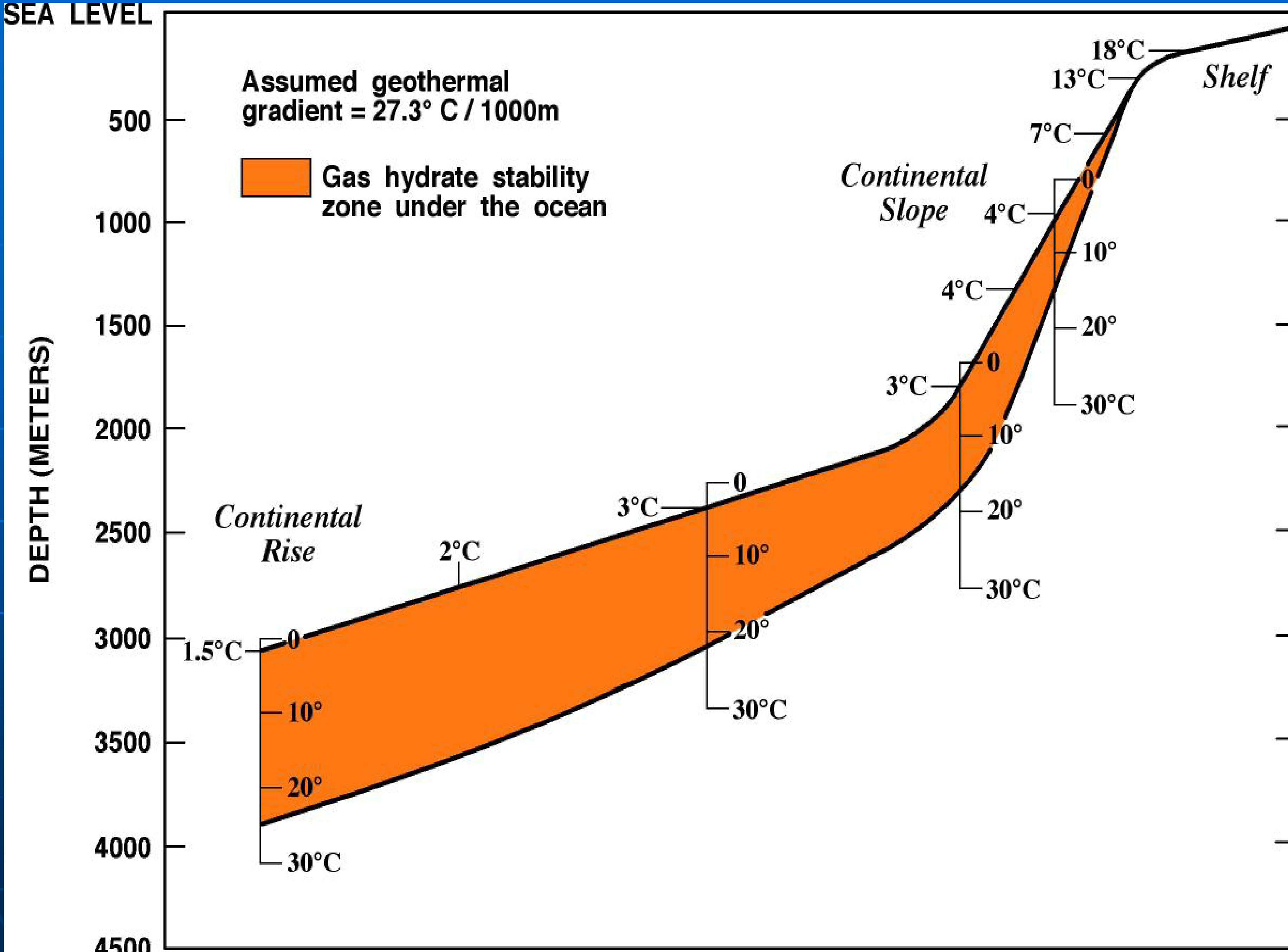
Natural Gas Hydrate in Marine Sediments

GHSZ can be up to 1 km thick




SEA LEVEL
Assumed geothermal gradient = 27.3° C / 1000m
Gas hydrate stability zone under the ocean
DEPTH (METERS)
500
1000
1500
2000
2500
3000
3500
4000
4500
Shelf
18°C
13°C
7°C
Continental Slope
4°C
0
10°
20°
30°C
4°C
3°C
0
10°
20°
30°C
Continental Rise
2°C
3°C
0
10°
20°
30°C
1.5°C
0
10°
20°
30°C

Hydrate Deposition

- High Grade (sandy beds)
  - High Pore Fill in 'High Porosity' Beds
  - Small Areas
  - Highly concentrated Hydrate
  - Growth Dominated: Higher supply of NG
- Low Grade (muddy beds)
  - Low Pore Fill in Low Porosity Beds/Secondary Porosity / Dispersed Hydrate
  - Large Areas
  - Nucleation Dominated: Lower NG Supply
  - Often Associated with Subjacent Gas Deposits

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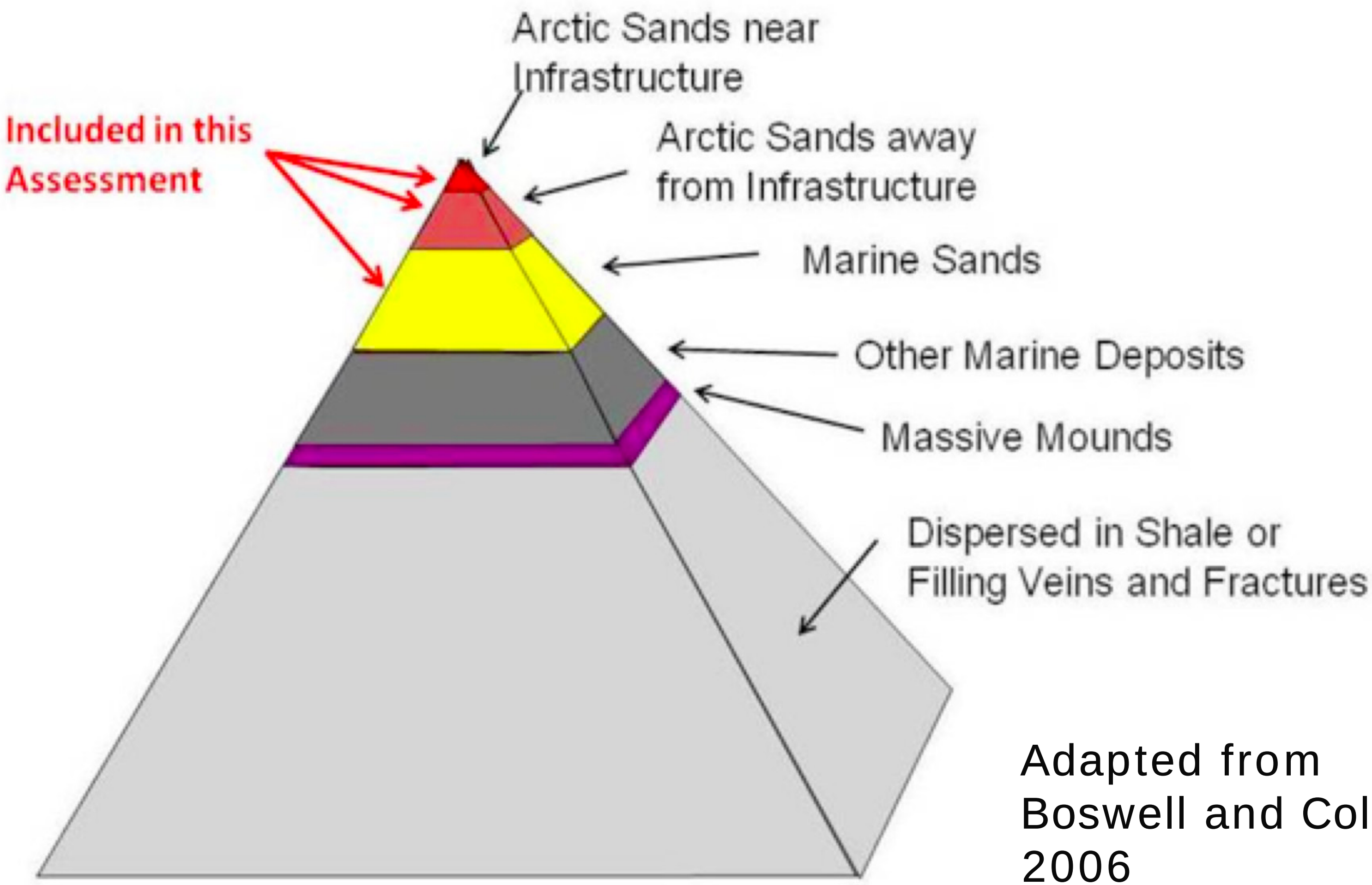
Most Hydrate is disseminated in Fine Grained sediments



Adapted from Boswell and Collett, 2006

Gas in Place (TCF) in Sands

Locations: United Nations Designations

Location	Range	Median
USA	1,500 - 15,434	7,013
Canada	533 - 8,979	2,228
Western Europe	36 - 14,858	1,425
Central & E. Europe	0 – 105	13
FSU	1,524 - 10,235	3,829
North Africa	6 - 1,829	218
Eastern Africa	42 - 25,695	1,827
W. & Cent. Africa	79 - 26,672	3,181
Southern Africa	121 - 26,369	3,139
Middle East	31 - 3,848	573
China	10 - 1,788	177

Location	Range	Median
Other East Asia	14- 2,703	371
India	36 - 6,268	933
Other South Asia	20 - 3,497	557
Japan	71 – 471	212
Oceania	38 - 6,750	811
Other Pacific Asia	64 - 25,946	1,654
Latin America & the Caribbean	258 - 31,804	4,940
Southern Ocean	144 - 45,217	3,589
Arctic Ocean	178 - 55,524	6,621

	Range	Median
Total	4,705 - 313,992	43,311

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Commercial Development

- High Grade Deposits = Sands
- Hydrate in muddy sediments are primarily Disseminated & in veins
- Total modern hydrate in muddy sediments many orders of magnitude more than high grade deposits
- Huge amount of gas concentrated by hydrate in continental slope/rise sediments by hydrate

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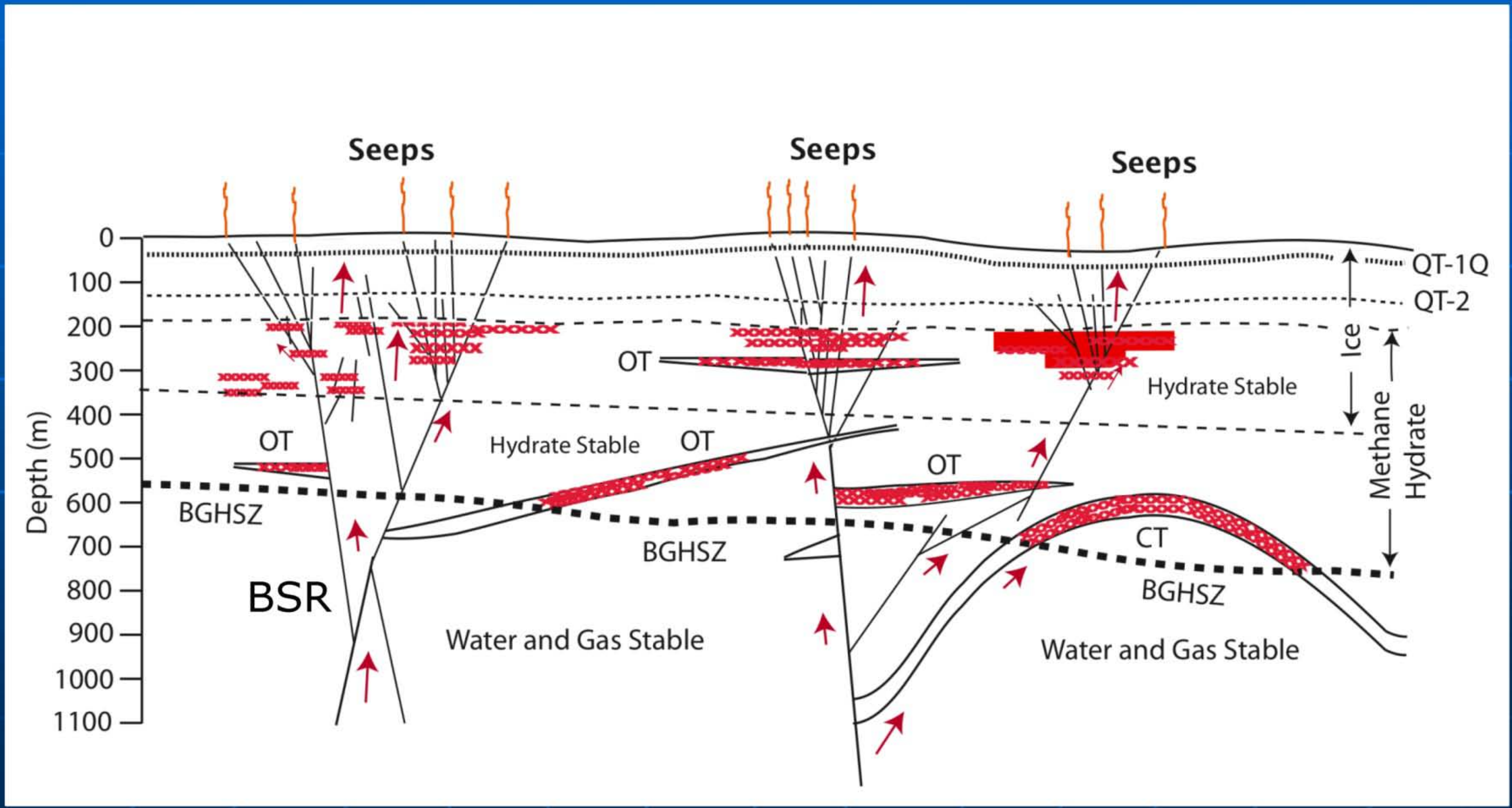
Diffusional (& fracture) gas transport in muddy sediments



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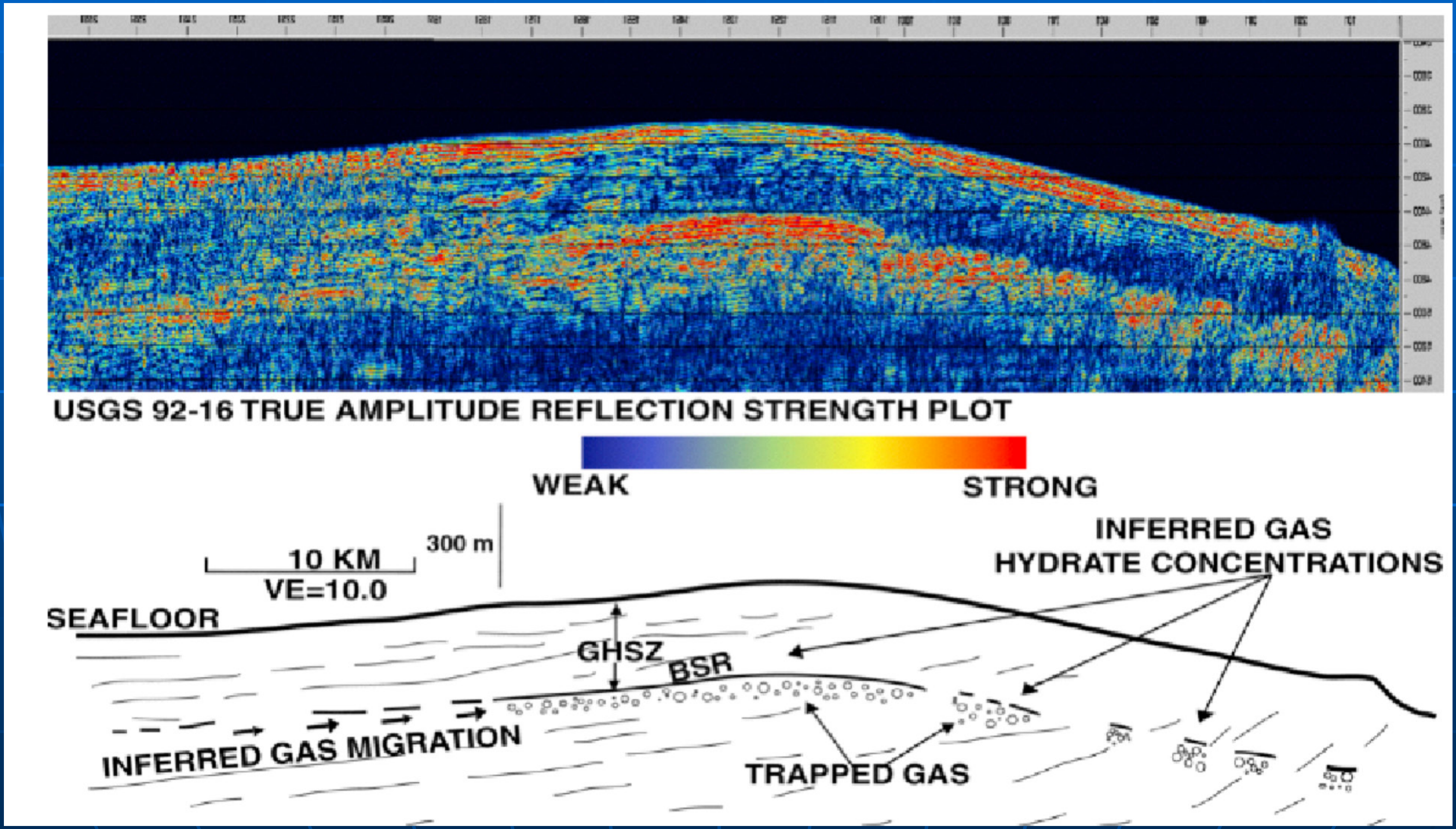
Presenter's Notes: Dispersed Hydrate nucleation could be caused by local biogenic production of methane that raises the concentration to the point at which hydrate will nucleate. Once nucleated, lower concentration dissolved methane will allow for growth. More complex microstructures in clays may introduce longer diffusion paths

GHSZ in Blake Ridge



From W. Dillon, USGS

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Ancient Hydrate

- The same processes that have generated the modern hydrates we find today were at work throughout geologic history:

Temperature/Pressure

Gas

Water

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Hydrate Conversion / Diagenesis

- Hydrate may occur anywhere within the GHSZ (thermodynamic stability)

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Hydrate Conversion / Diagenesis

- Hydrate may occur anywhere within the GHSZ (thermodynamic stability)
- Most common in the lower 1/3 of the GHSZ

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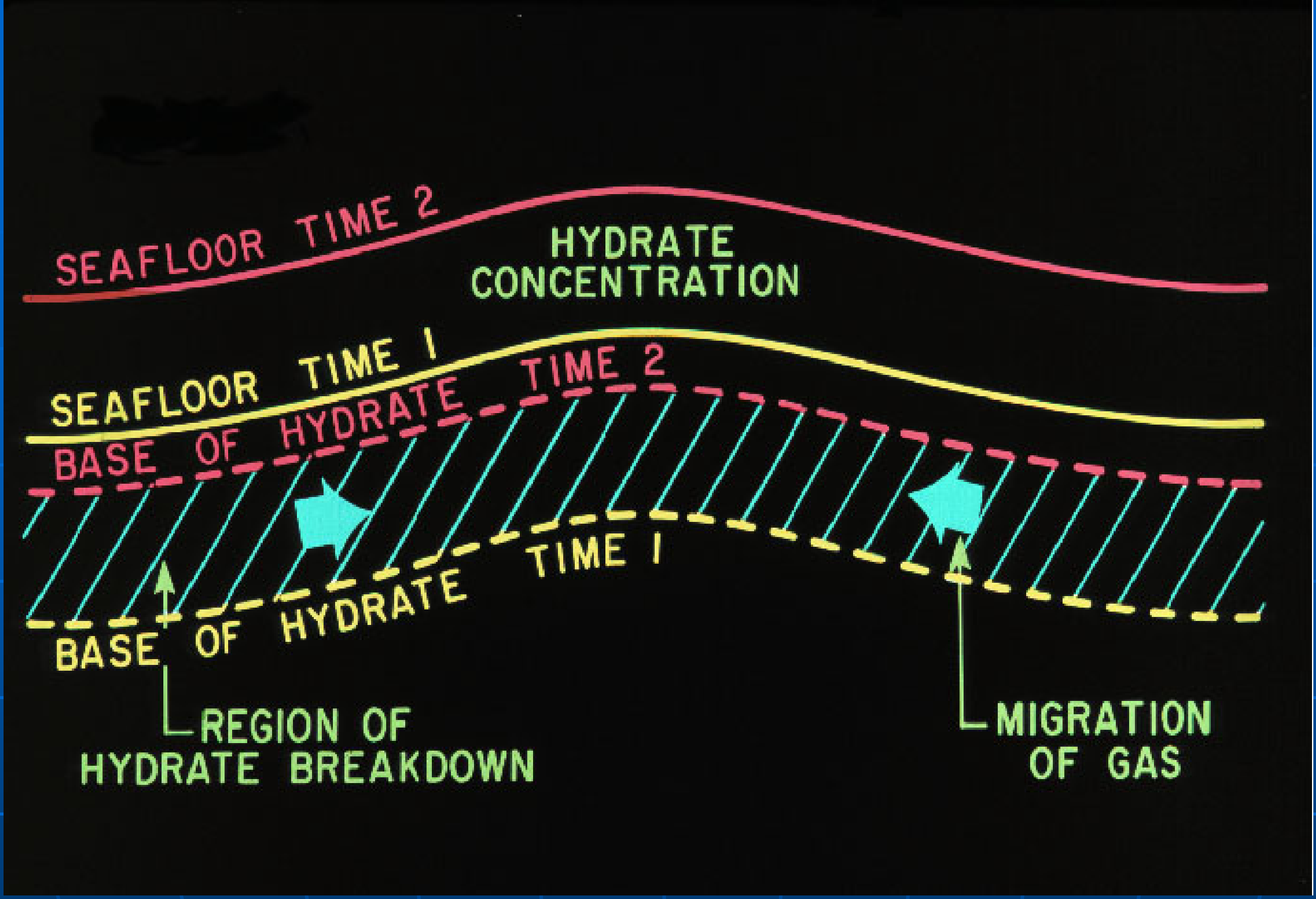

- Through time, sedimentation ‘raises’ seafloor level
- Base of the GHSZ rises to maintain thickness of GHSZ
- Sediments at base of GHSZ more compact
- Further gas concentration below GHSZ

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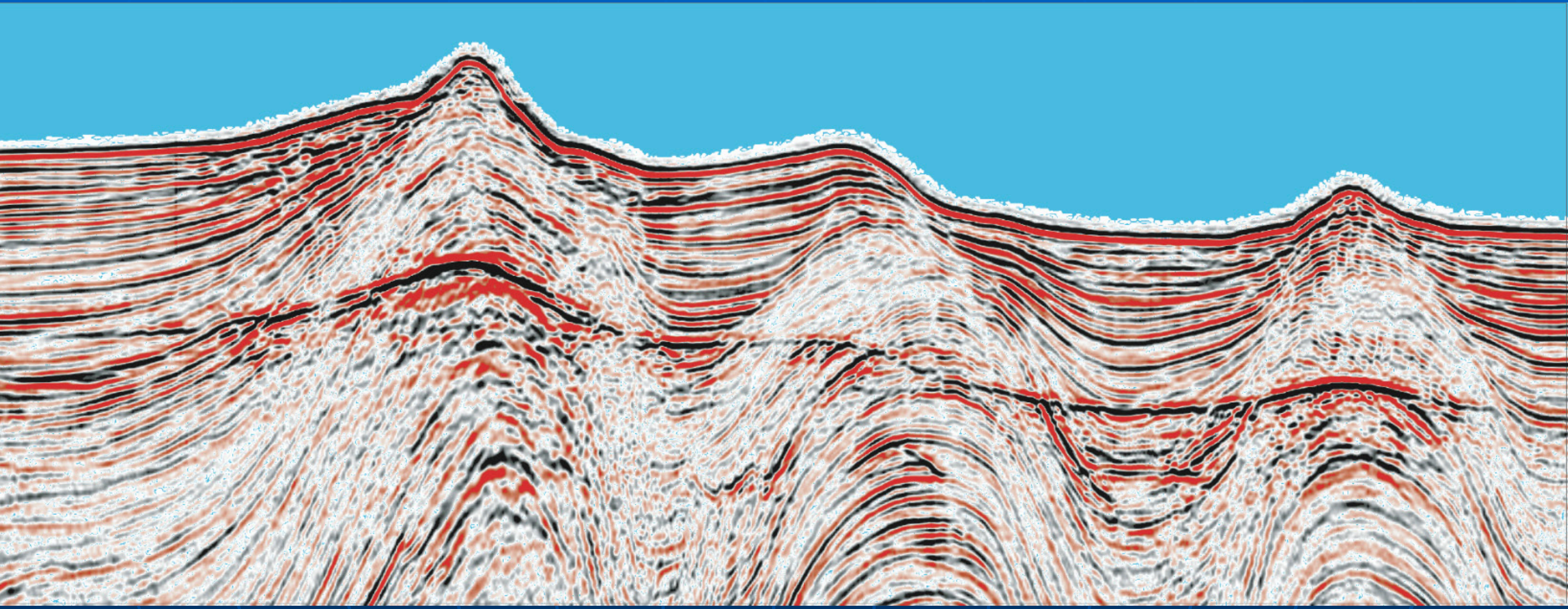
GHSZ & BSR - Makassar Straits



From Max, et al., 2006

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Model: Early Concentration of Natural Gas in Shales

- Early diagenesis of muddy sediments
- Shallow burial biogenic gas production
  - From entire sediment pile
- Gas in GHSZ forms Hydrate
- Hydrate concentrates huge amounts of gas as solid grains/veins
- Hydrate retains gas during early compaction & diagenesis

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Some Sweet Spots Could Reflect Retained Early Gas

- Hydrate forms when shale porosity is high
- Being a strong solid, sediment packs around hydrate
- Hydrate preserves some original porosity during and following compaction
- When hydrate converts to gas and water, 20% of its volume is porosity available for gas

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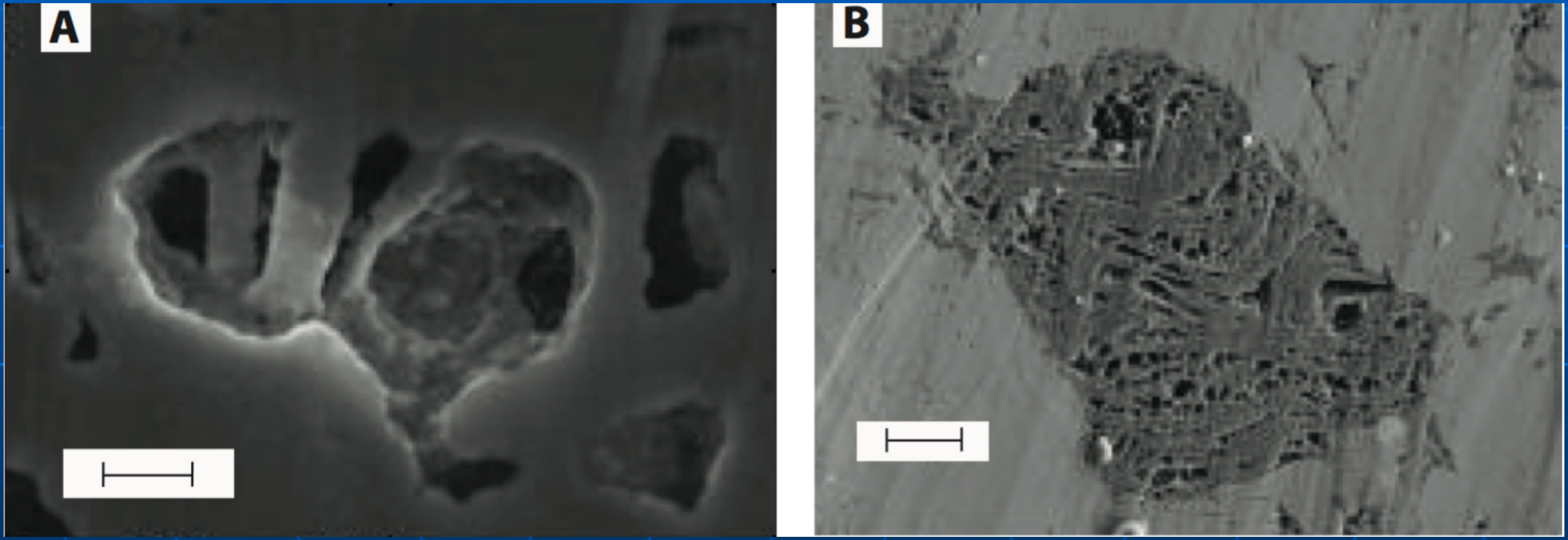
Relict Hydrate Volumes?



after Jarvie (2010)

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World-Wide Opportunities

- Lower Paleozoic of Denmark, Sweden, and Poland
  (including Gdansk Depression, Warsaw Trough, and Lublin Trough)
- Carboniferous basinal marine shale of Northwest England to Poland
  (Cheshire Basin, Anglo-Dutch Basin, Northwest German Basin, Northeast German-Polish Basin)
- Upper Jurassic Mikulov Formation in the Deep Vienna Basin.
- Upper Devonian Kellwasser Shale of Germany
- Jurassic - Lower Cretaceous Vaca Muerta Shale of Argentina
  (Neuquin Basin)

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Summary

- Most gas shale formed under conditions far from hydrate stability and is completely unrelated to gas hydrate.

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- But there are some basins where the possibility of a hydrate precursor should be considered.

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Summary

- Most gas shale formed under conditions far from hydrate stability and is completely unrelated to gas hydrate.
- But there are some basins where the possibility of a hydrate precursor should be considered.
- There may be sweet spots that we would miss if we only consider TOC.

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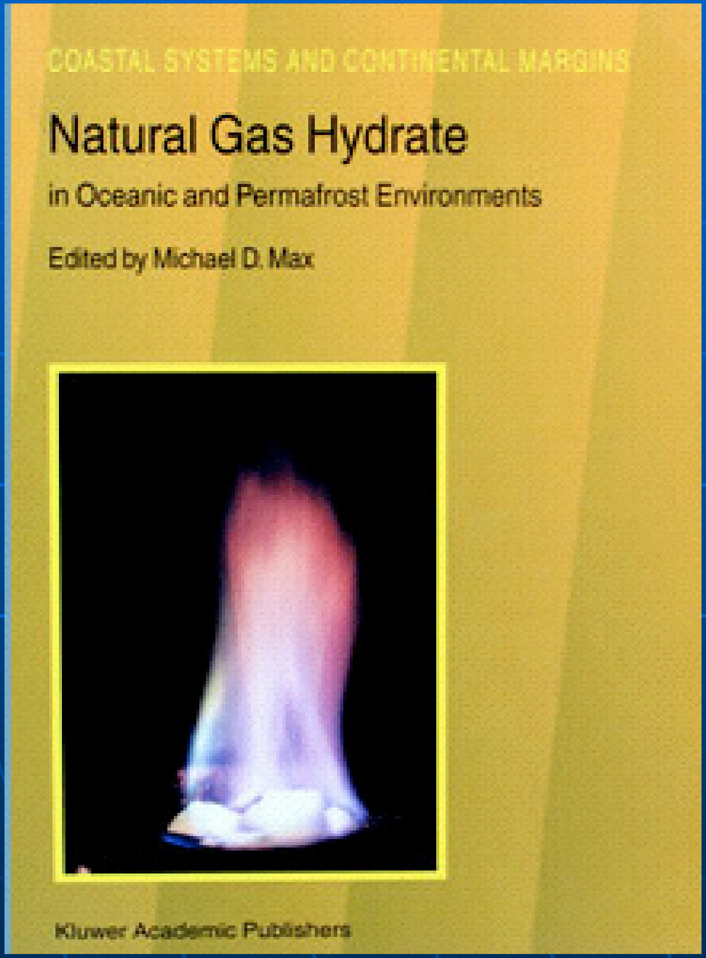
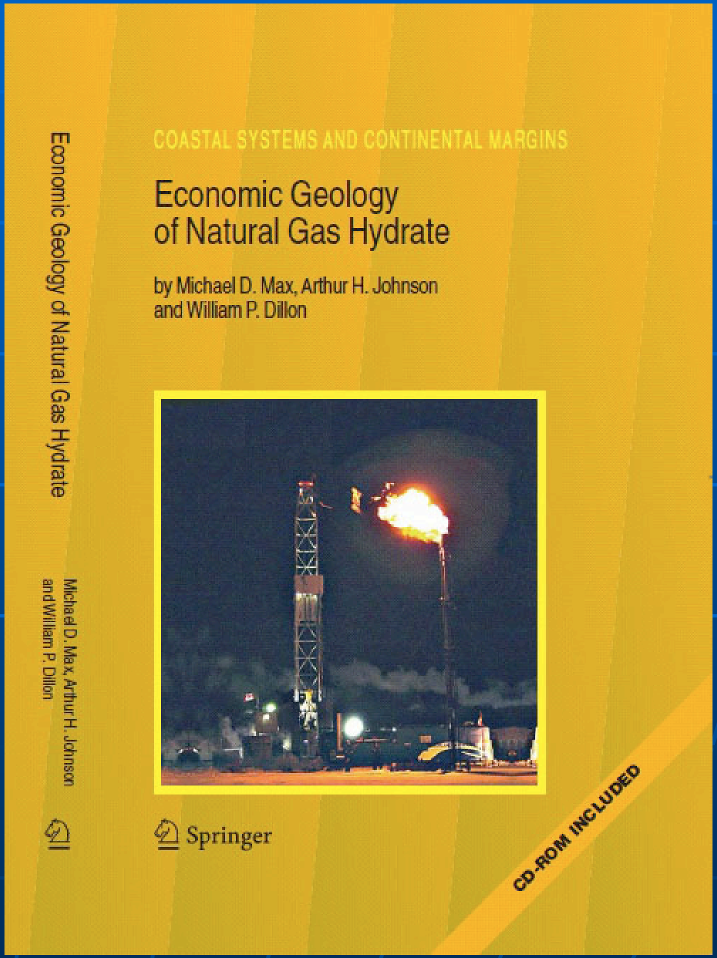
For More Information





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