Physical Properties related to the study of Gas Hydrate

Bill Waite

WWAITE@USGS.GOV

USGS

Workshop on Gas Hydrates– AMGG/CAGE/UIT (March, 2019)

Tools to help *you* guess what will happen next in *your* study

Bill Waite

WWAITE@USGS.GOV

USGS

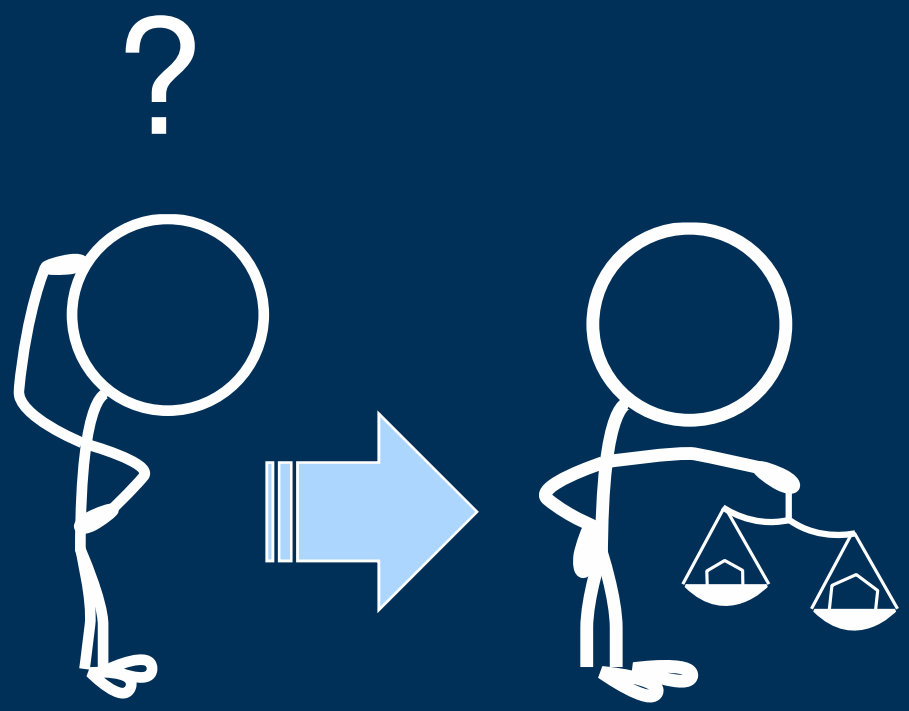
Workshop on Gas Hydrates– AMGG/CAGE/UIT (March, 2019)

Tools to help *you* guess what will happen next in *your* study

Tools to help *you* guess what will happen next in *your* study

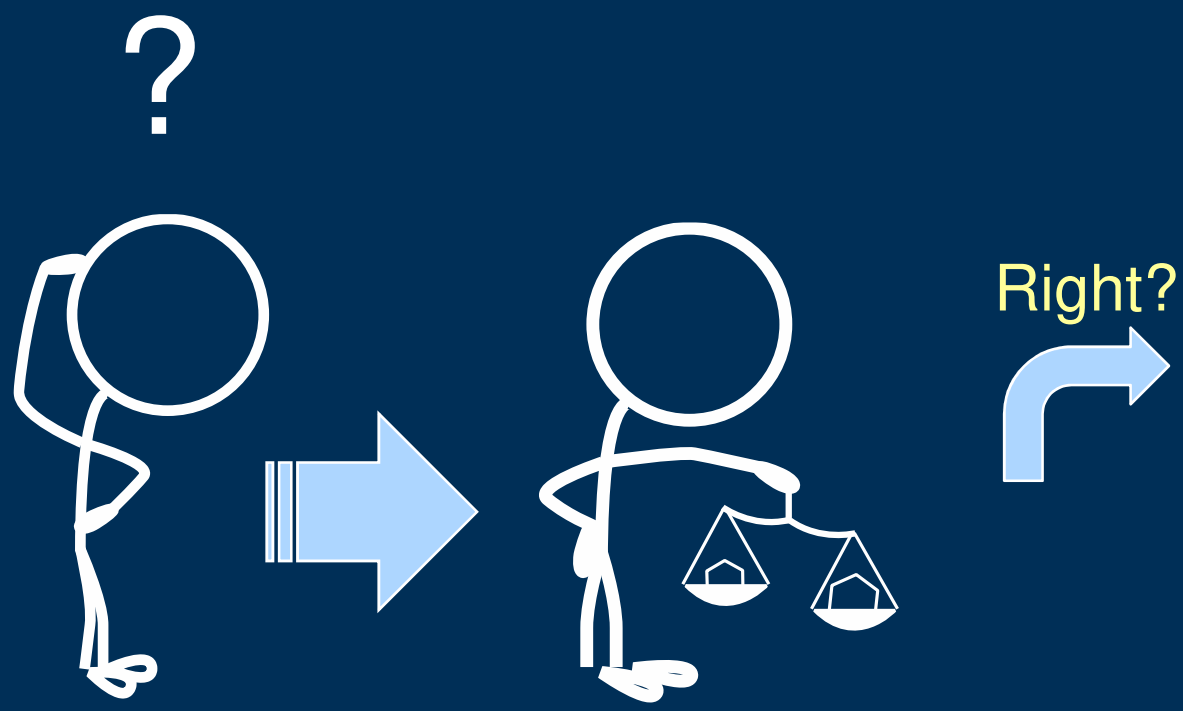
Guess

Tools to help *you* guess what will happen next in *your* study

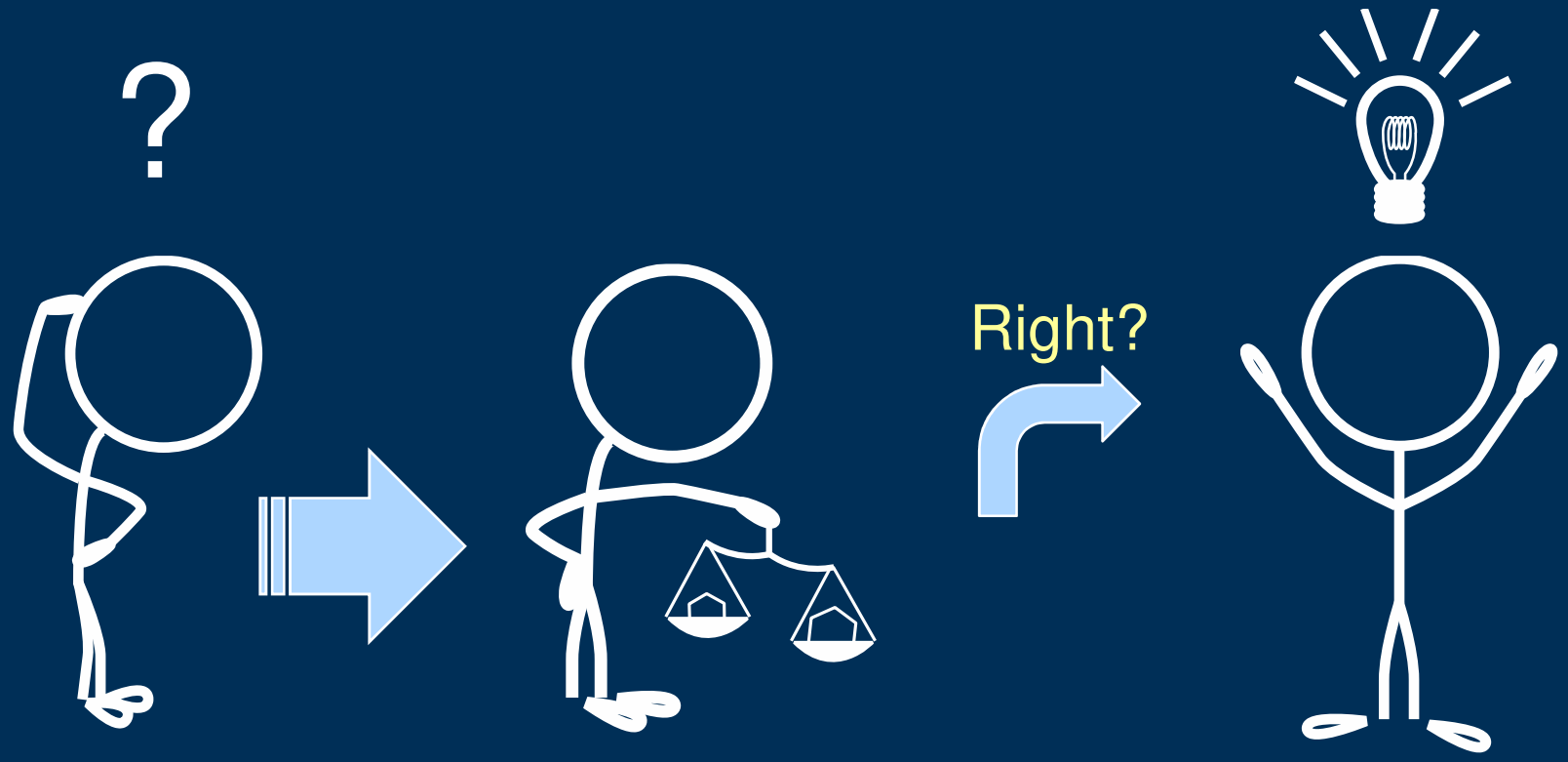


Guess Test

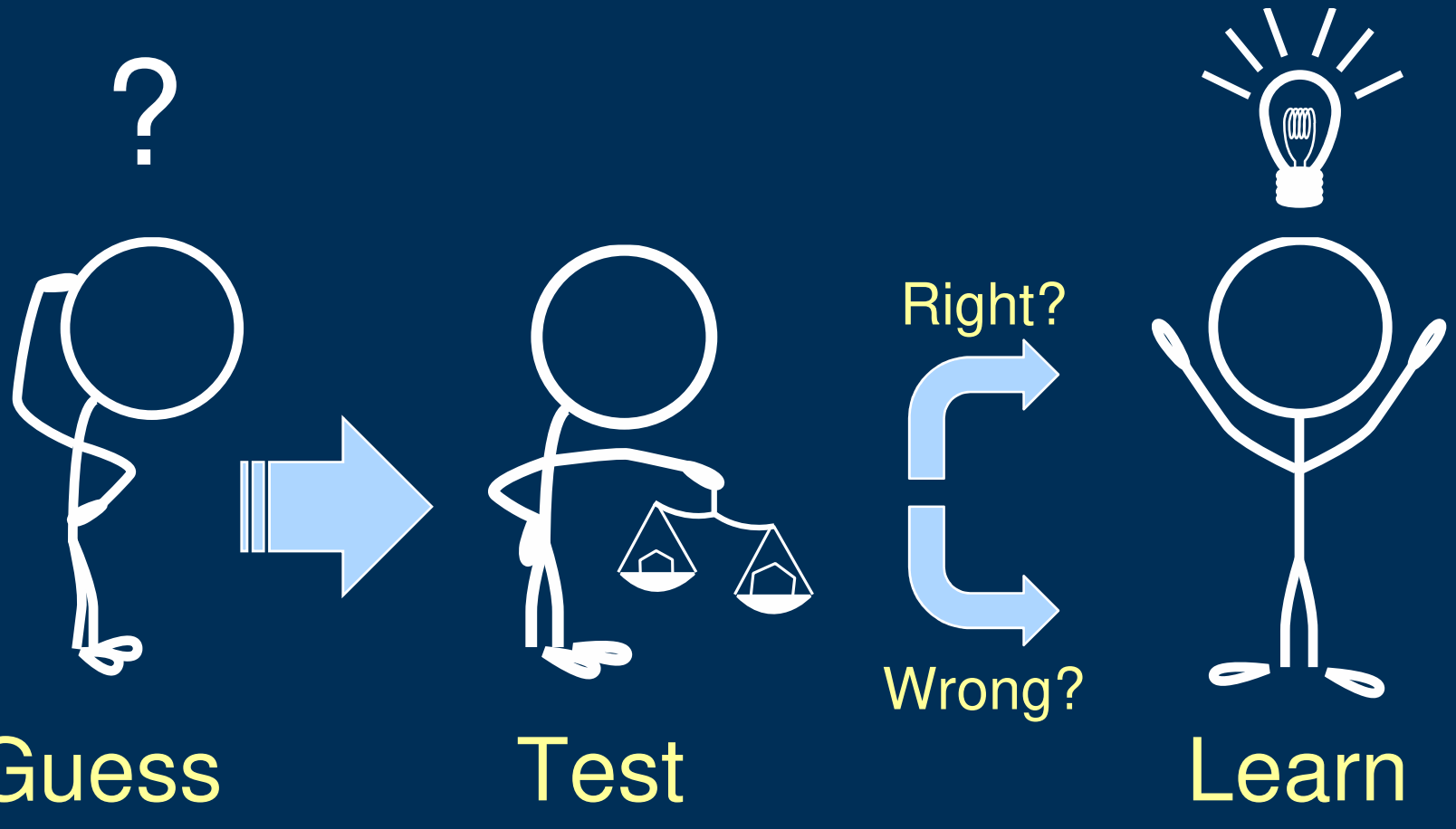
Tools to help *you* guess what will happen next in *your* study



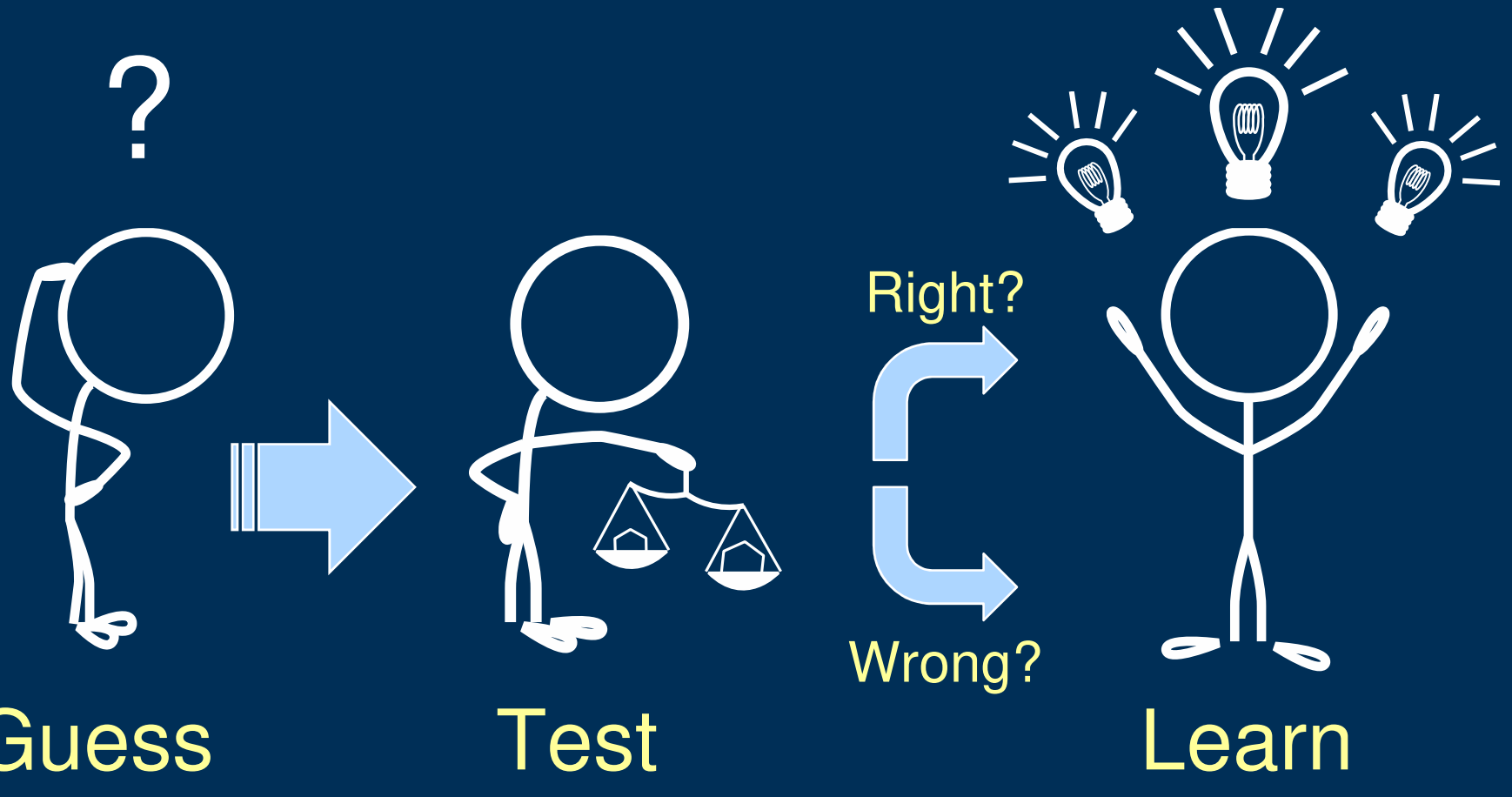
Tools to help *you* guess what will happen next in *your* study



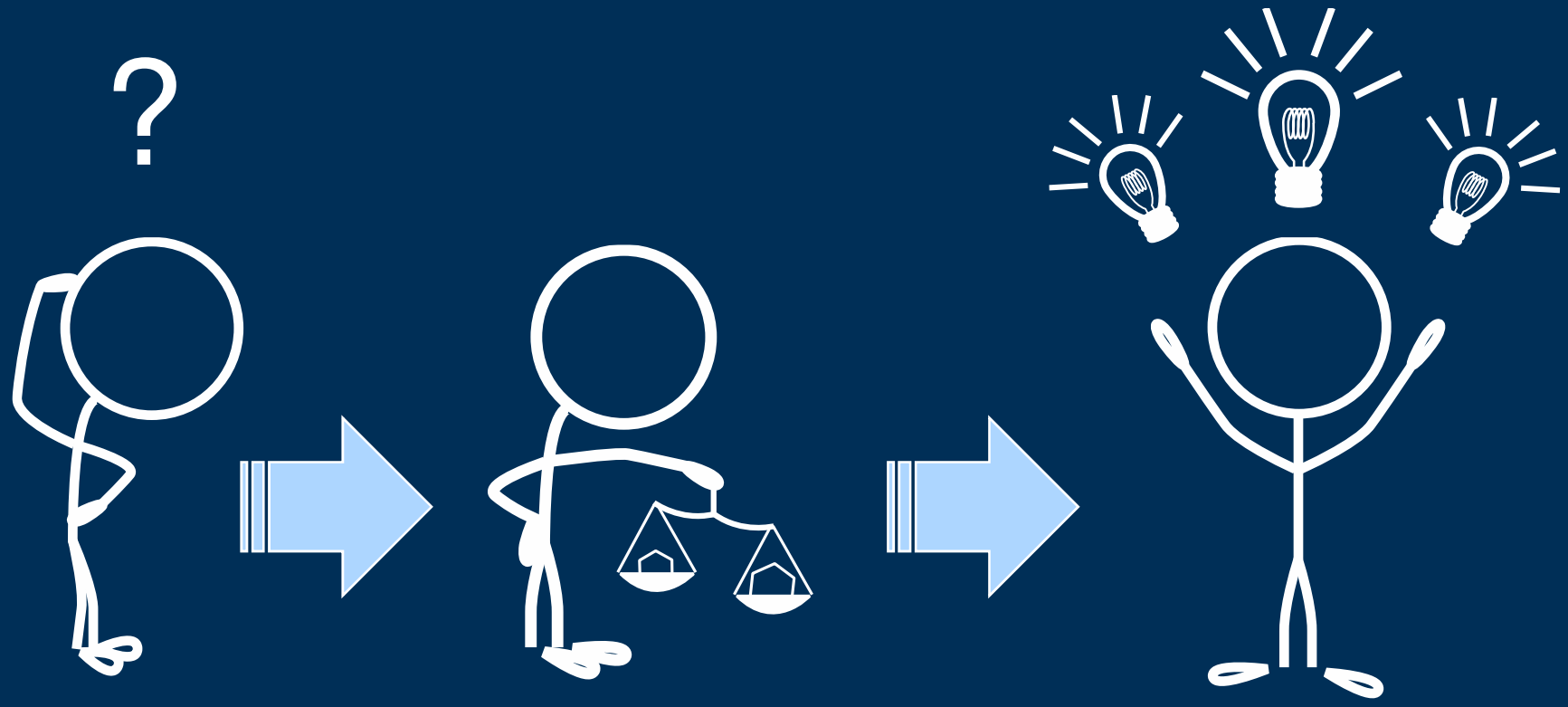
Tools to help *you* guess what will happen next in *your* study



Tools to help *you* guess what will happen next in *your* study



Tools to help *you* guess what will happen next in *your* study



What are the tools?

What are the tools?

Physical Properties

What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation
    -
    -
    -
    -

What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation
  - .
  - .
  - .
  - .

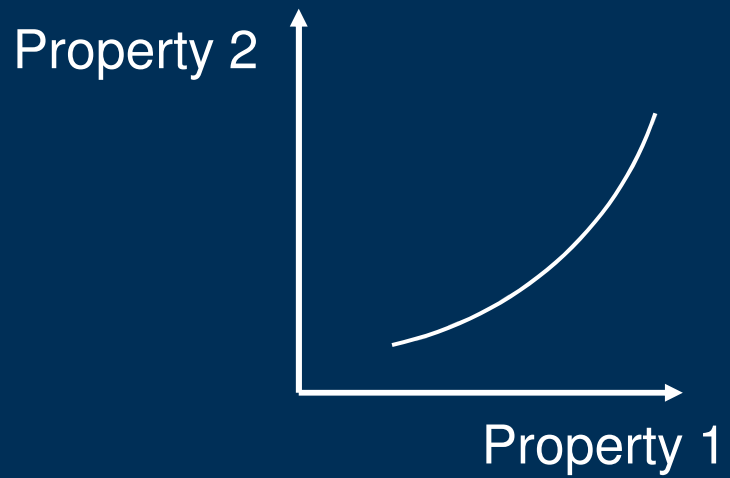
Correlations

What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation
  - .
  - .
  - .
  - .

Correlations

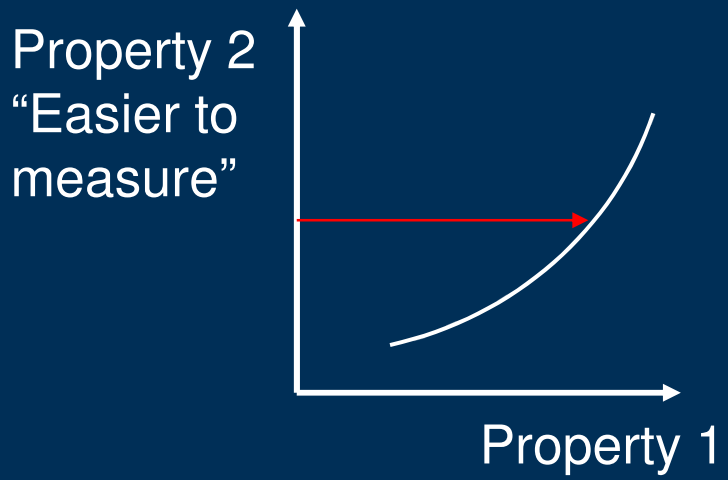


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation
  - .
  - .
  - .
  - .

Correlations

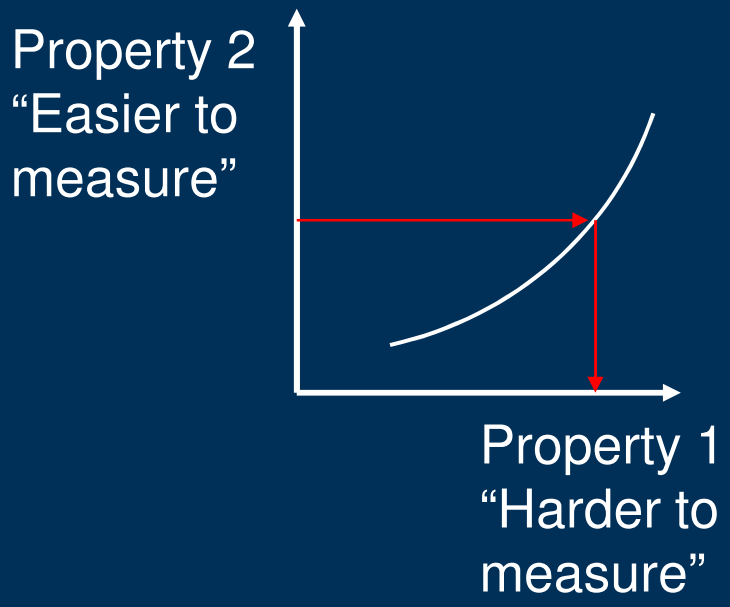


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation
  - .
  - .
  - .
  - .

Correlations

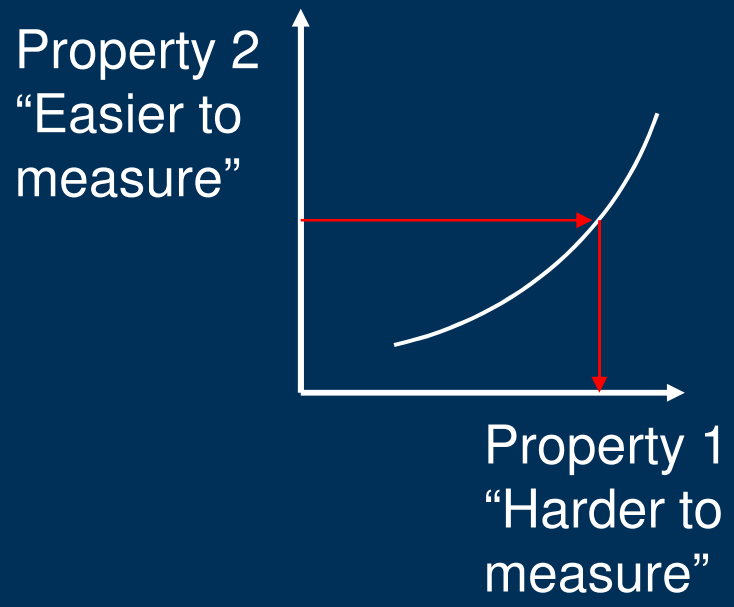


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation

Correlations

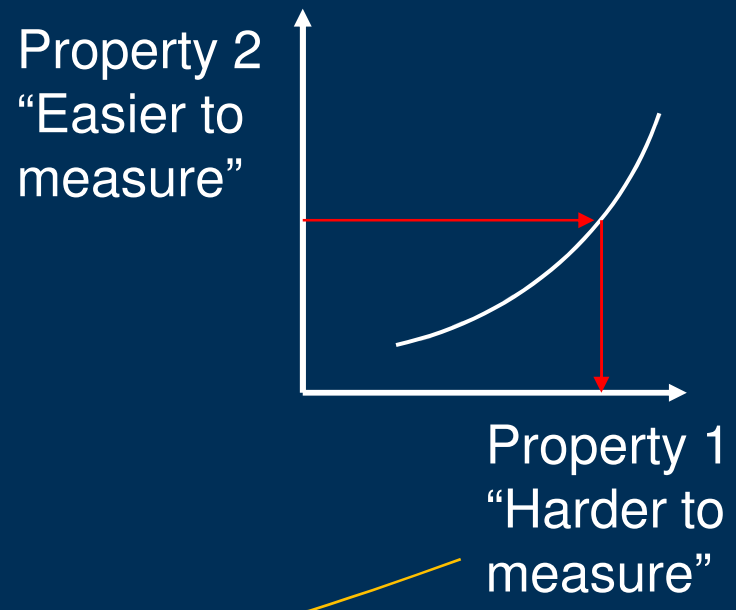


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation

Correlations

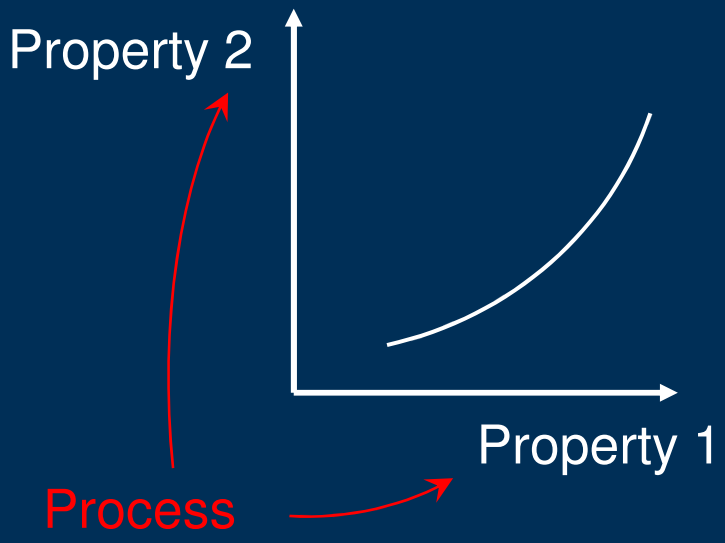


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation
- .
- .
- .
- .

Correlations

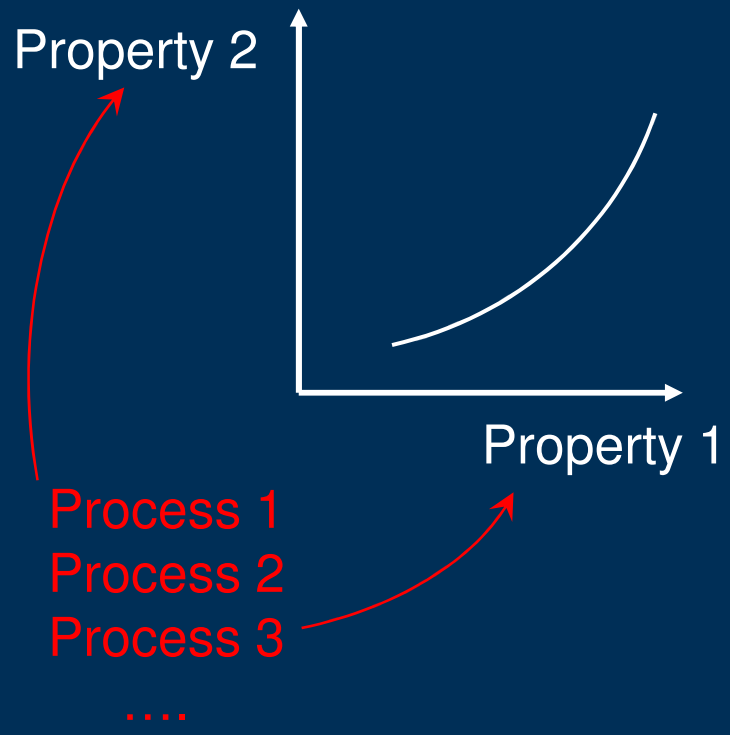


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation

Correlations

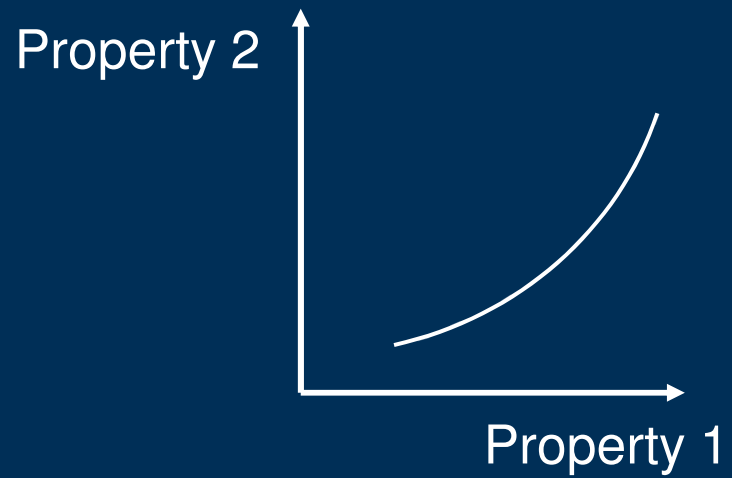


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation

Correlations

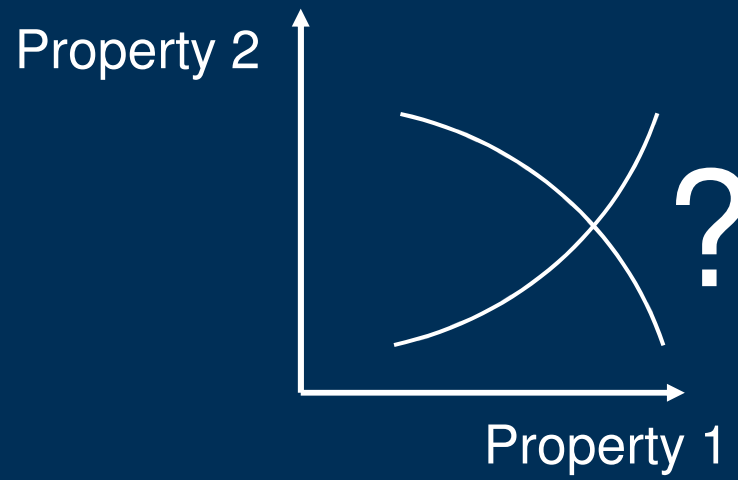


What are the tools?

Physical Properties

- Density
- Velocity
- Resistivity
- Permeability
- Compressibility
- Thermal properties
- Gas hydrate saturation

Correlations



Workshop Outline

Workshop Outline

- Finding gas hydrate in nature

Workshop Outline

- Finding gas hydrate in nature
- Characterizing gas hydrate occurrences

Workshop Outline

- Finding gas hydrate in nature
- Characterizing gas hydrate occurrences
- Can methane be extracted for profit?

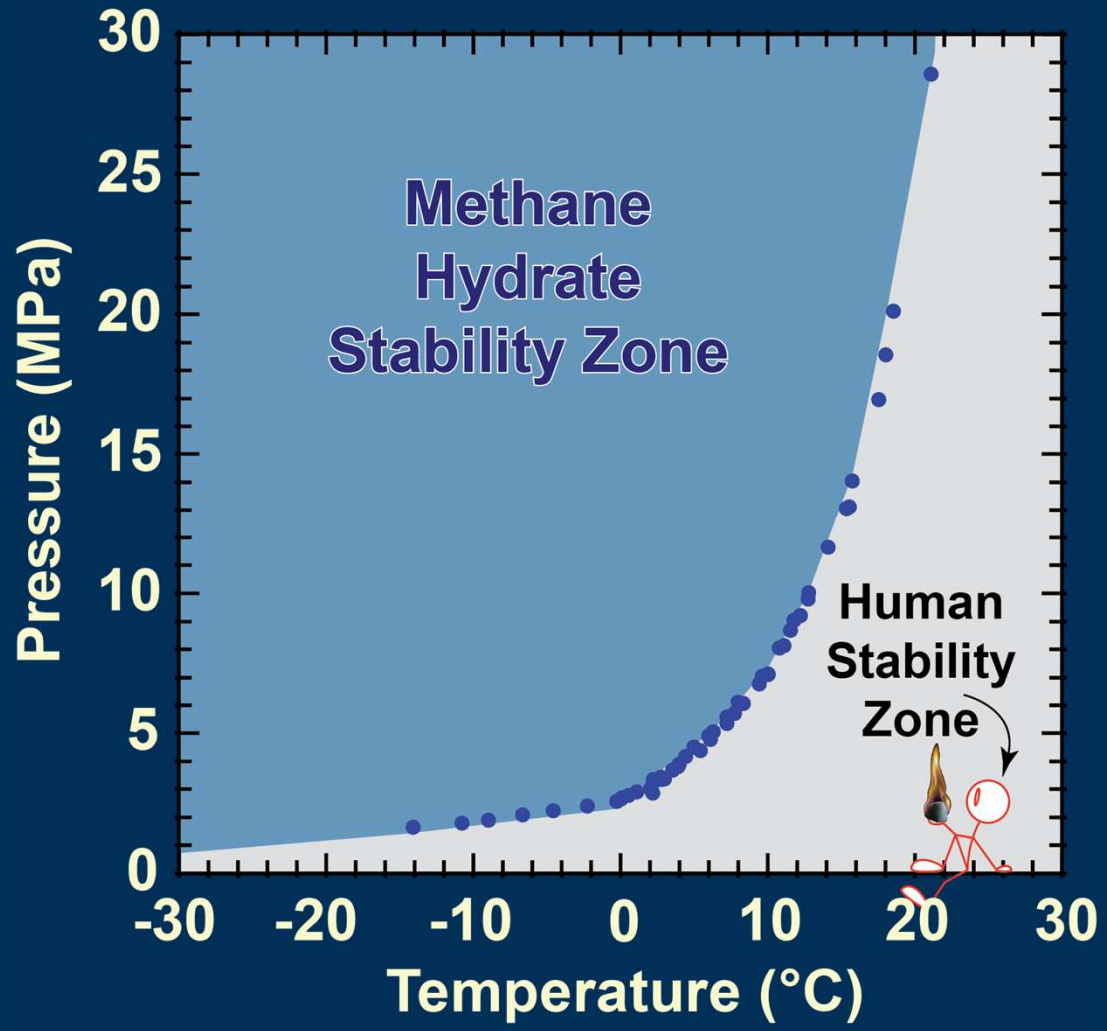
Workshop Outline

- Finding gas hydrate in nature
- Characterizing gas hydrate occurrences
- Can methane be extracted for profit?
- Gas hydrate formation & breakdown
  (Geologic time)

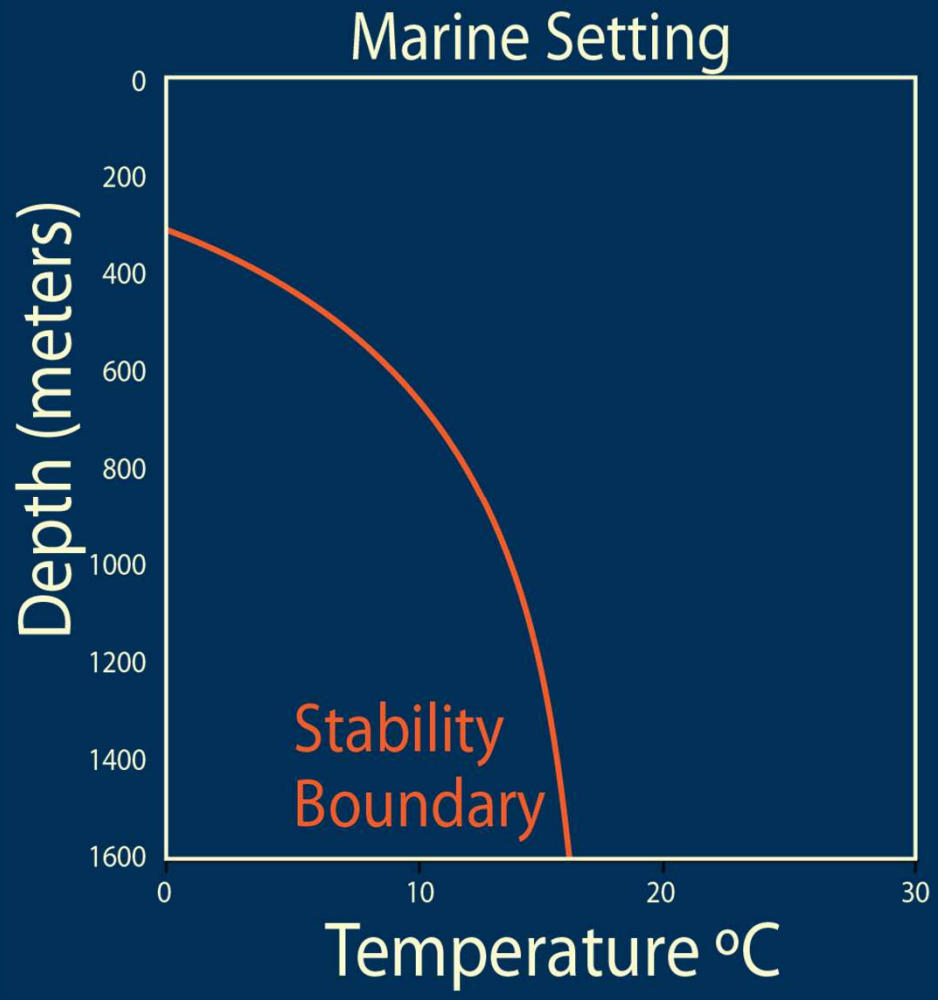
Workshop Outline

- **Finding gas hydrate in nature**
- **Characterizing gas hydrate occurrences**
- **Can methane be extracted for profit?**
- **Gas hydrate formation & breakdown**
  (Geologic time)

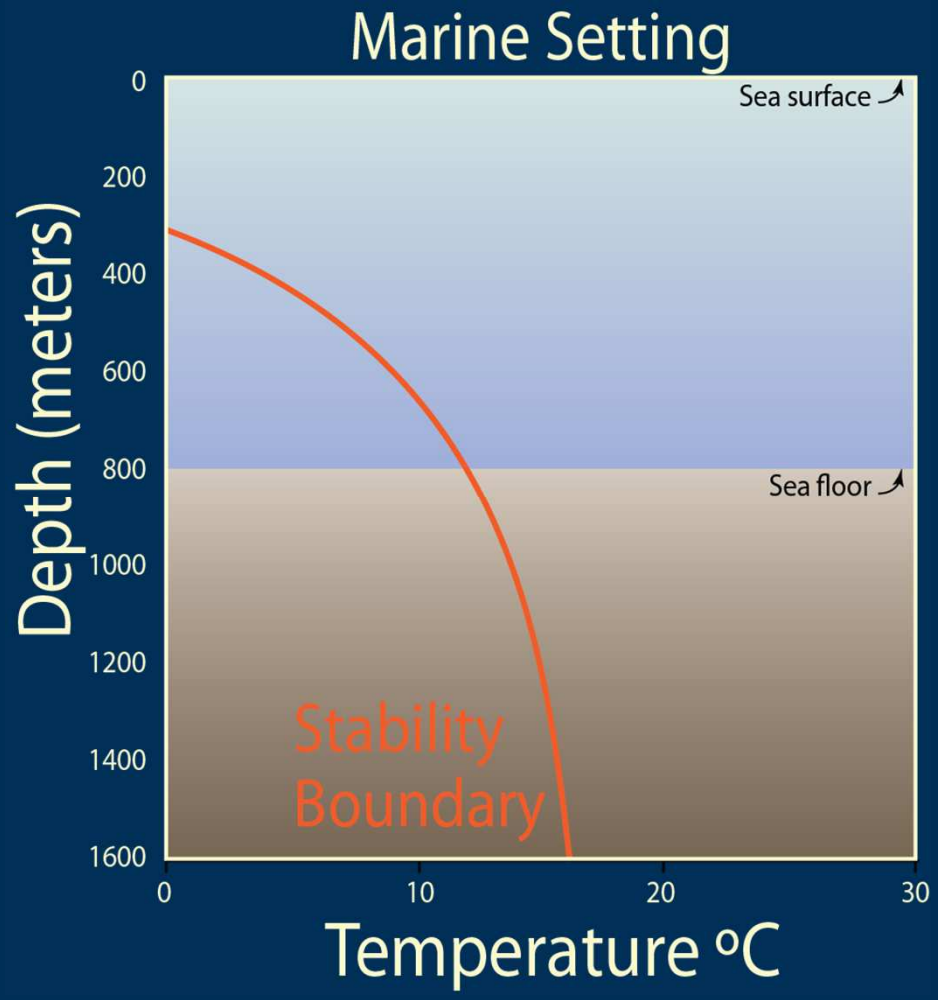
Methane gas hydrate phase stability: pressure and temperature requirements



Methane gas hydrate phase stability: pressure and temperature requirements

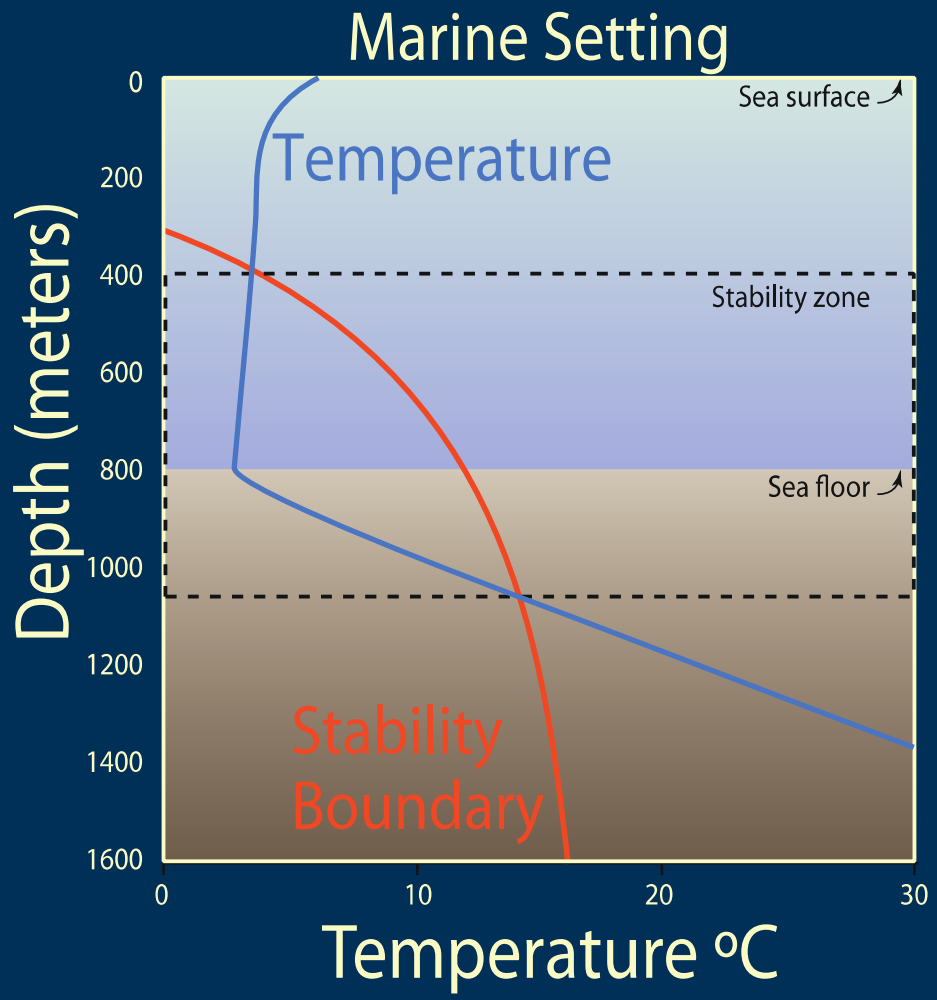


Methane gas hydrate phase stability: pressure and temperature requirements



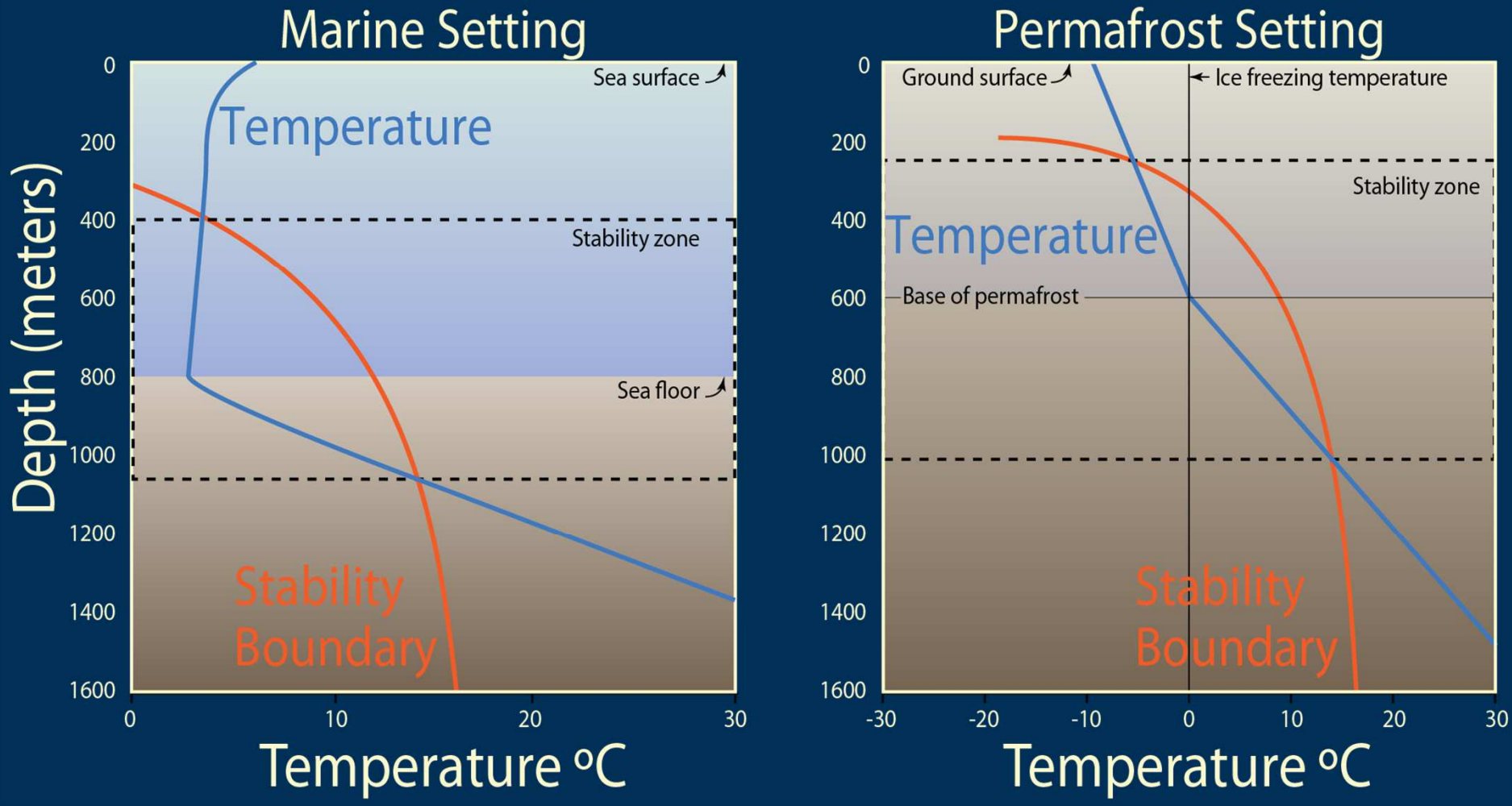
Beaudoin et al. (2014), U.N. Environmental Programme

Methane gas hydrate phase stability: pressure and temperature requirements



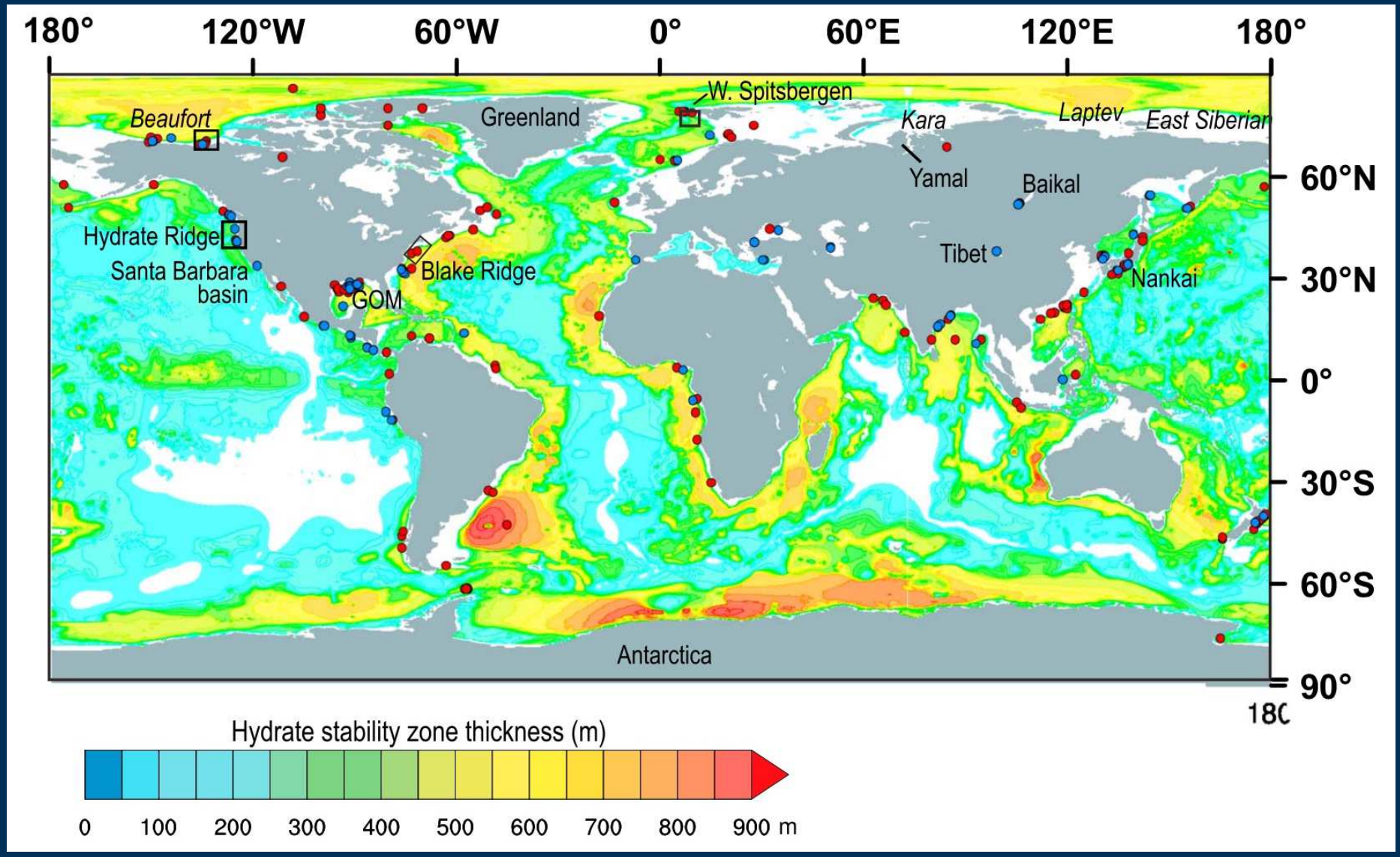
Beaudoin et al. (2014), U.N. Environmental Programme

Methane gas hydrate phase stability: pressure and temperature requirements

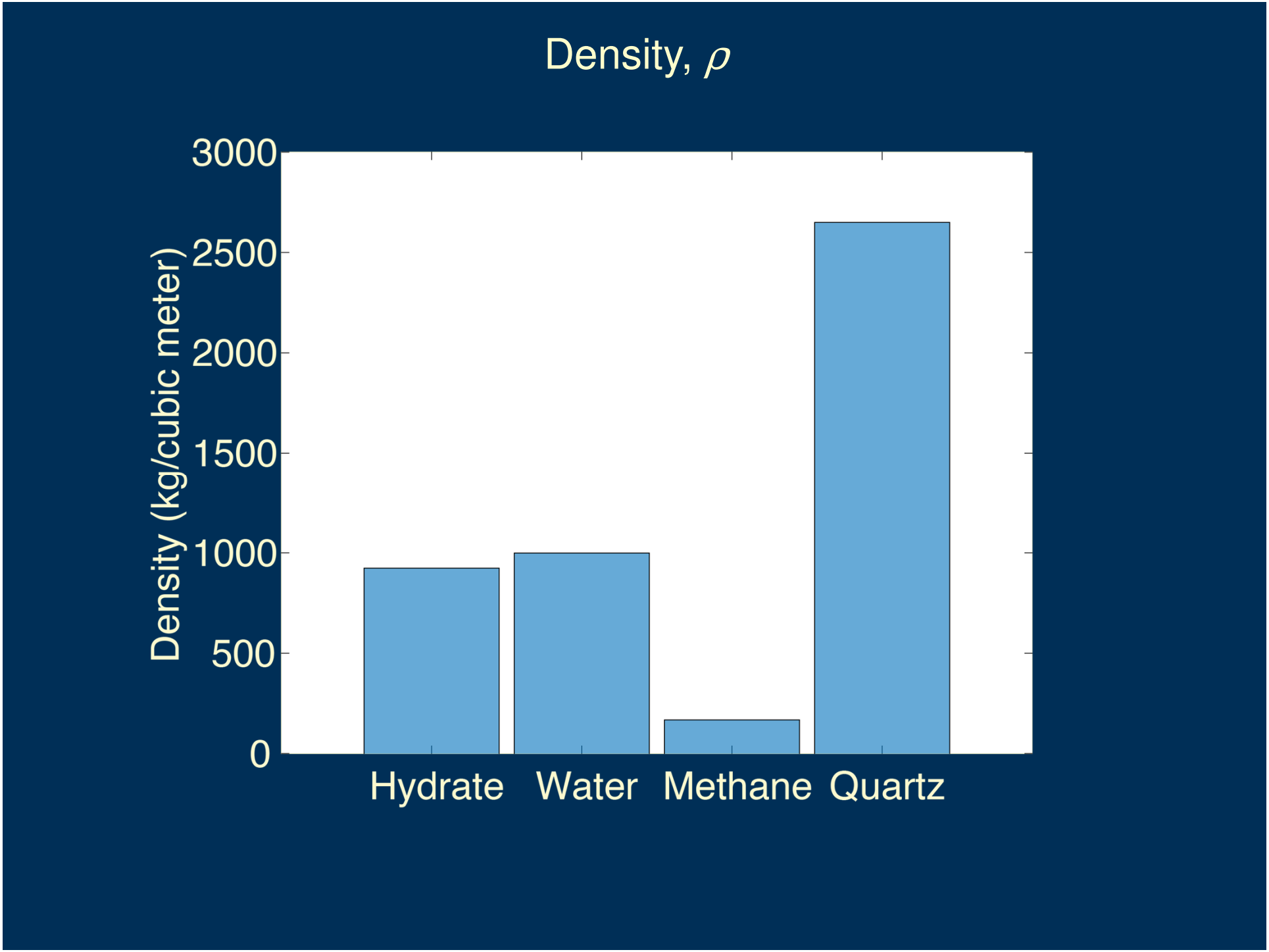


Beaudoin et al. (2014), U.N. Environmental Programme

Global methane gas hydrate distribution

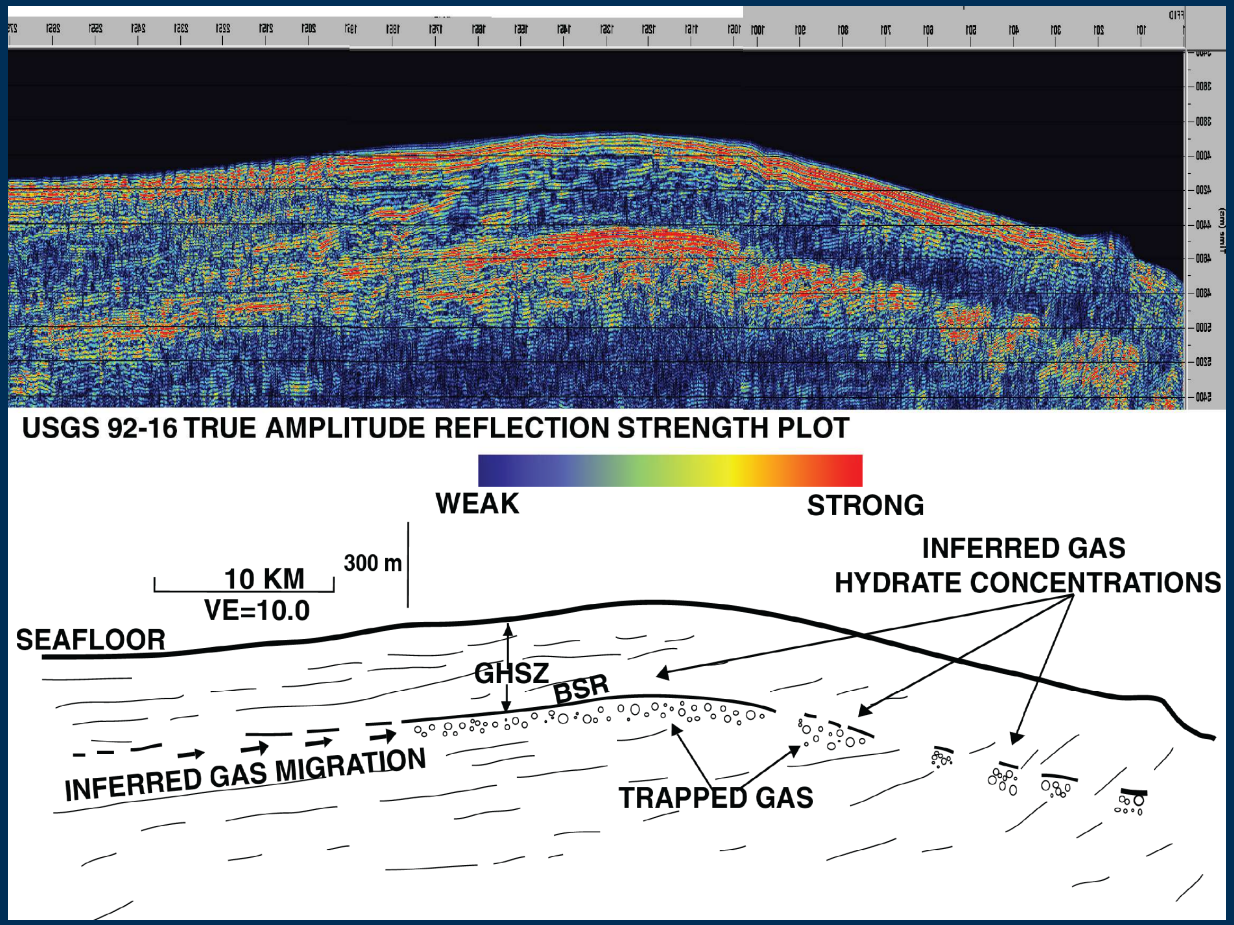


Ruppel et al. (2017), Rev of Geophysics


Density, ρ
Density (kg/cubic meter)
3000
2500
2000
1500
1000
500
0
Hydrate
Water
Methane
Quartz

Using ρ in the field: Bottom Simulating Reflector (BSR)

Blake Ridge (offshore USA)

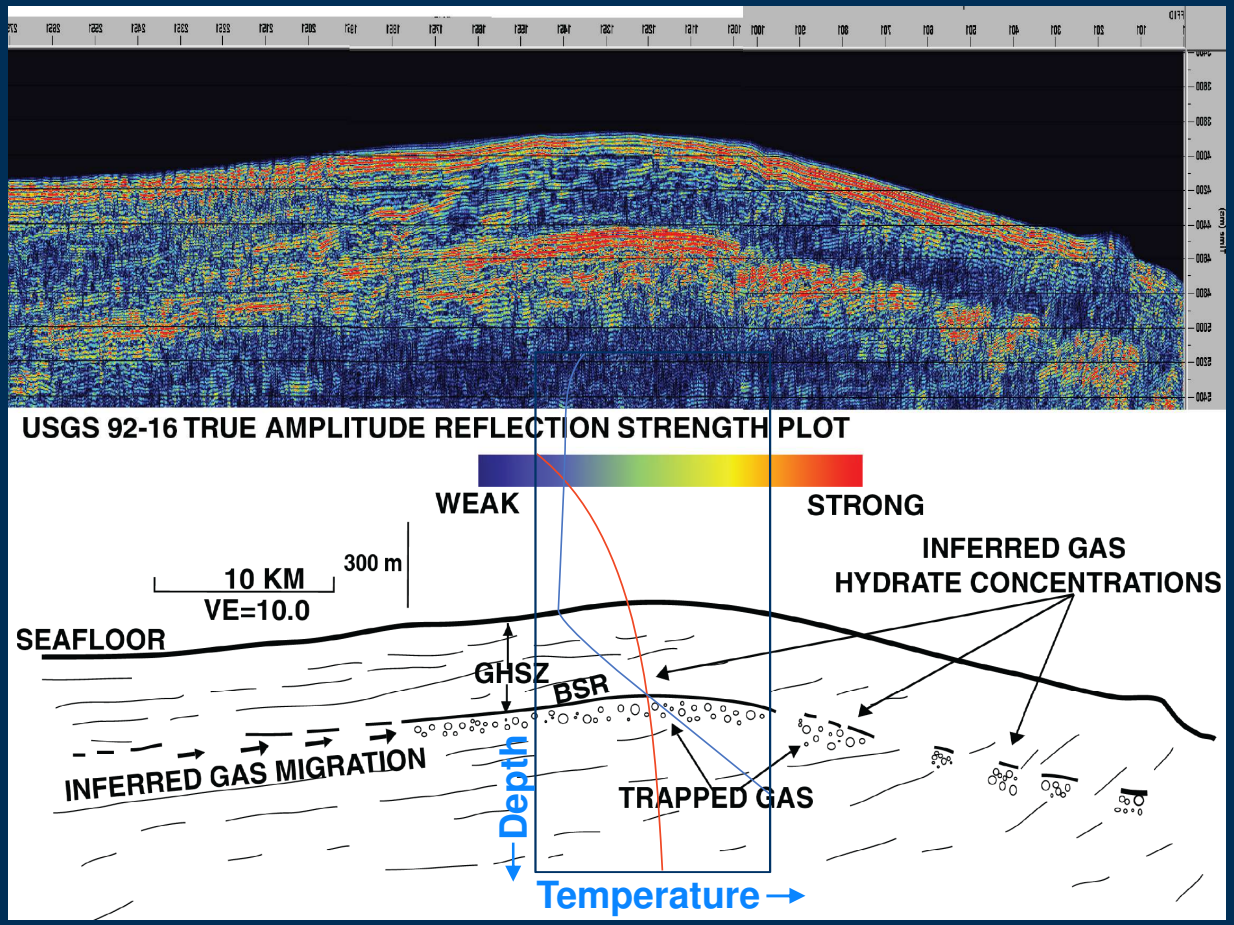


Reflection strength increases for large change in density*velocity (impedance contrast)

Max and Dillon (1998), J. Petroleum Geology

Using ρ in the field: Bottom Simulating Reflector (BSR)

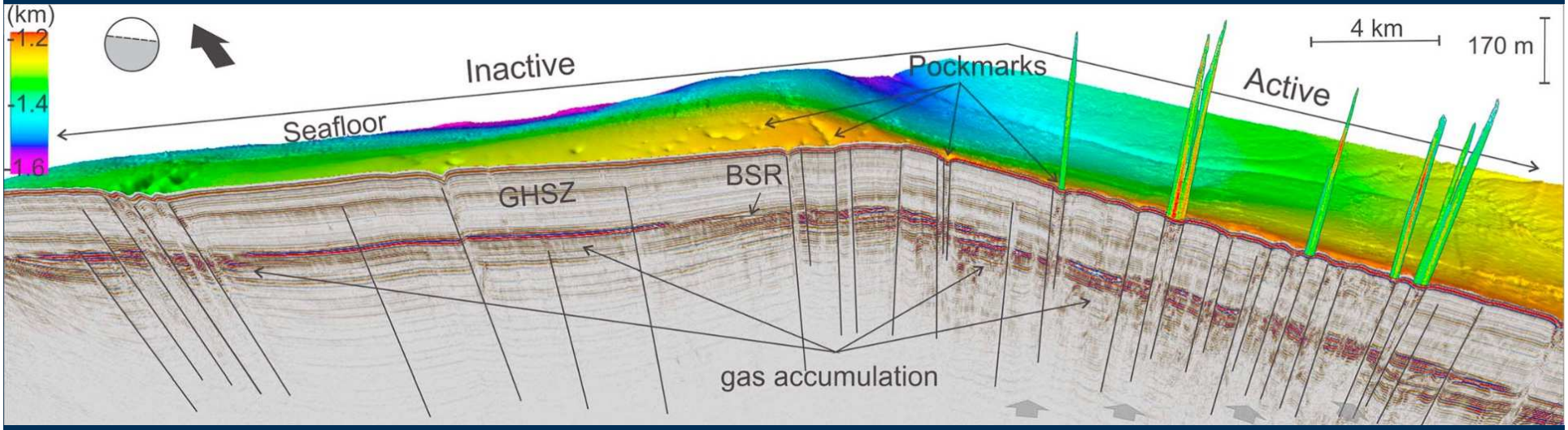
Blake Ridge (offshore USA)



Max and Dillon (1998), J. Petroleum Geology

Using ρ in the field: Bottom Simulating Reflector (BSR)

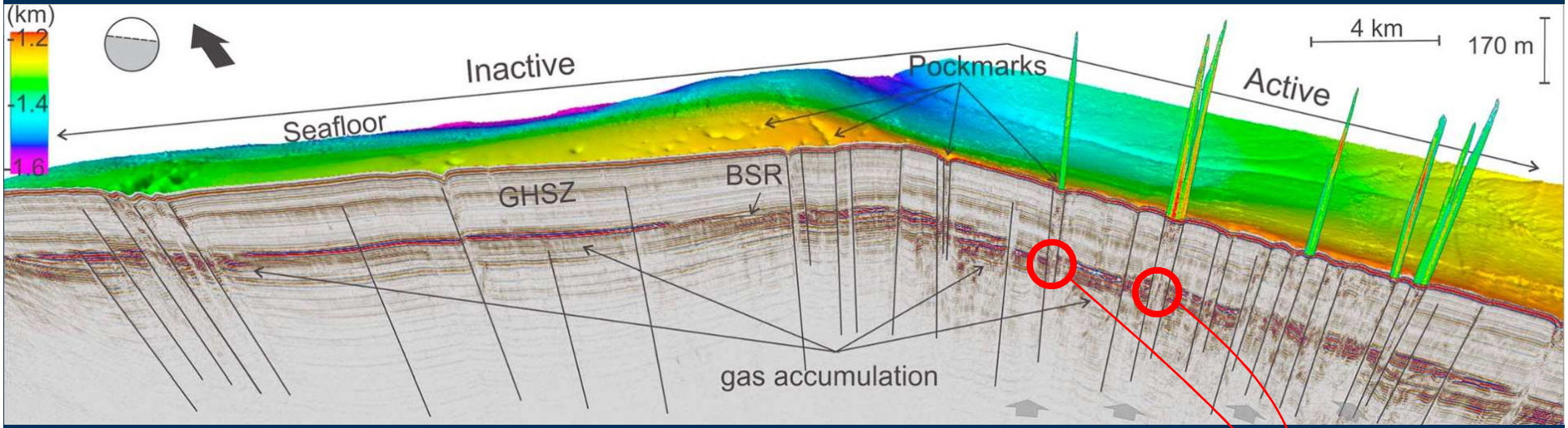
Vestnesa Ridge (offshore Svalbard)



Plaza-Faverola et al. (2017), JGR

Using ρ in the field: Bottom Simulating Reflector (BSR)

Vestnesa Ridge (offshore Svalbard)

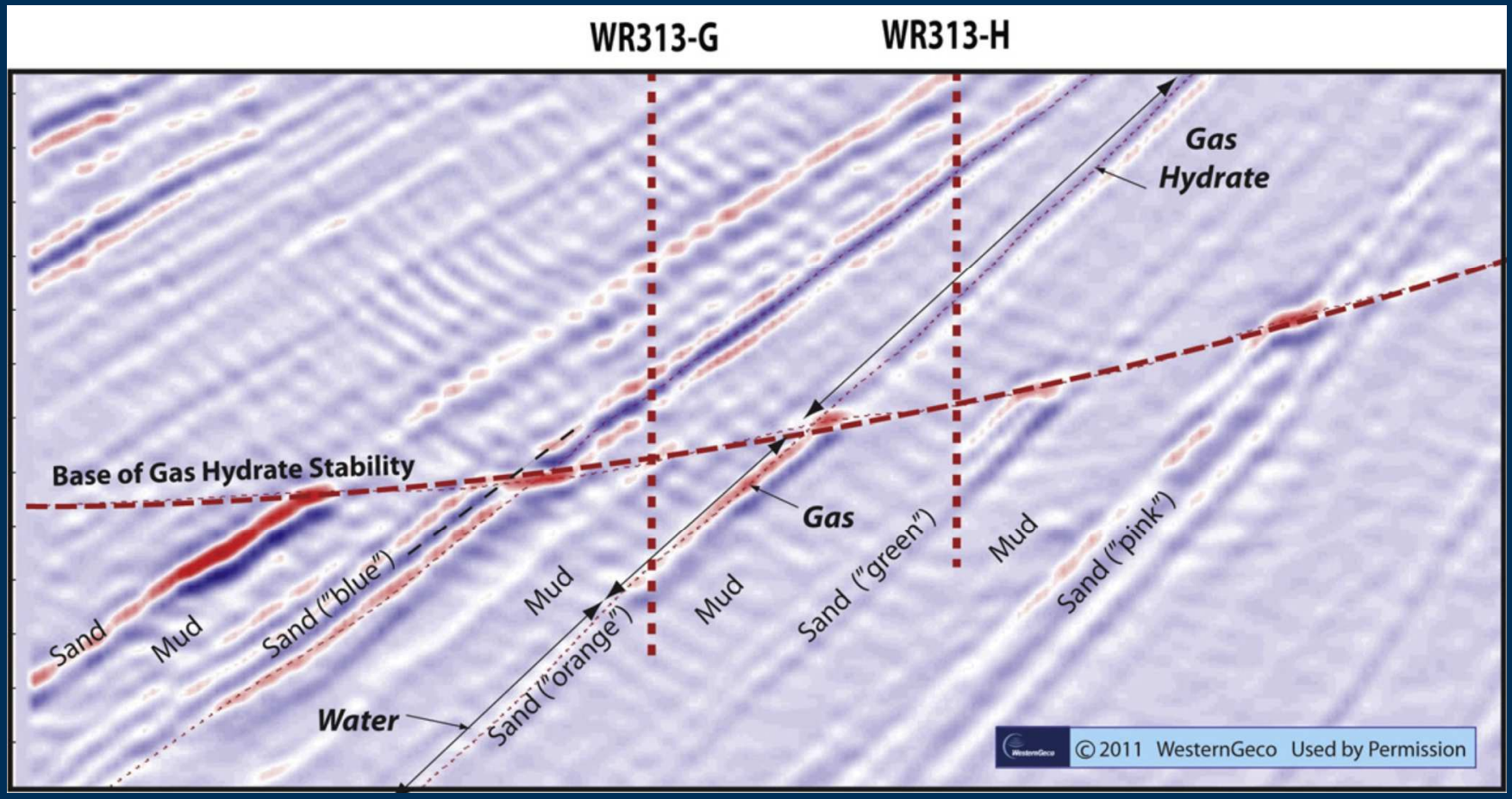


BSR can be harder to see where gas can escape

Plaza-Faverola et al. (2017), JGR

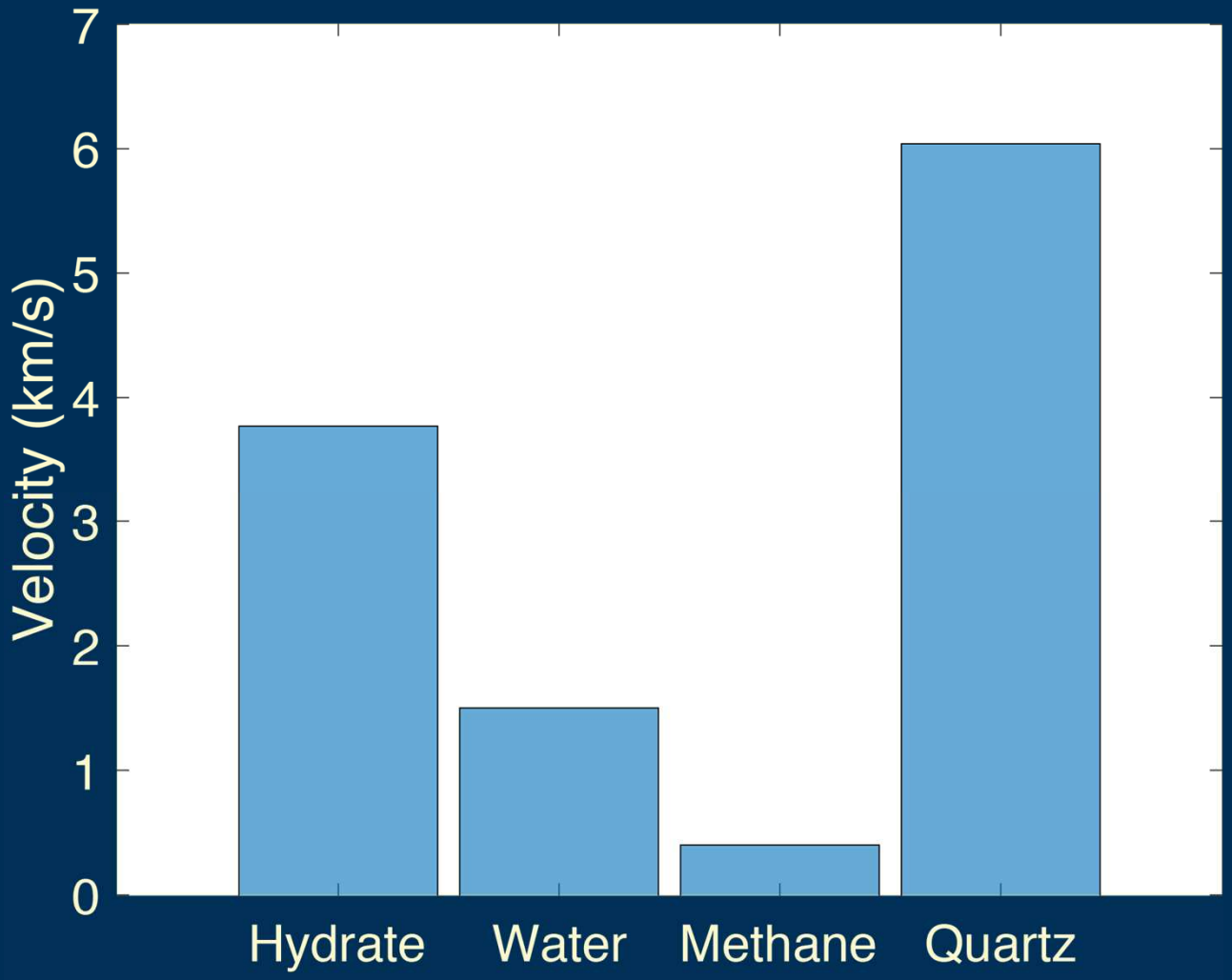
Using ρ in the field: Alternative BSRs

Gulf of Mexico (offshore USA)

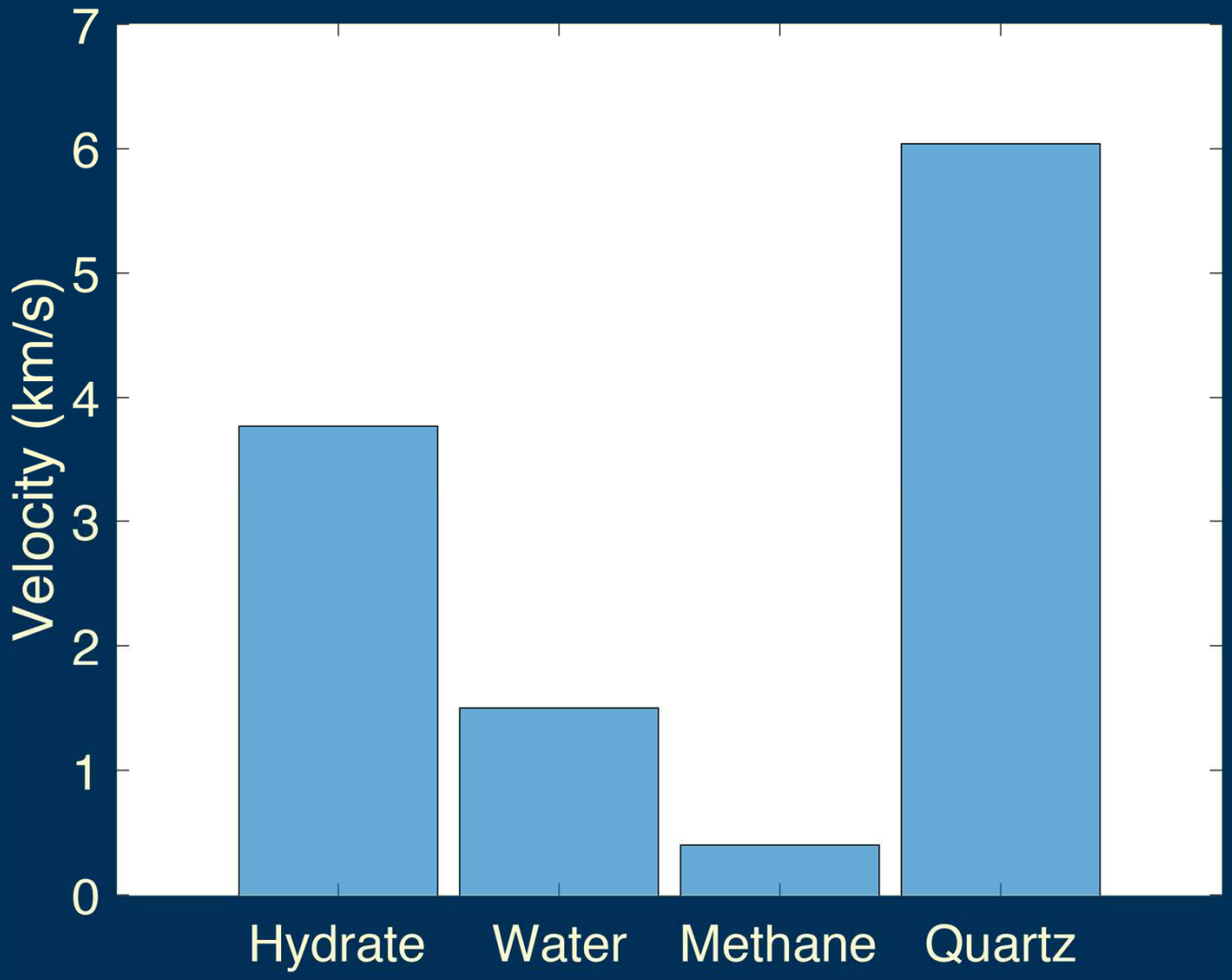


Boswell et al. (2012), Marine and Petroleum Geology

Compressional Wave Velocity, V_p



Compressional Wave Velocity, V_p

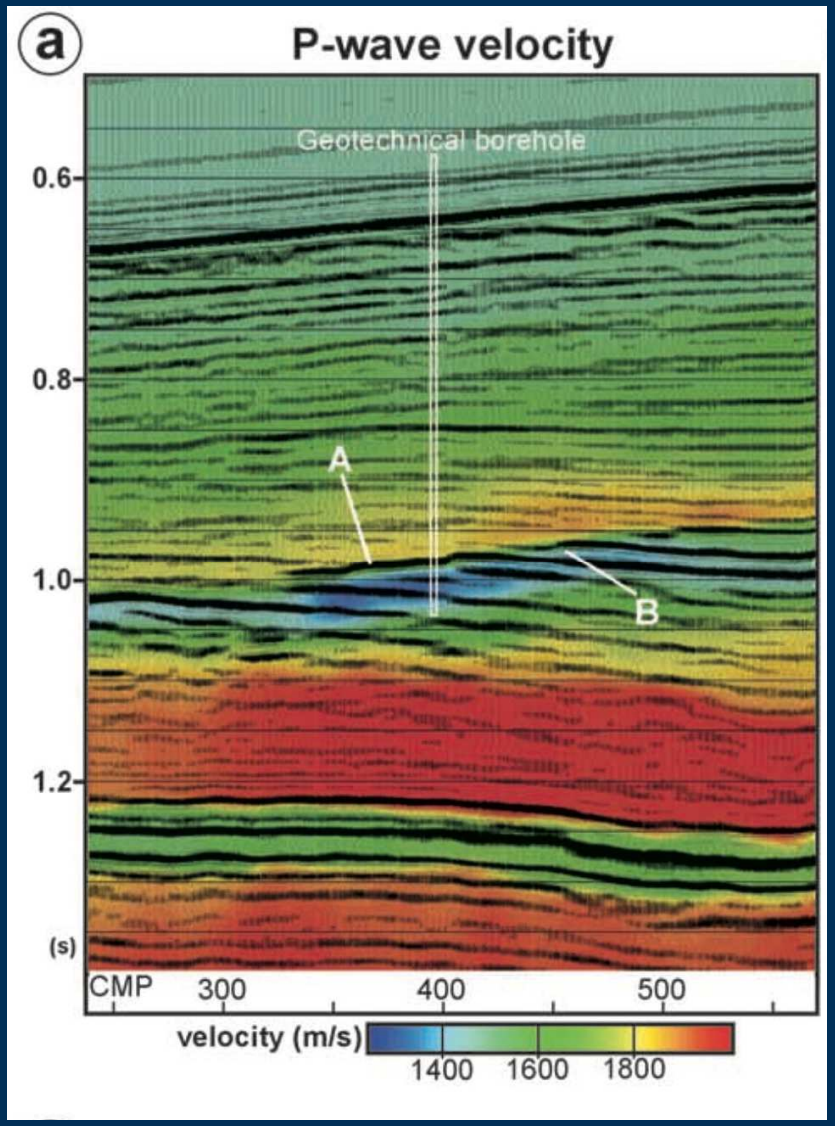


Forming hydrate will *increase* V_p in sediment

Forming gas will *decrease* V_p in sediment

Using V_p in the field: Finding regions of high V_p

Storegga slide (offshore Norway)

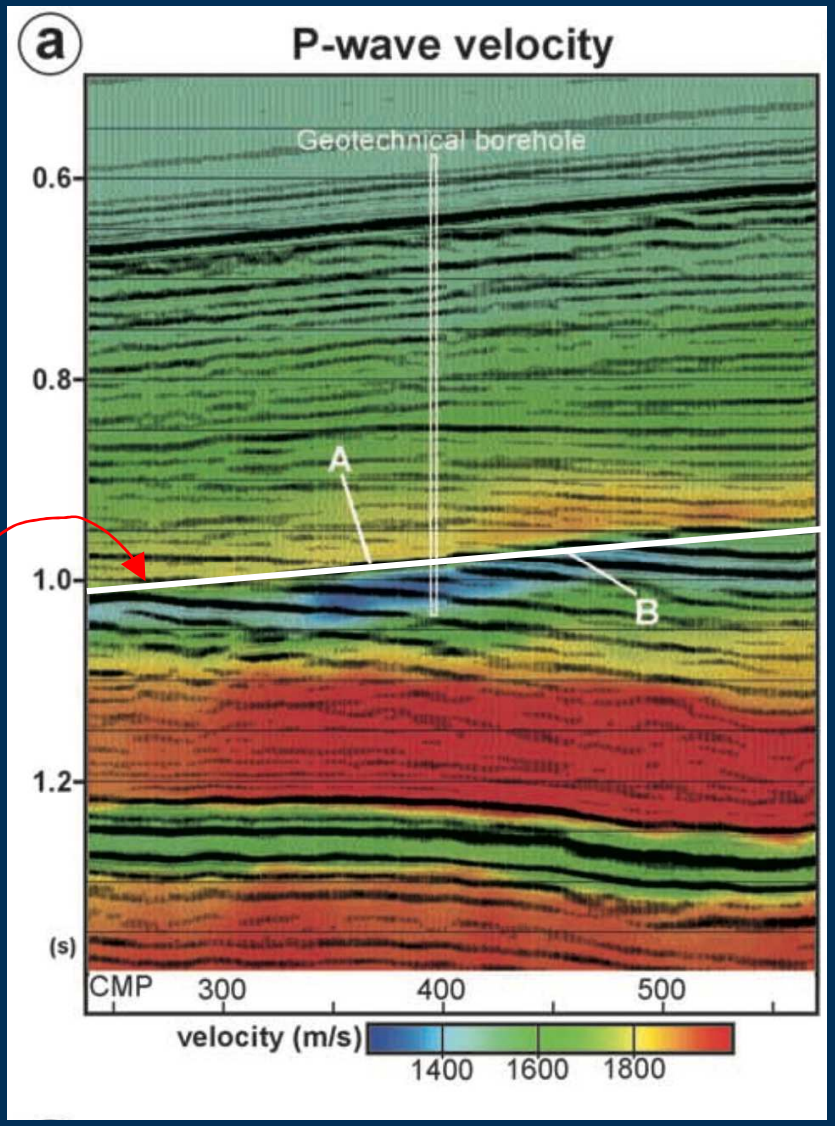


Bunz and Mienert (2004), JGR

Using V_p in the field: Finding regions of high V_p

Storegga slide (offshore Norway)

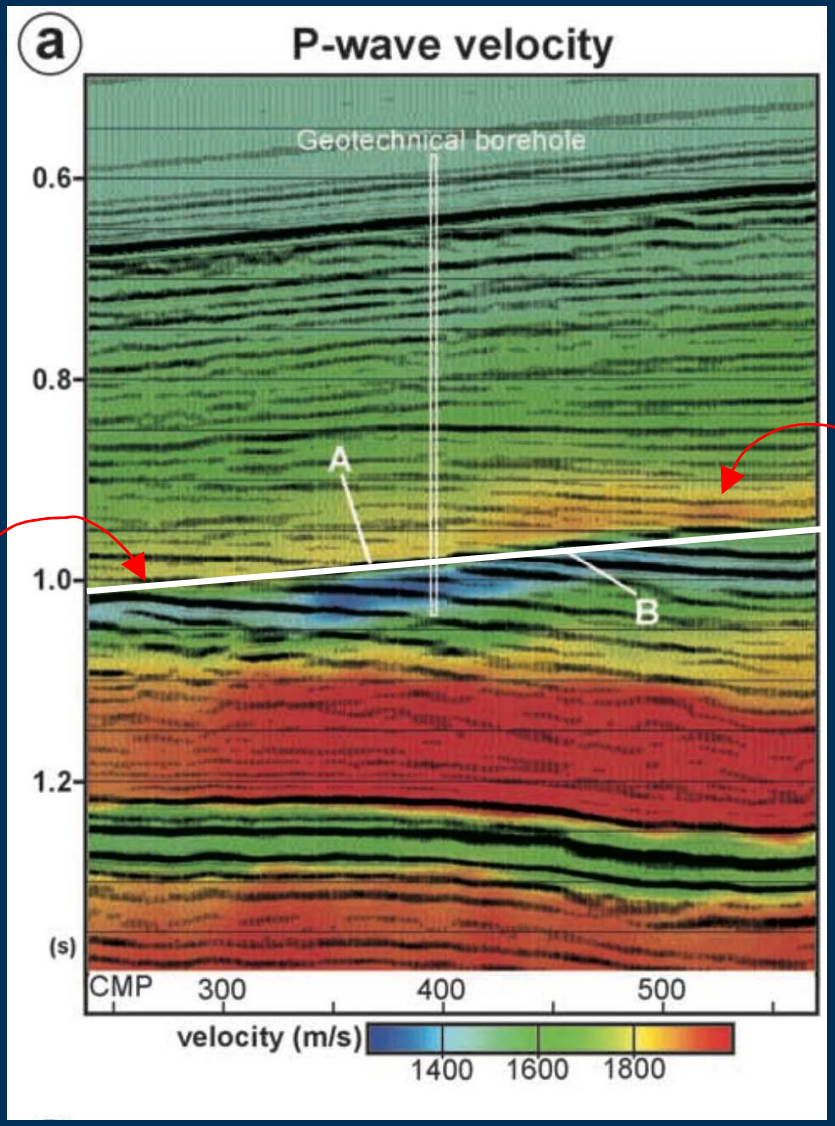
BSR on top of the low V_p section that contains gas



Bunz and Mienert (2004), JGR

Using V_p in the field: Finding regions of high V_p

Storegga slide (offshore Norway)

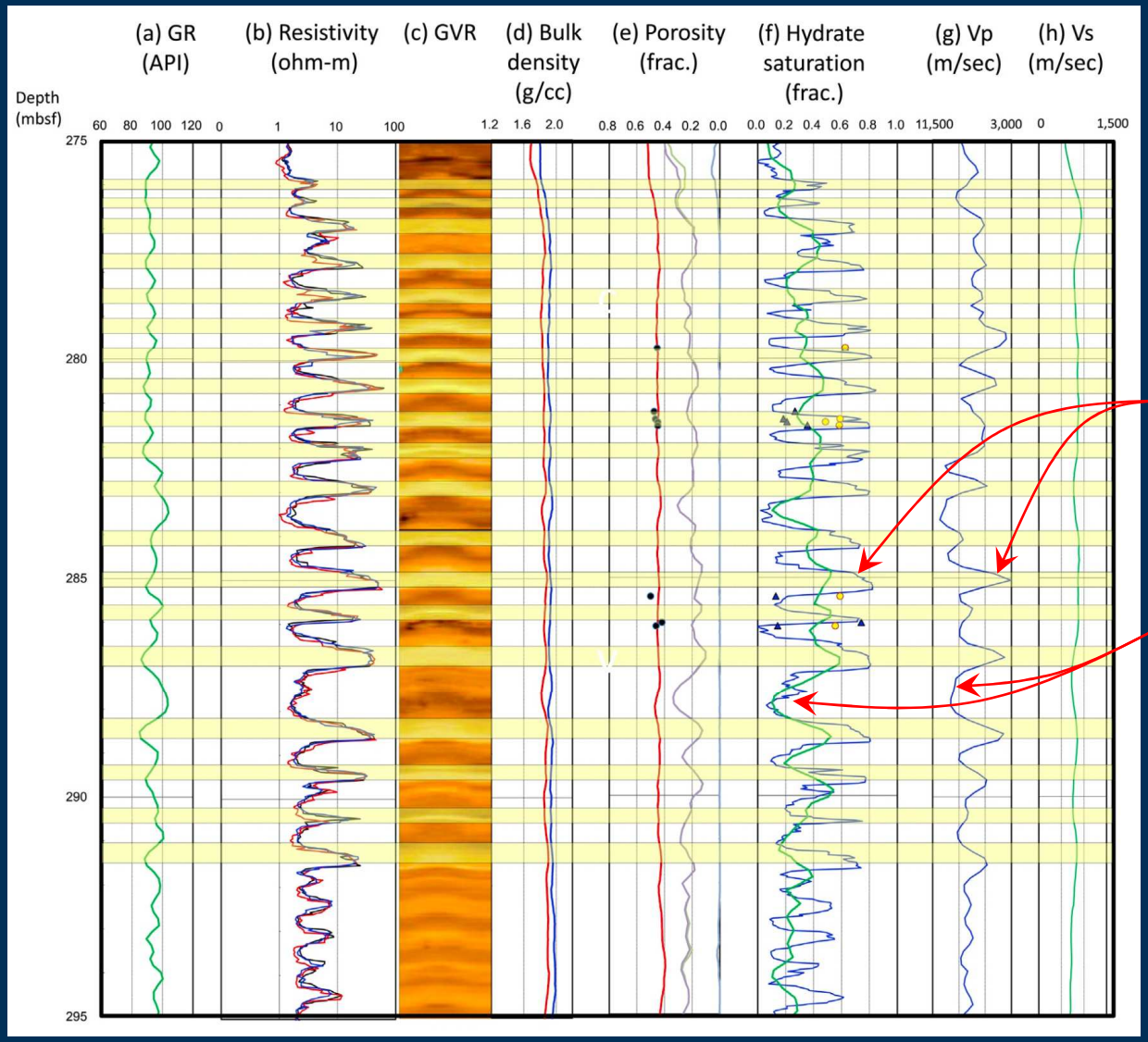


BSR on top of the low V_p section that contains gas

Higher V_p above BSR is due to gas hydrate

Bunz and Mienert (2004), JGR

Using V_p in the field: Finding regions of high V_p



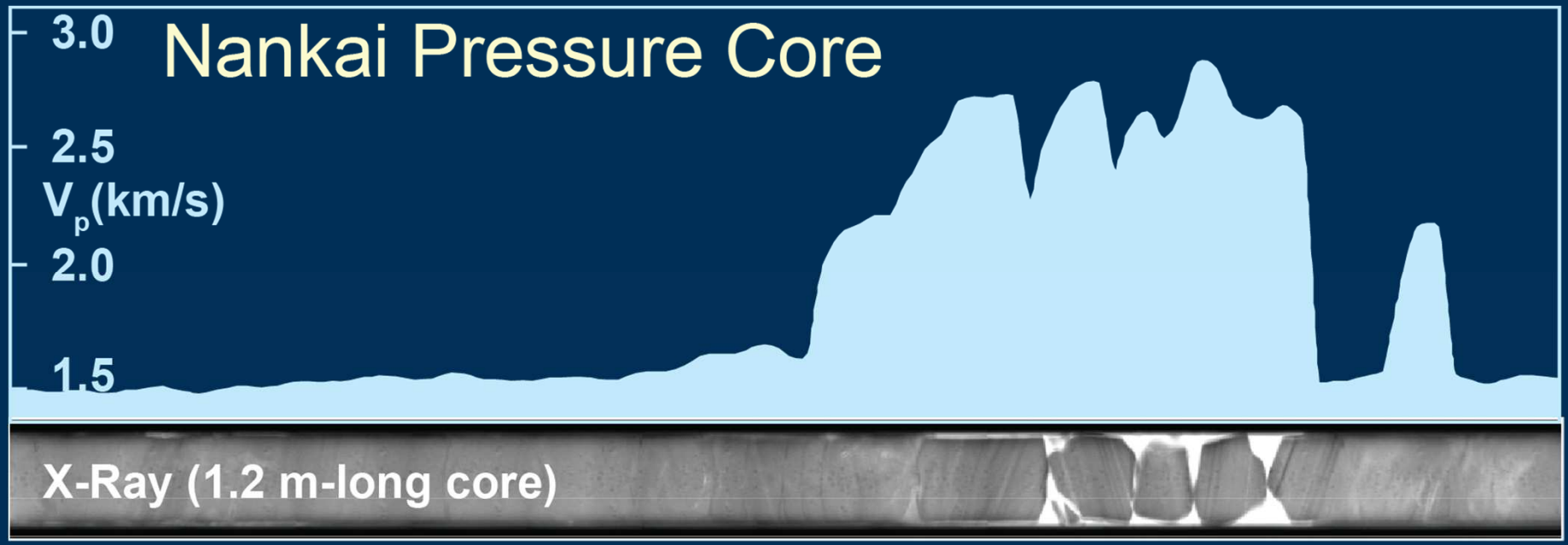
Higher V_p in sands is due to gas hydrate

Lower V_p in muds with no gas hydrate

Nankai Trough (offshore Japan)

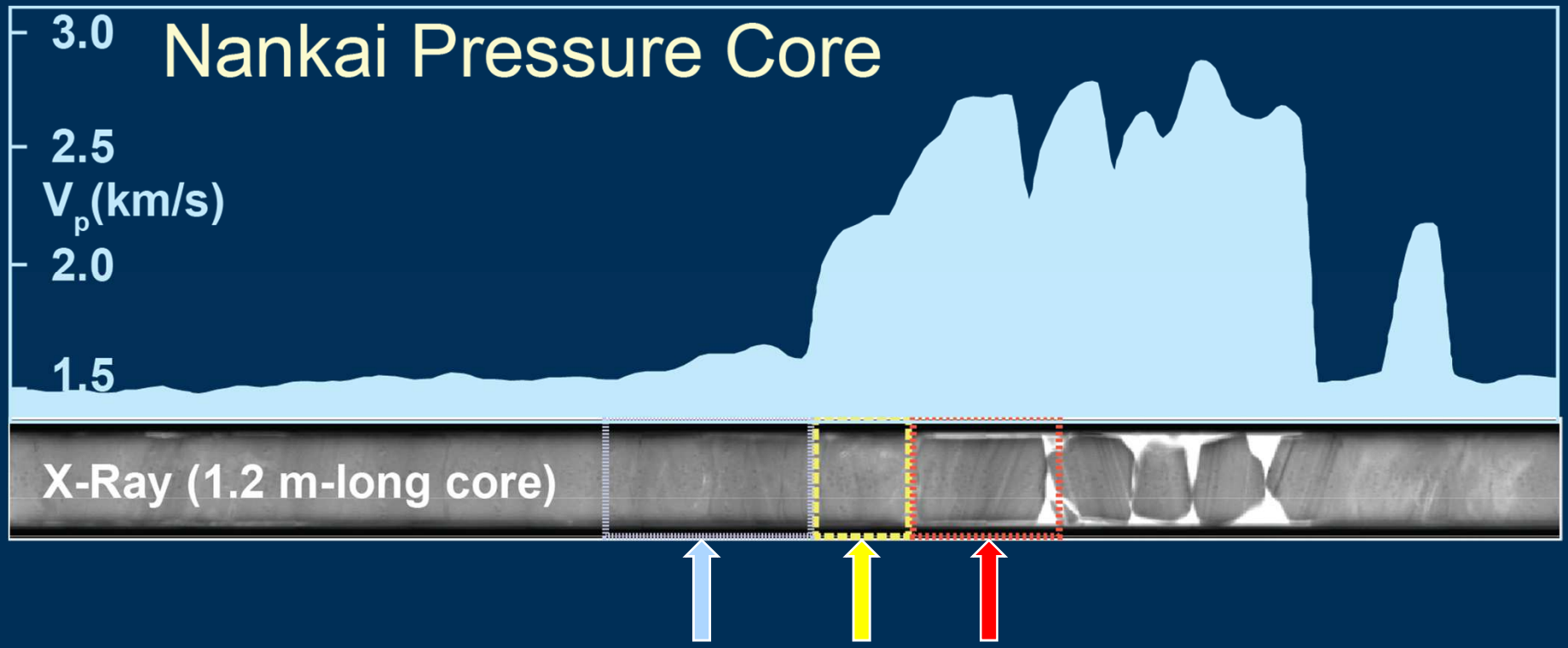
Fujii et al. (2015), MPG

V_p in the lab: identification of hydrate-bearing sediment



Santamarina et al. (2015), Marine and Petroleum Geology

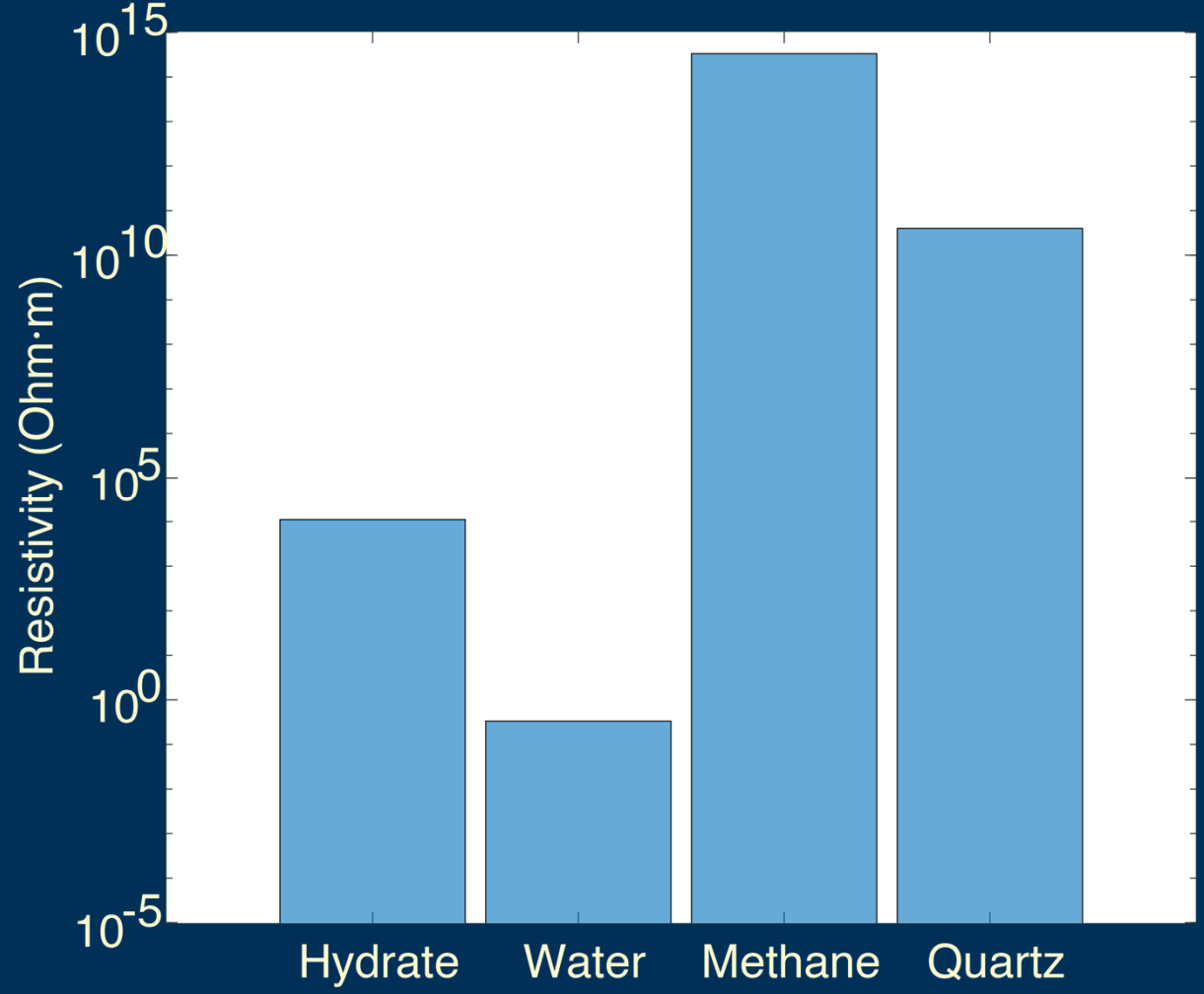
V_p in the lab: identification of hydrate-bearing sediment



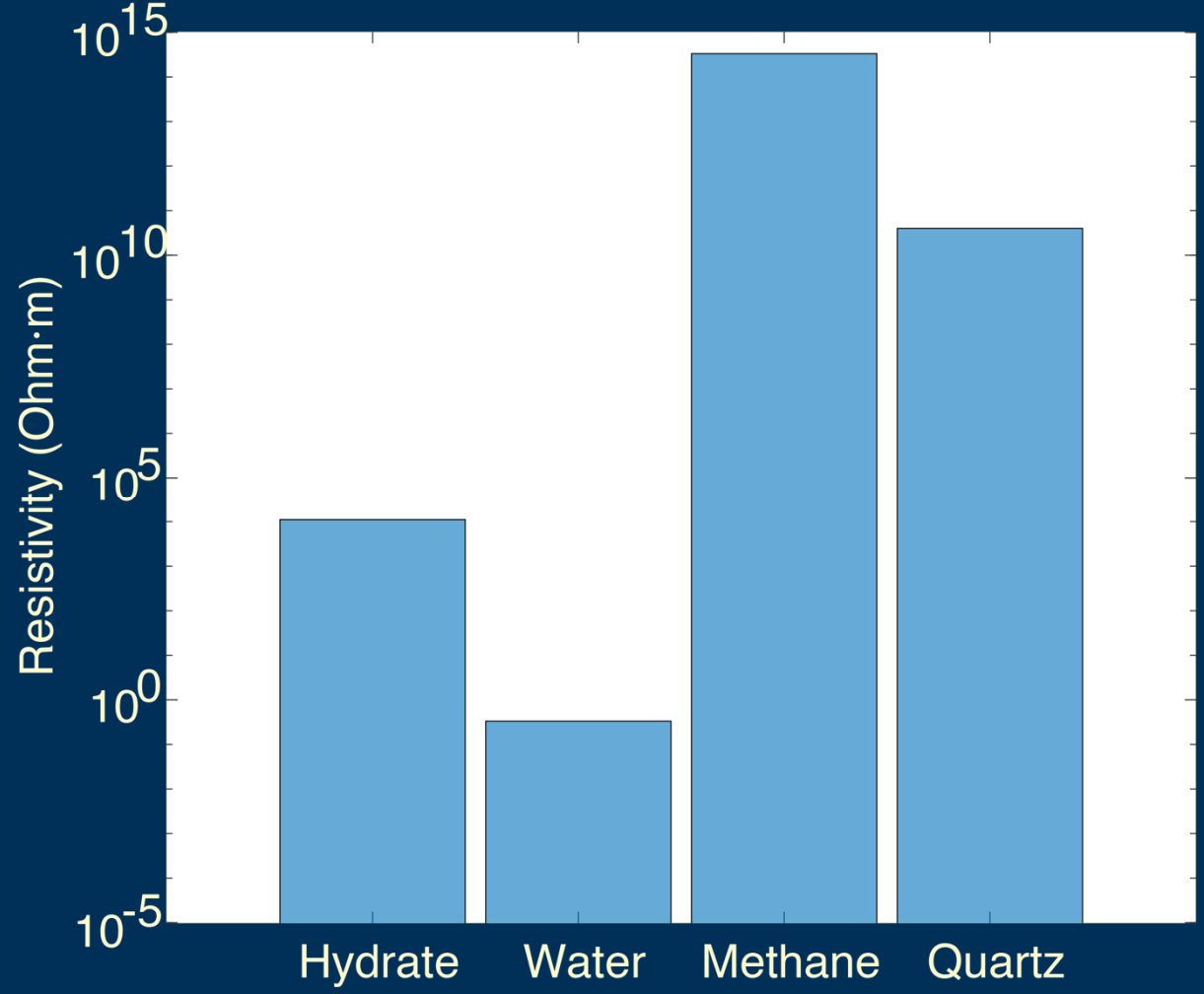
Locations chosen for three types of testing

Santamarina et al. (2015), Marine and Petroleum Geology

Electrical resistivity, *R*



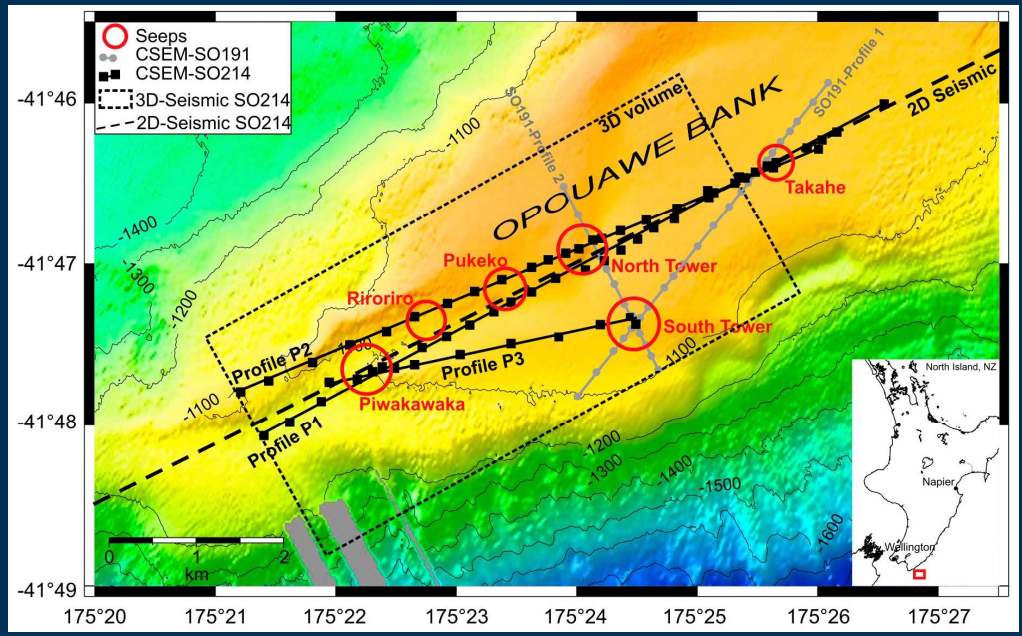
Electrical resistivity, *R*



Everything is an electrical insulator…
except the salty pore water

Electrical resistivity: mapping subsurface insulator distributions

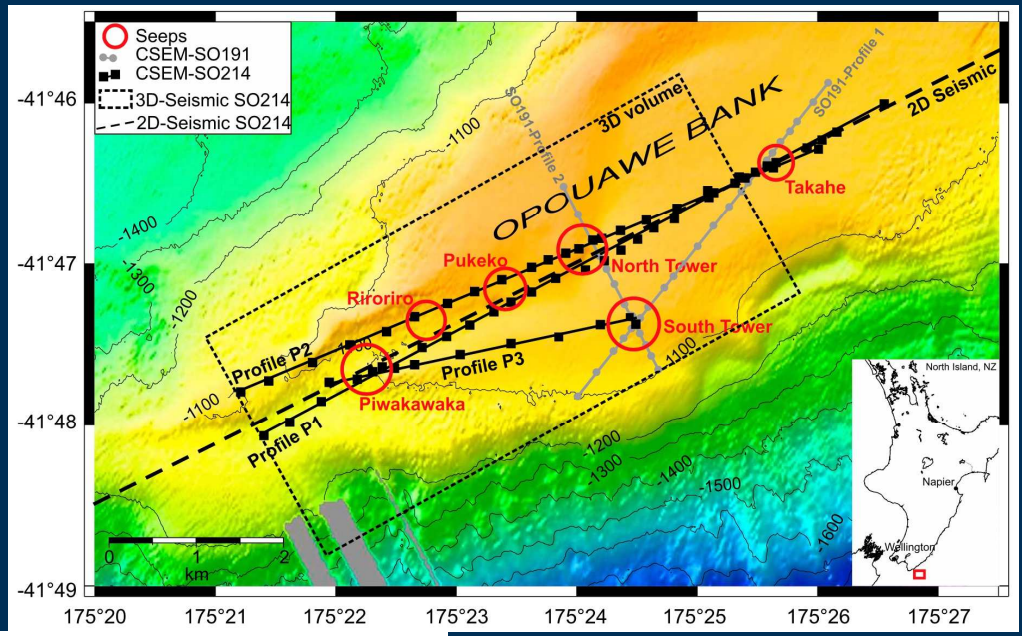
Hikurangi Margin (offshore New Zealand)

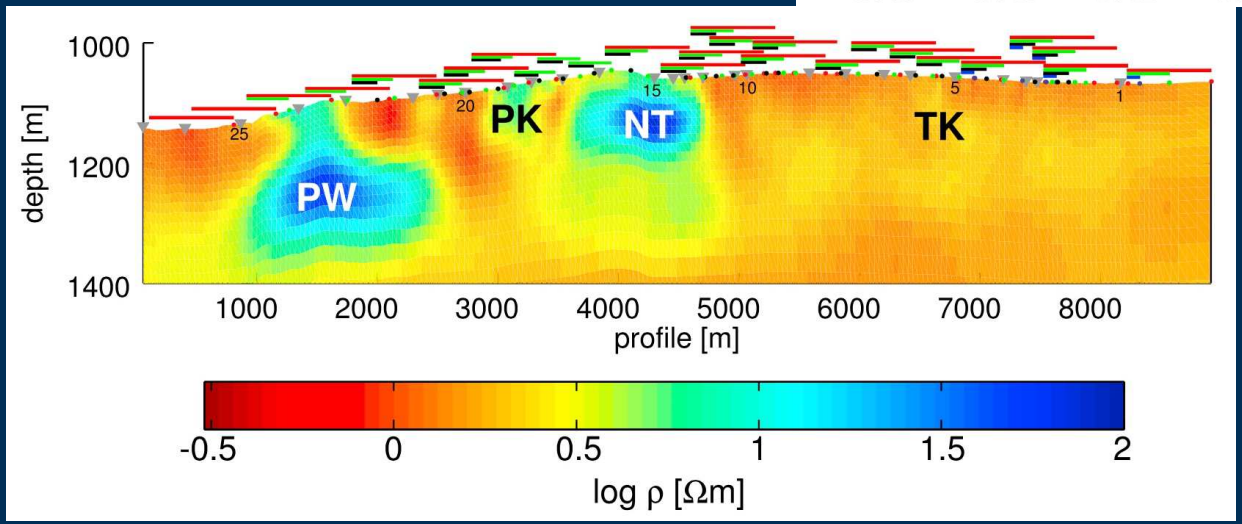


Schwalenberg et al. (2017), JGR

Electrical resistivity: mapping subsurface insulator distributions

Hikurangi Margin (offshore New Zealand)

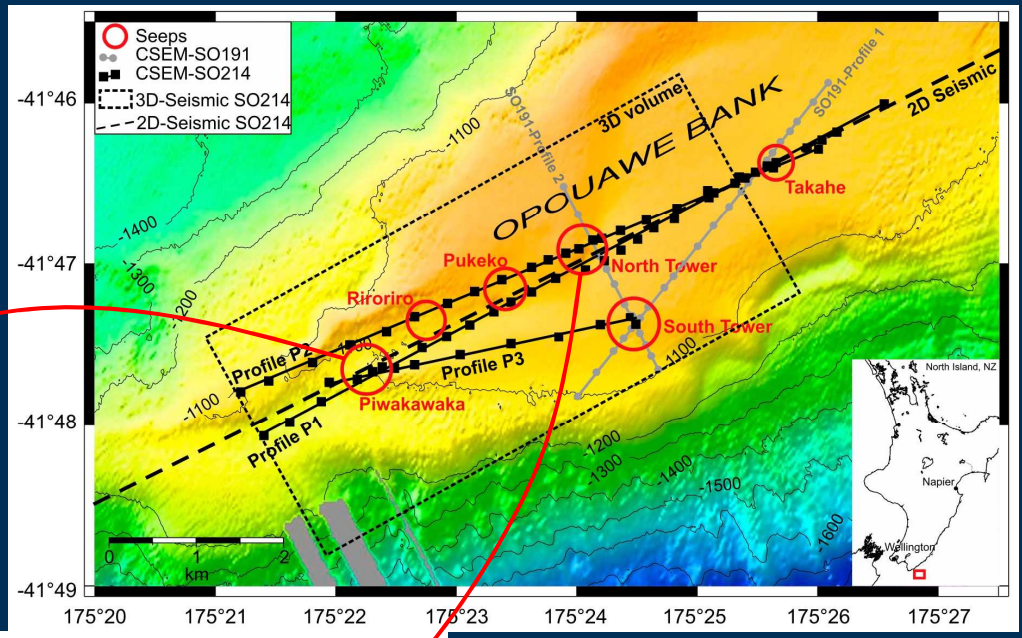


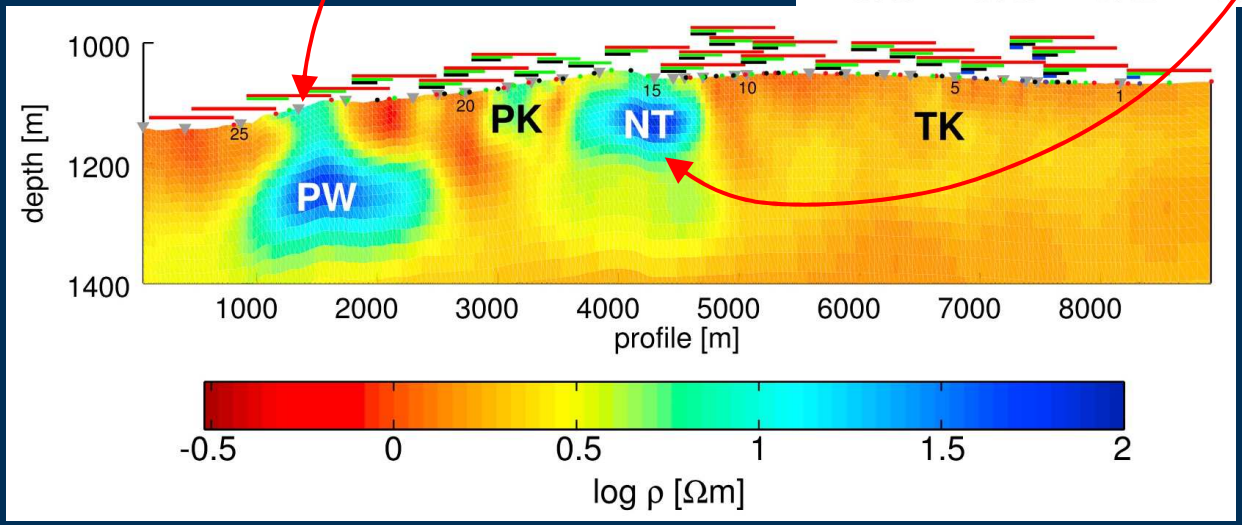


Schwalenberg et al. (2017), JGR

Electrical resistivity: mapping subsurface insulator distributions

Hikurangi Margin (offshore New Zealand)

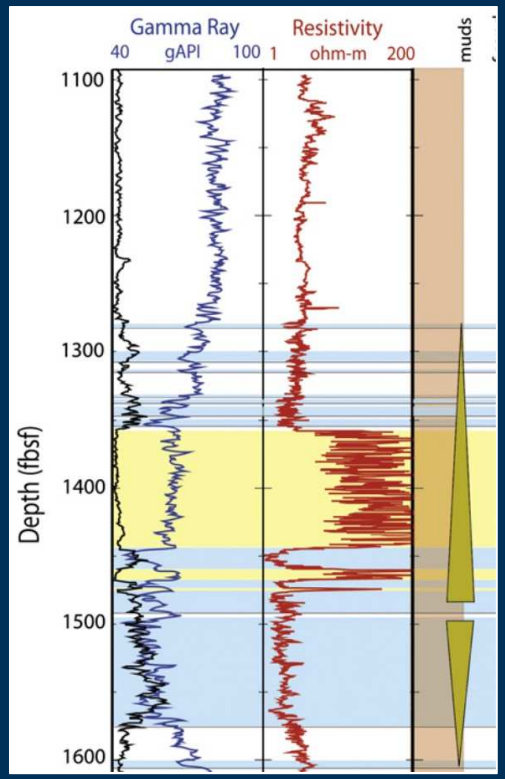




Schwalenberg et al. (2017), JGR

Electrical resistivity: mapping layers in a borehole

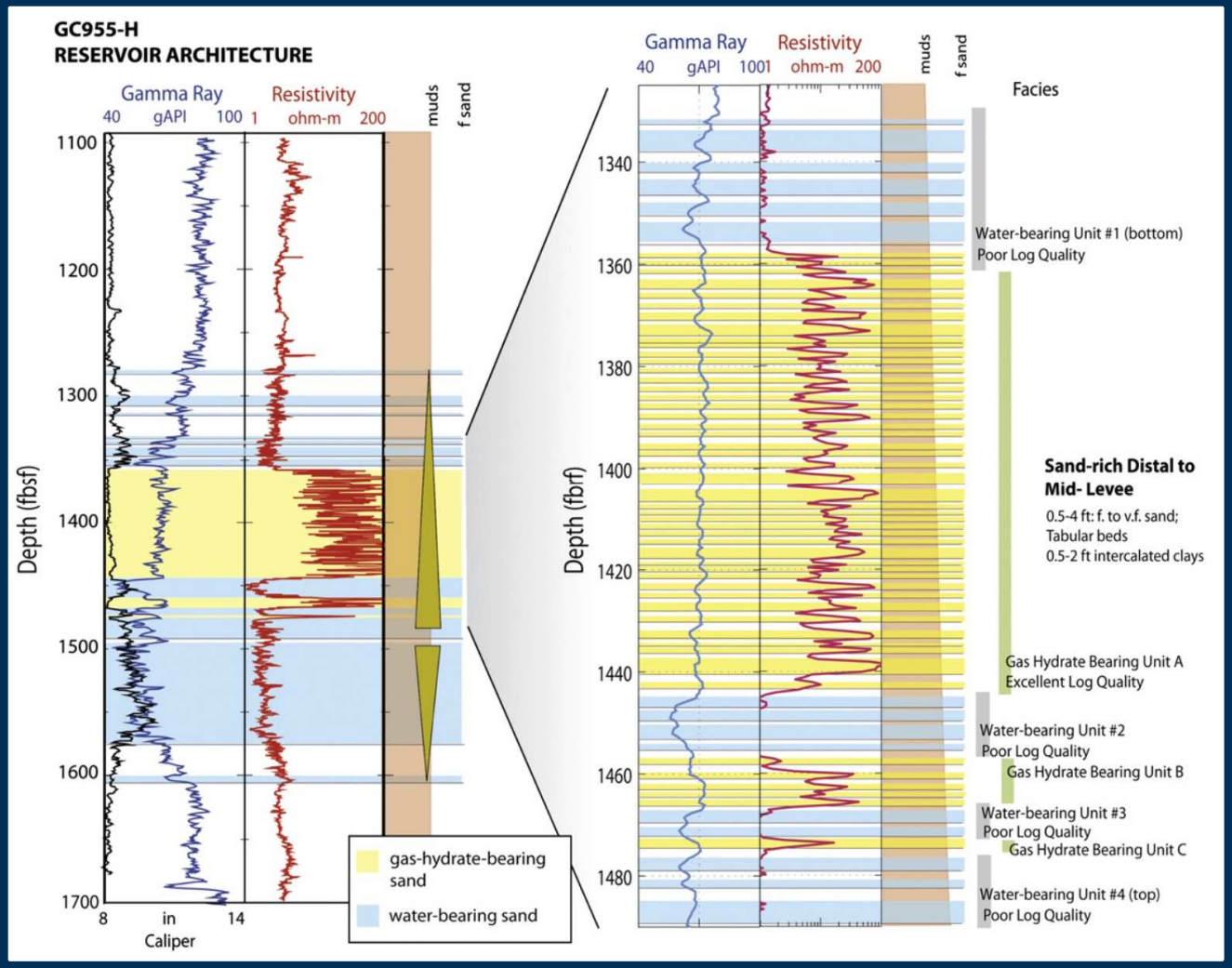
Gulf of Mexico (offshore USA)



Boswell et al. (2012b) Marine and Petroleum Geology

Electrical resistivity: mapping layers in a borehole

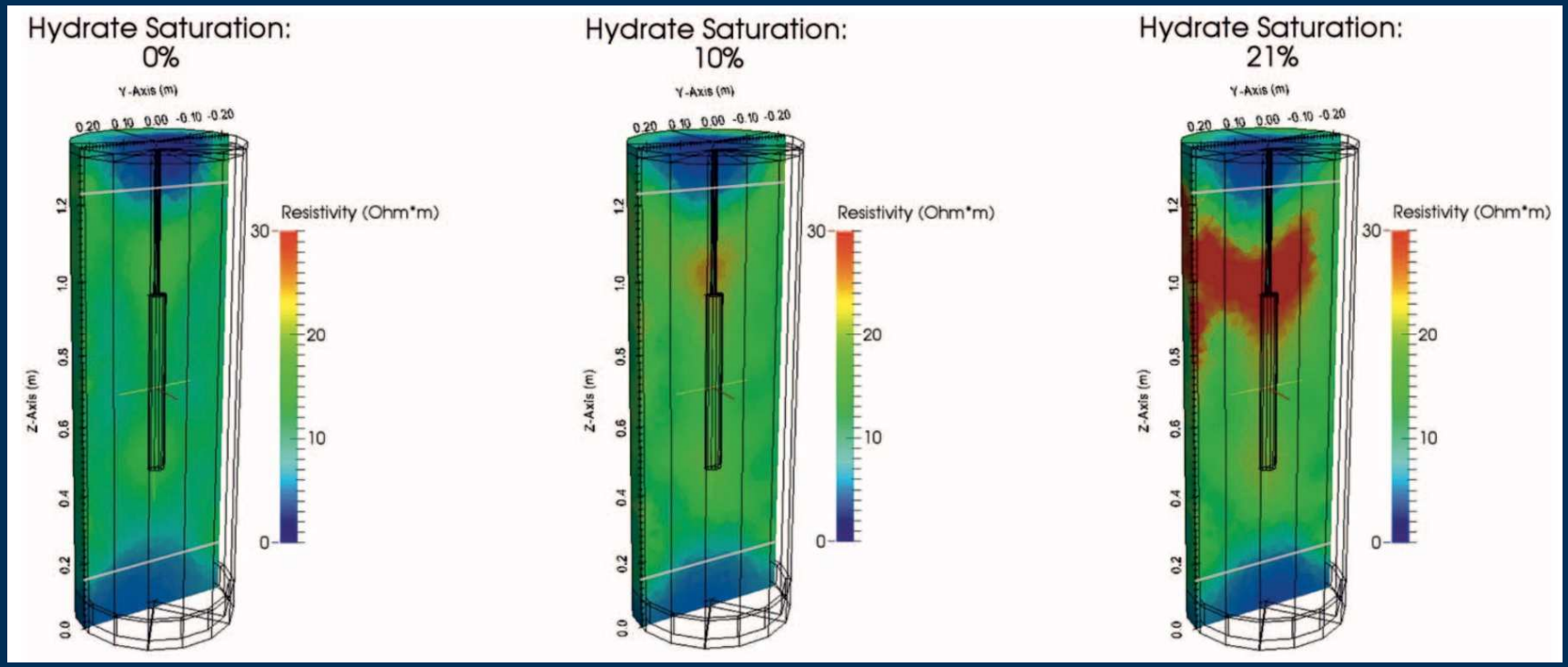
Gulf of Mexico (offshore USA)



Boswell et al. (2012b) Marine and Petroleum Geology

Electrical resistivity: mapping hydrate in the laboratory

Gas hydrate being grown from methane dissolved in circulating water

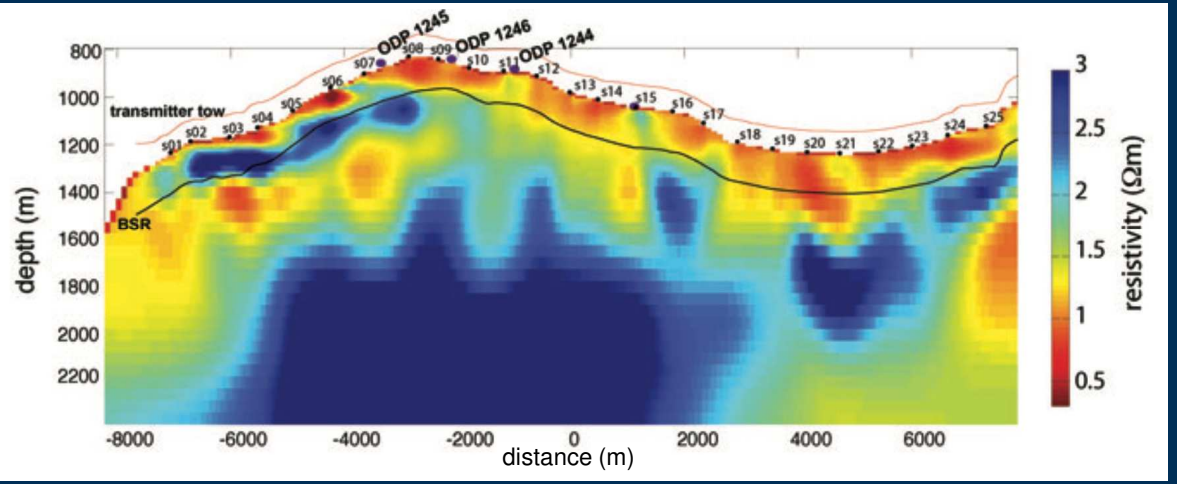


Time

Priegnitz et al. (2013), Rev. Sci. Inst.

What is the insulator? Gas or hydrate?

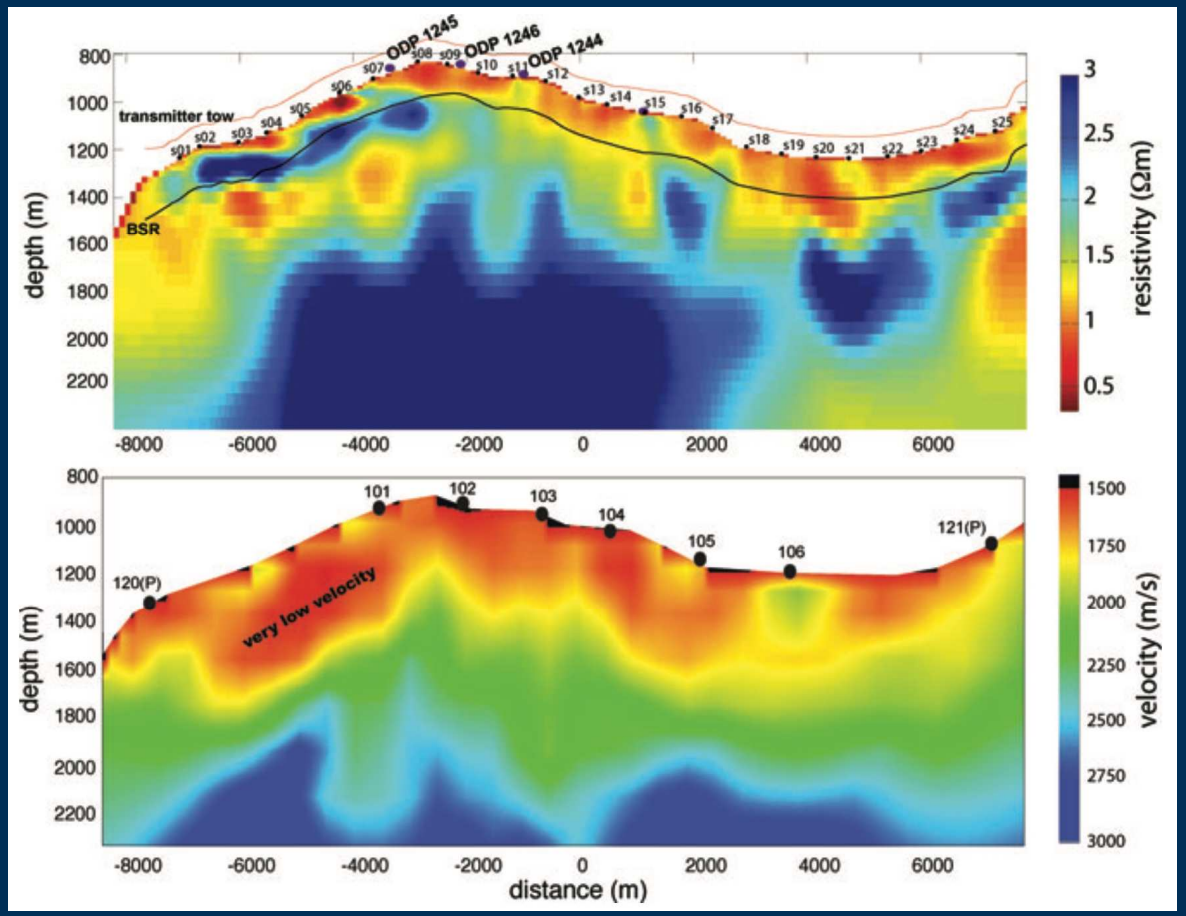
Hydrate Ridge (offshore USA)



Weitemeyer et al. (2011), GJI

Resistivity + Velocity can distinguish between gas and hydrate

Hydrate Ridge (offshore USA)

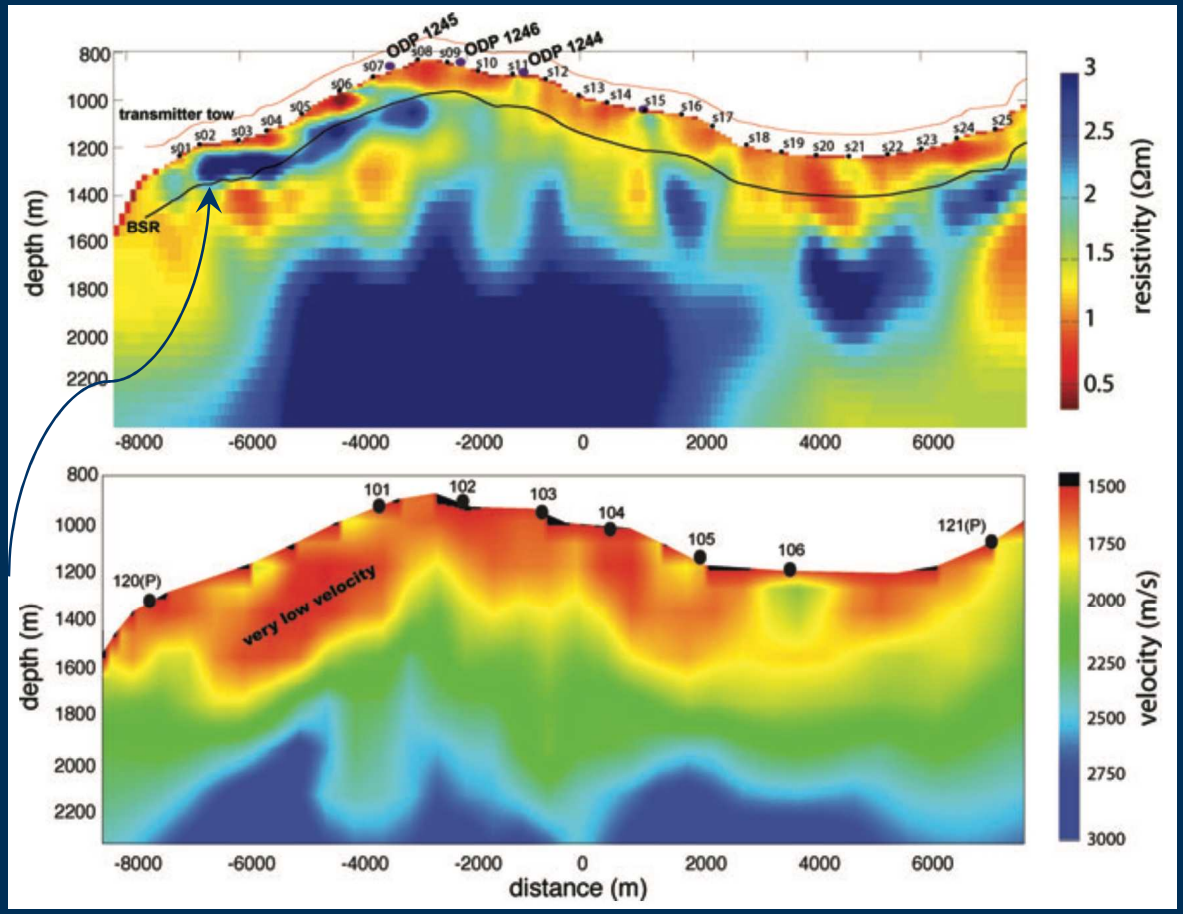


Weitemeyer et al. (2011), GJI

Resistivity + Velocity can distinguish between gas and hydrate

Hydrate Ridge (offshore USA)

High resistance

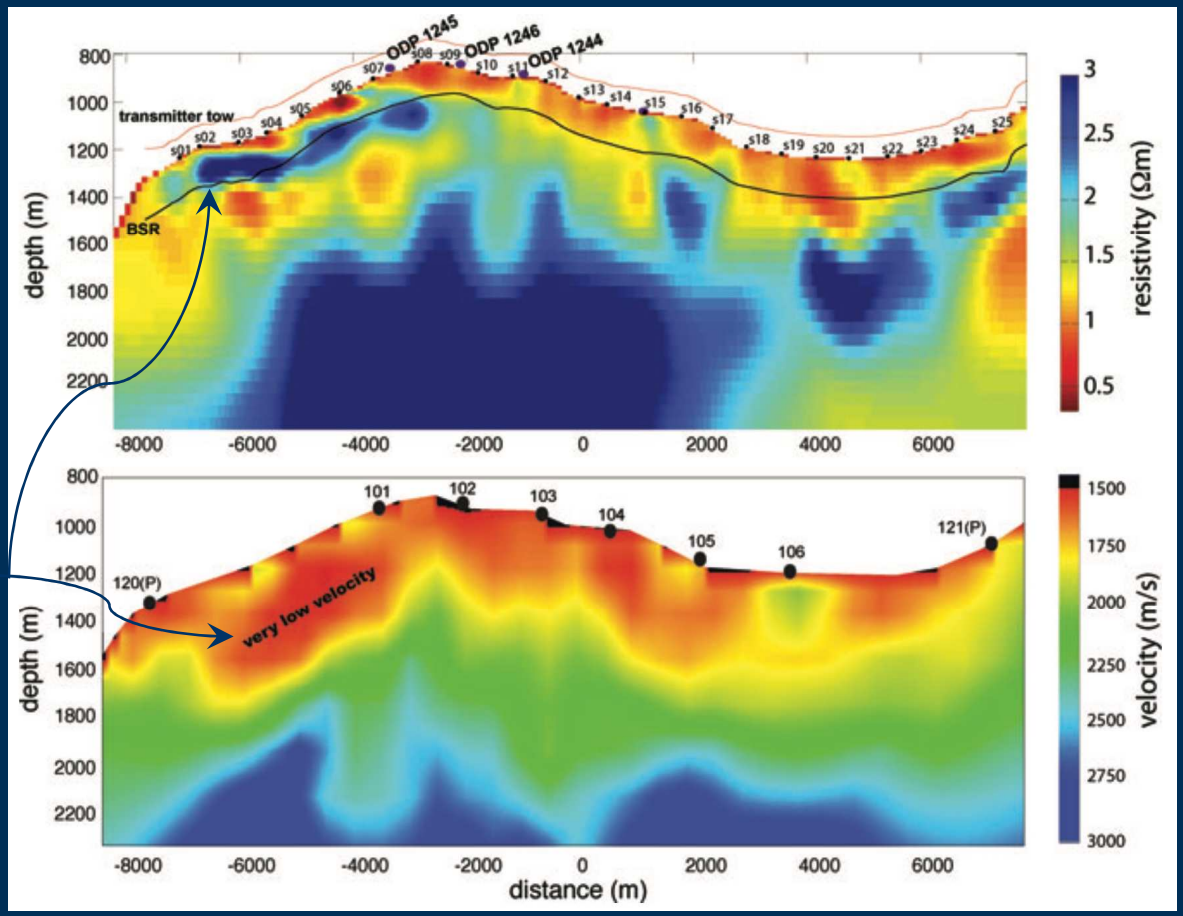


Weitemeyer et al. (2011), GJI

Resistivity + Velocity can distinguish between gas and hydrate

Hydrate Ridge (offshore USA)

High resistance
+ low velocity

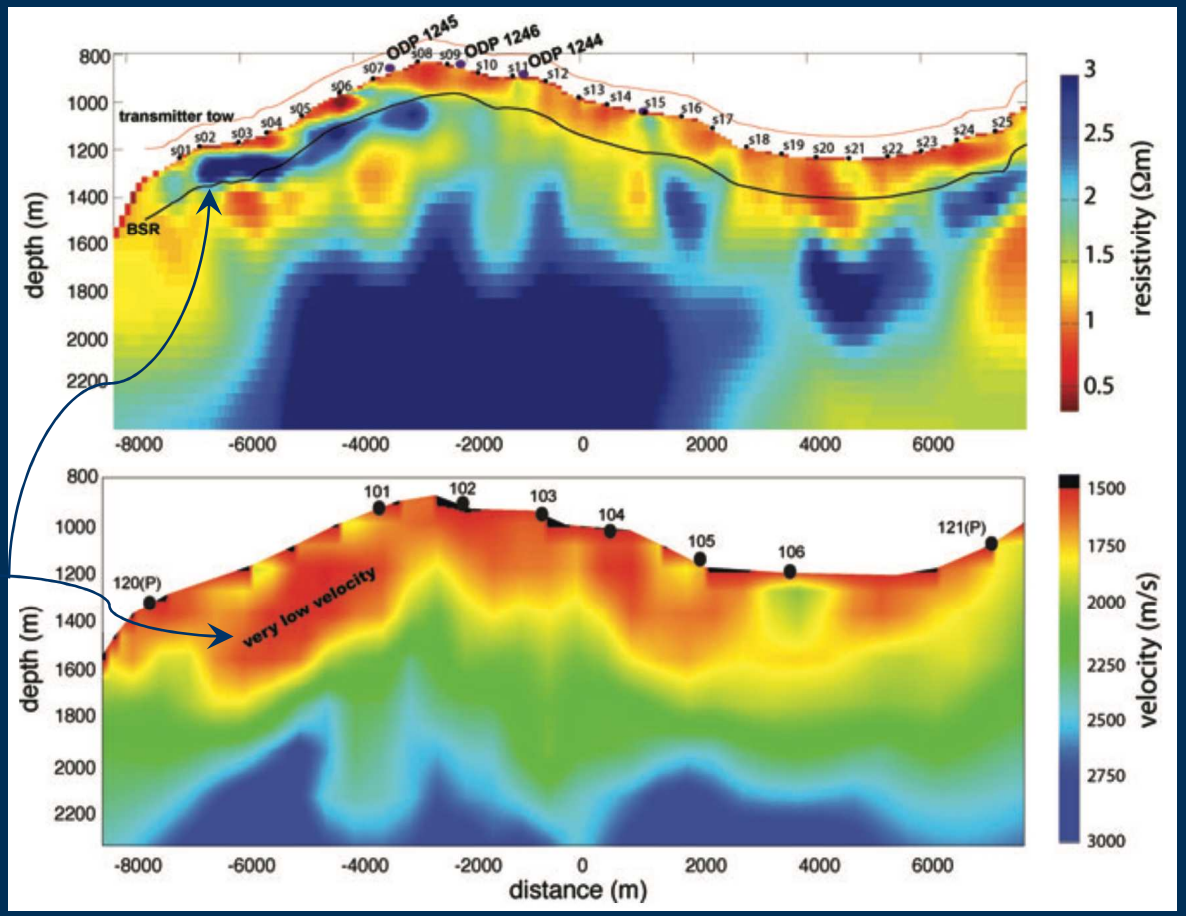


Weitemeyer et al. (2011), GJI

Resistivity + Velocity can distinguish between gas and hydrate

Hydrate Ridge (offshore USA)

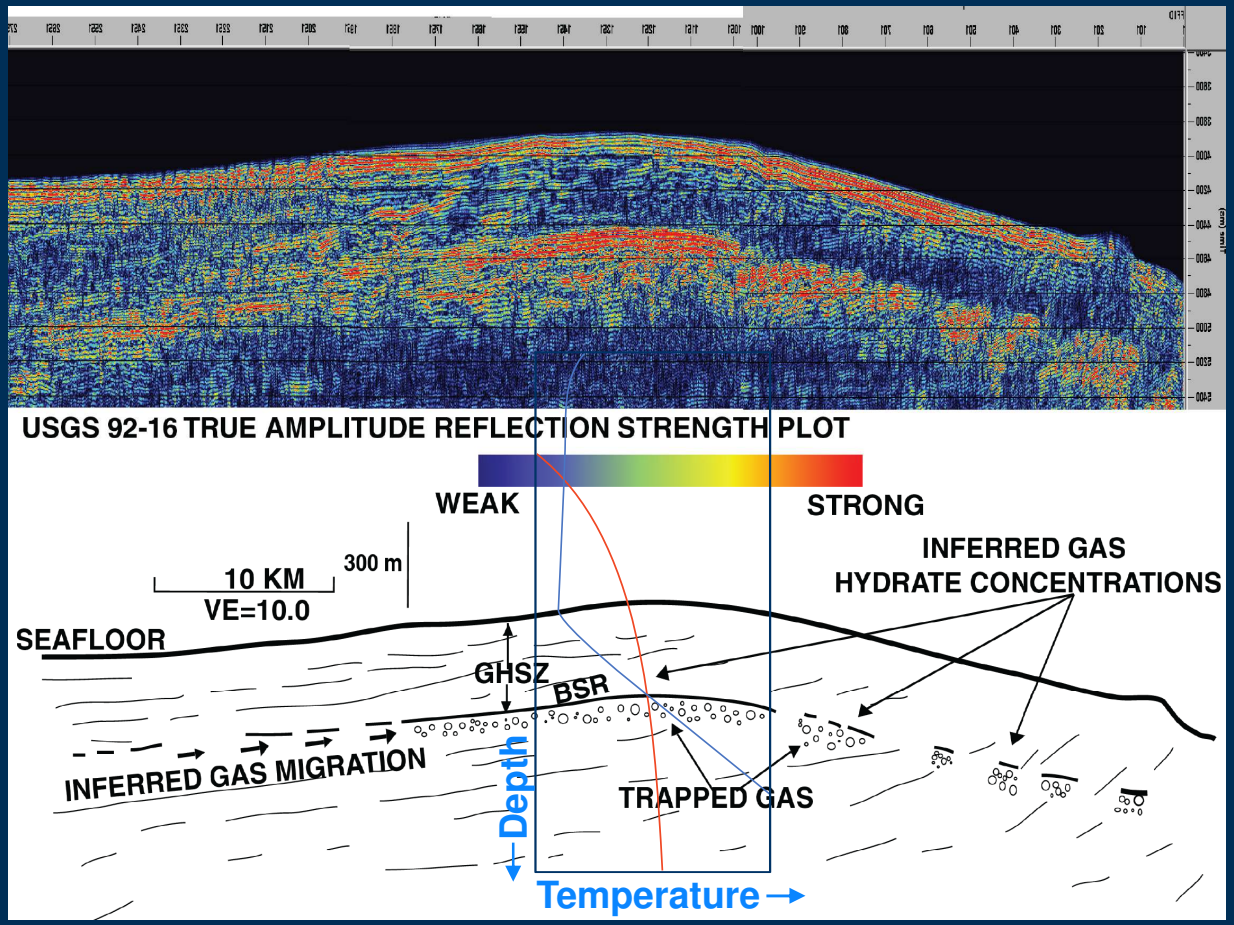
High resistance + low velocity gas



Weitemeyer et al. (2011), GJI

Using the BSR to guess the maximum hydrate depth

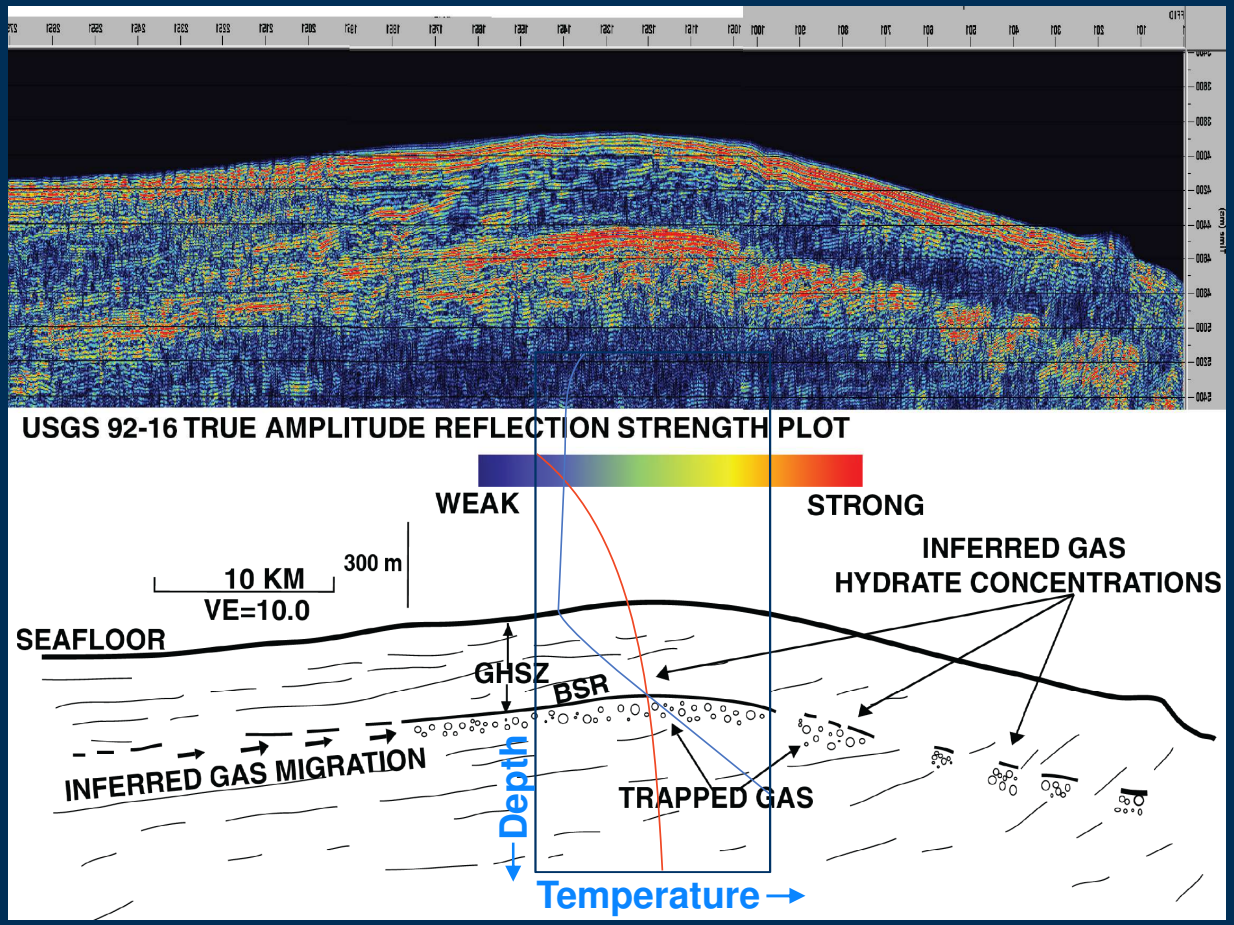
Blake Ridge (offshore USA)



Max and Dillon (1998), J. Petroleum Geology

Using the BSR to guess the maximum hydrate depth

Blake Ridge (offshore USA)



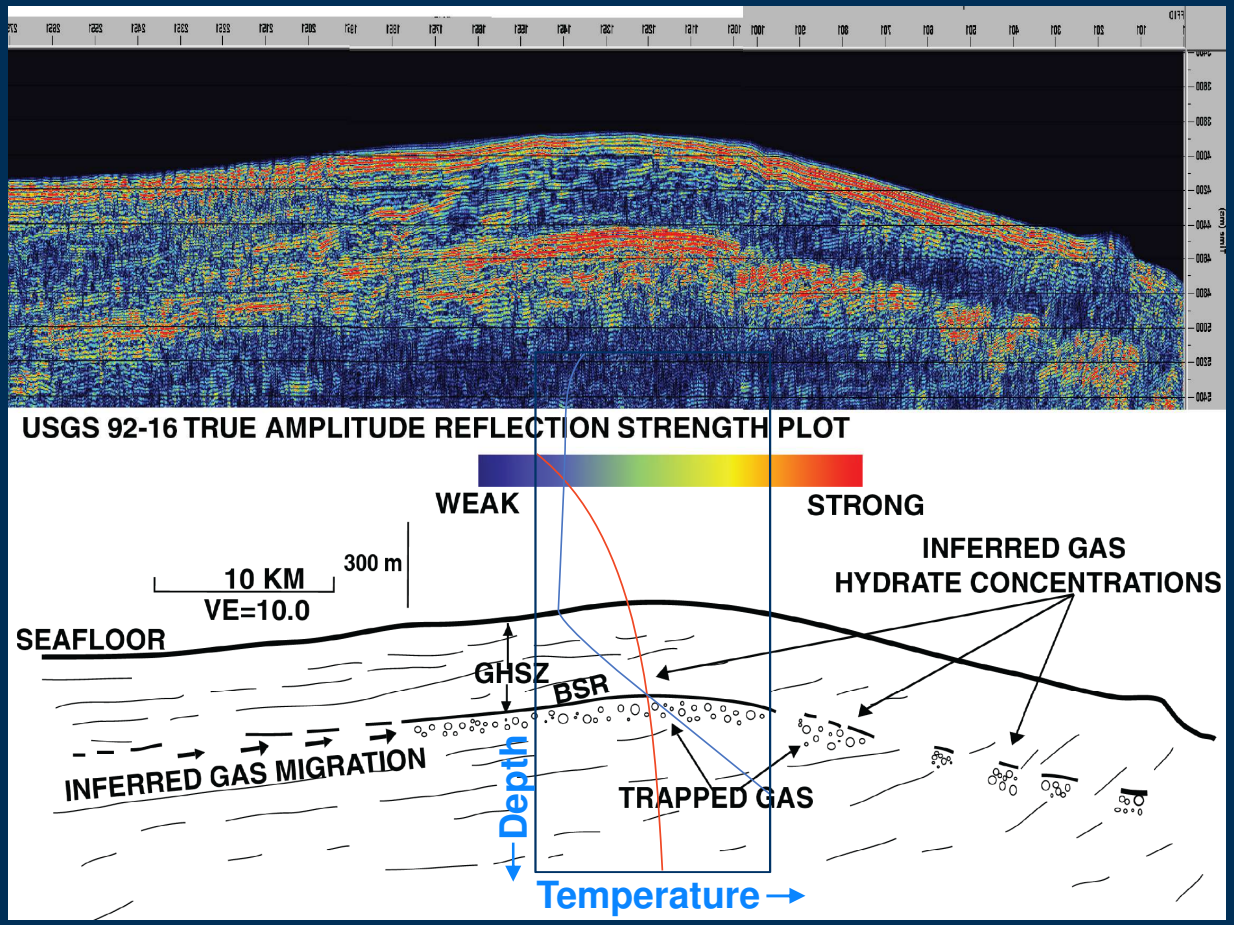
Need:

- Bottom Water Temperature
- Geothermal Gradient

Max and Dillon (1998), J. Petroleum Geology

Using the BSR to guess the maximum hydrate depth

Blake Ridge (offshore USA)

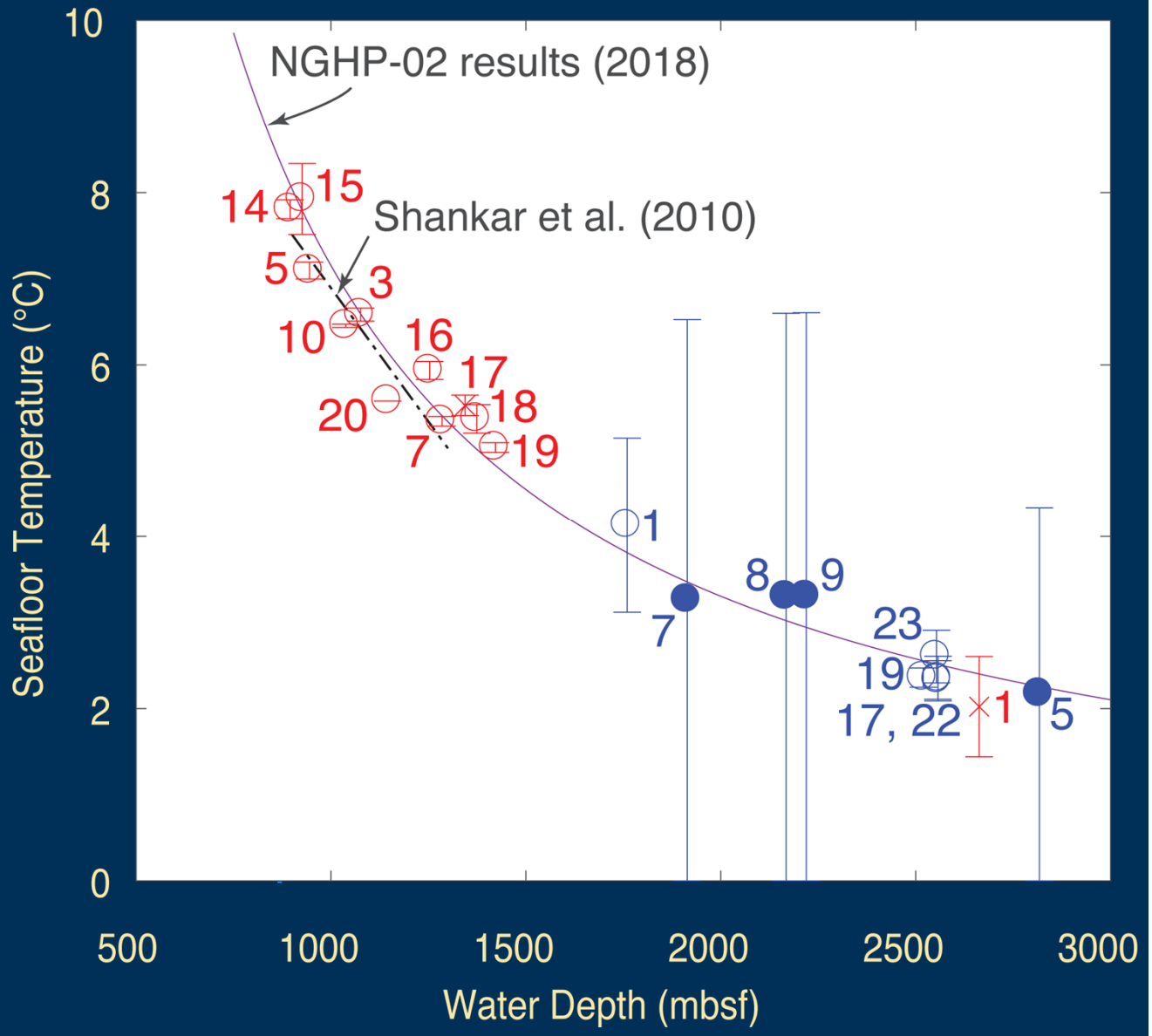


Need:

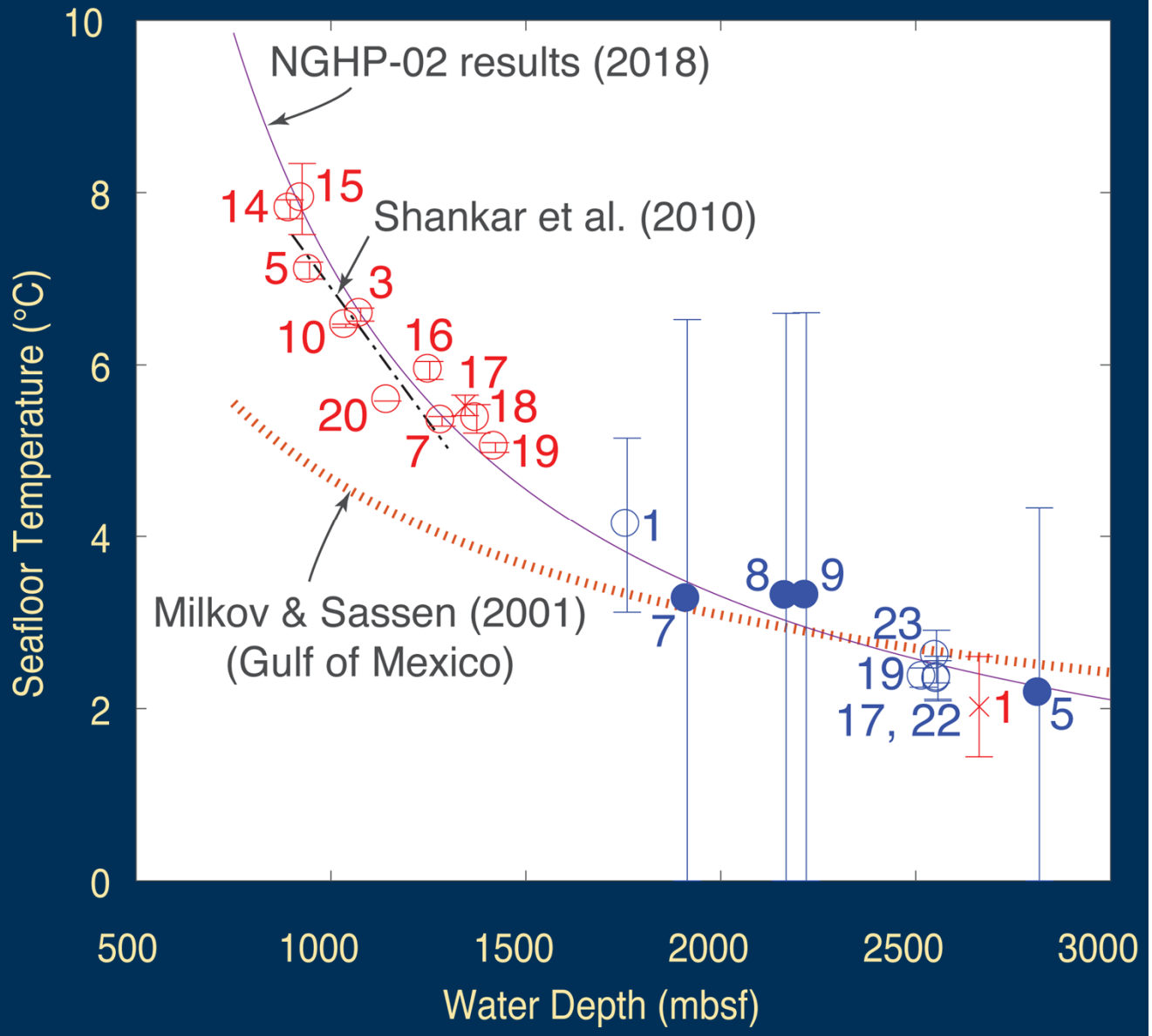
- Bottom Water Temperature
- Geothermal Gradient
- Stability Curve

Max and Dillon (1998), J. Petroleum Geology

Seafloor temperature dependence on water depth

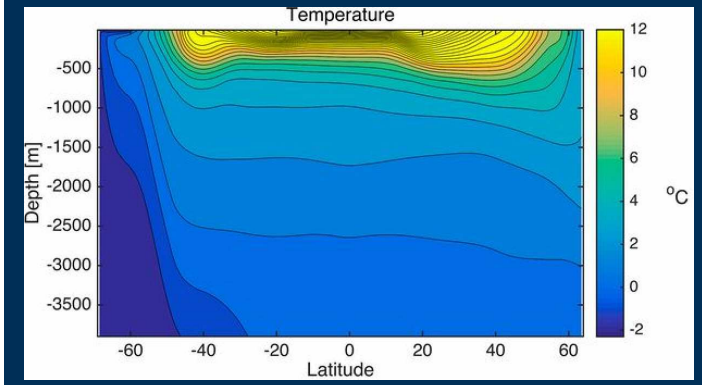


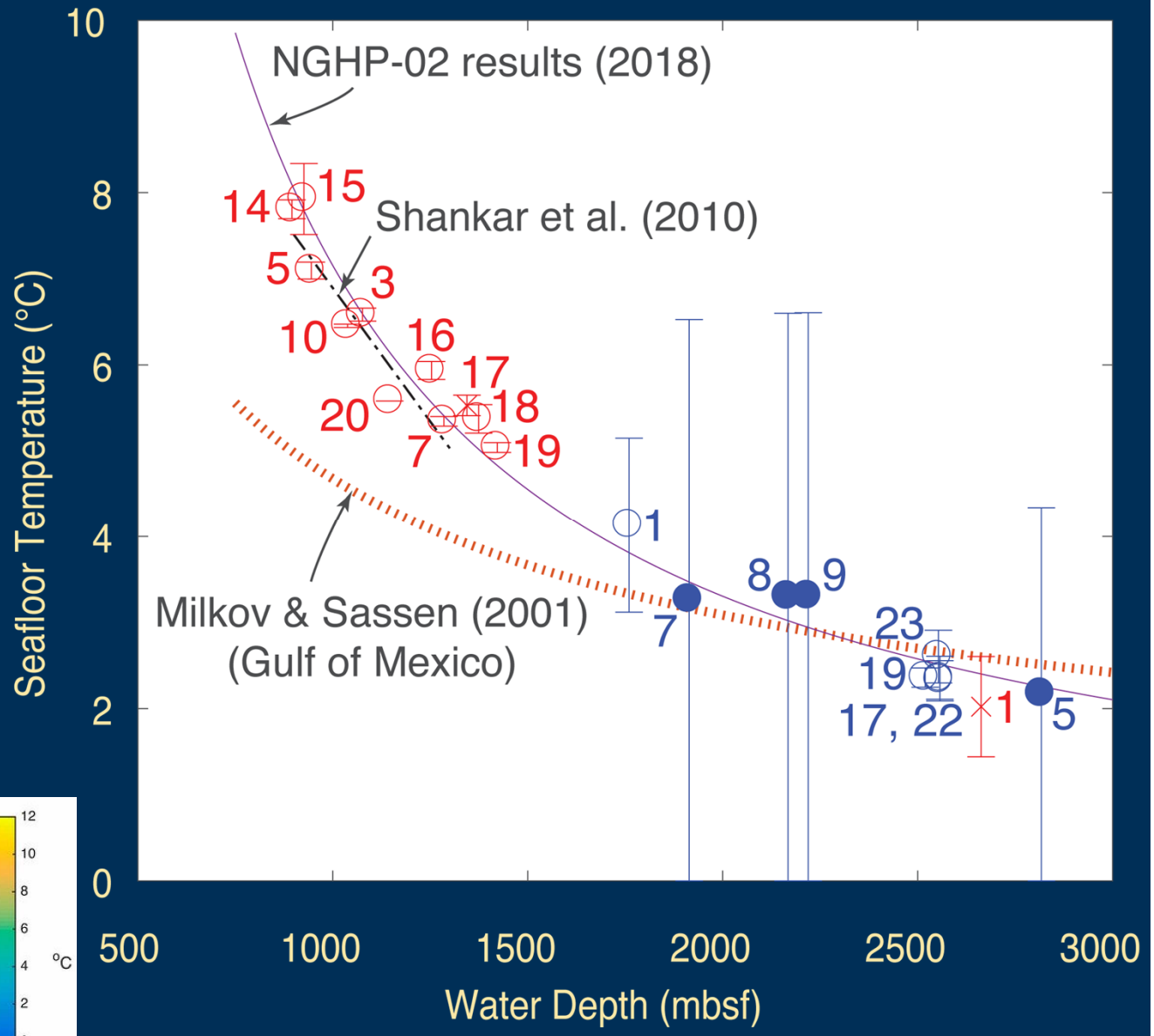
Seafloor temperature dependence on water depth



Seafloor temperature dependence on water depth

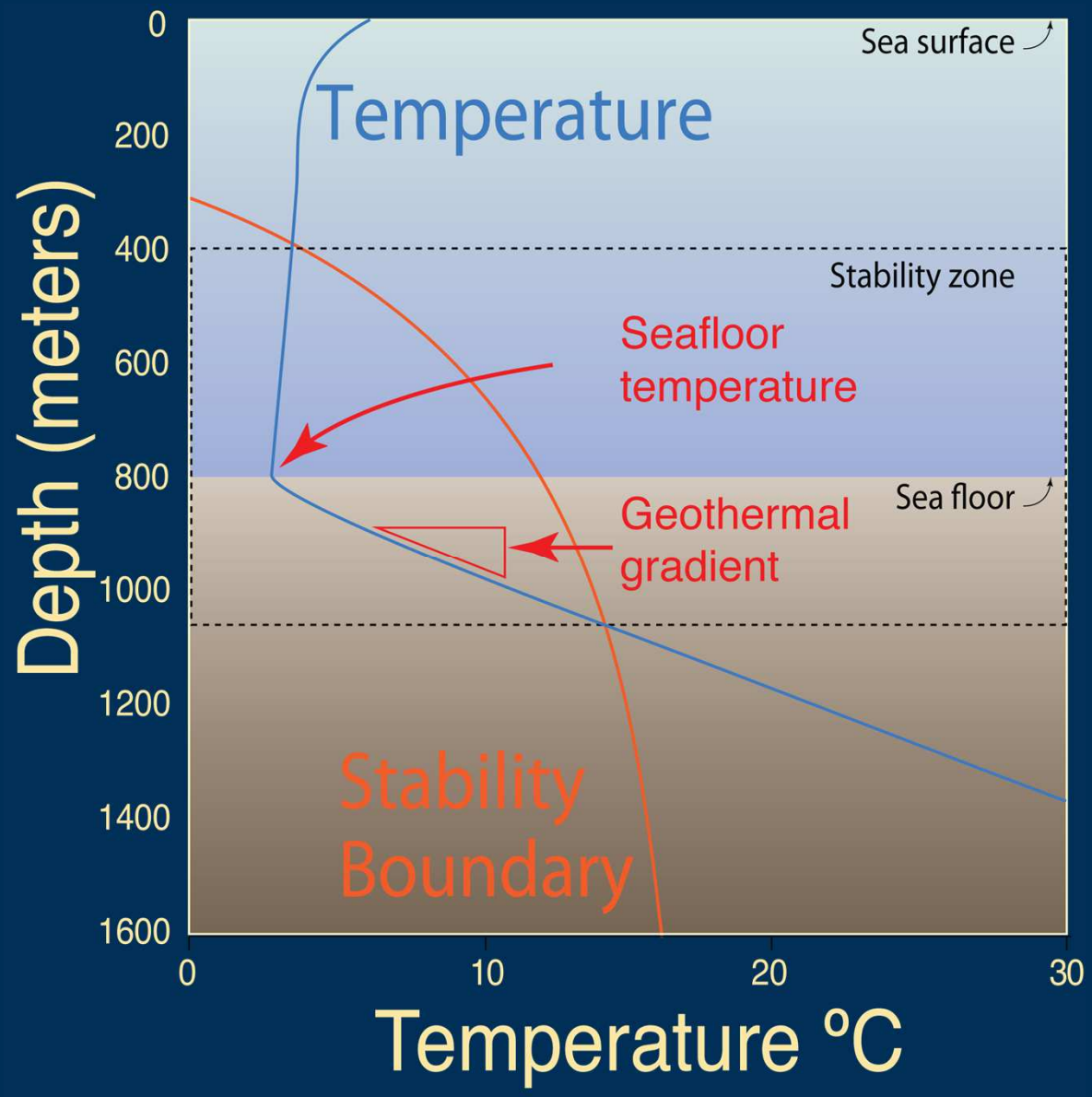
Cold, salty water sinks and spreads out



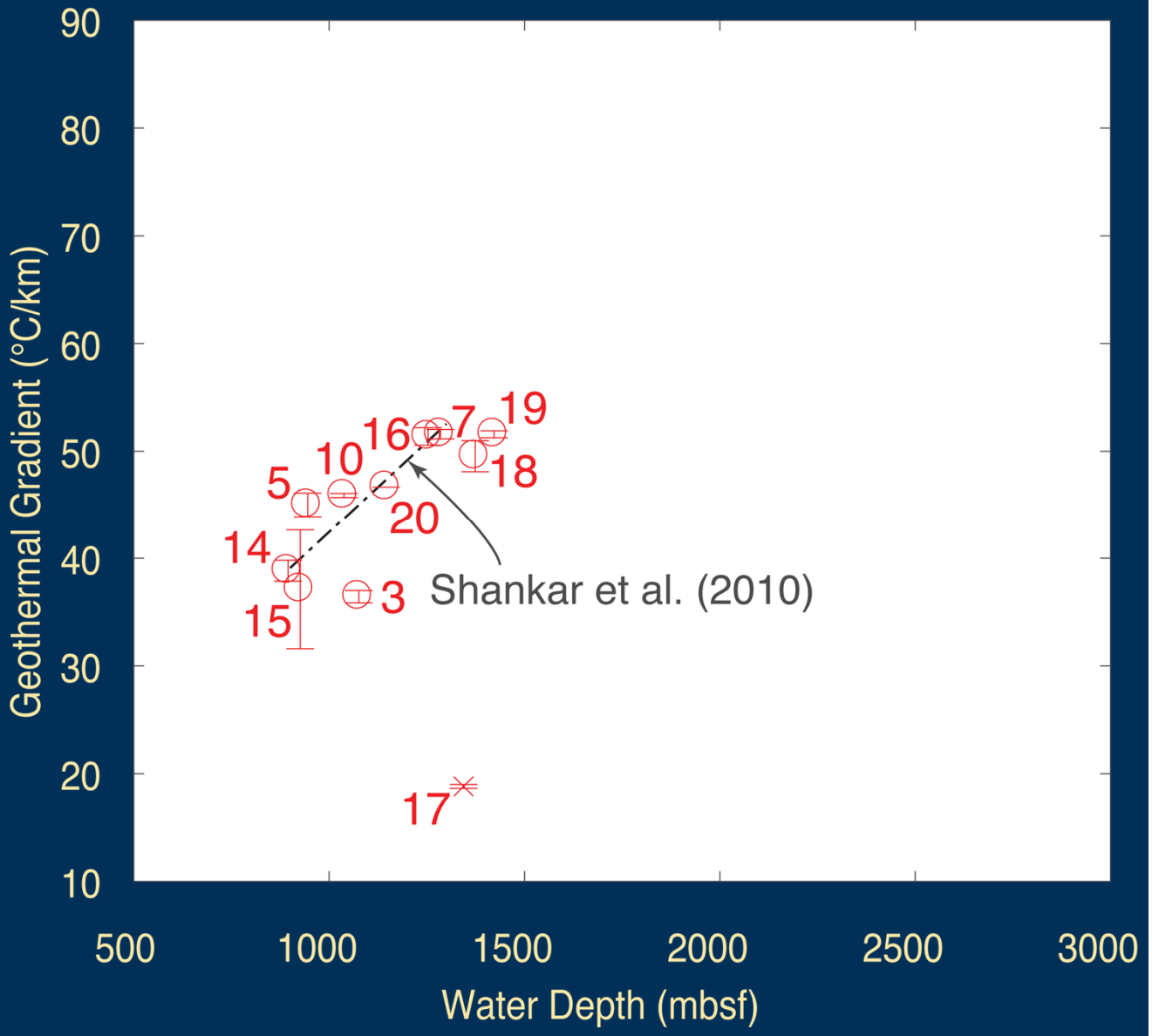


Jansen (2017), PNAS

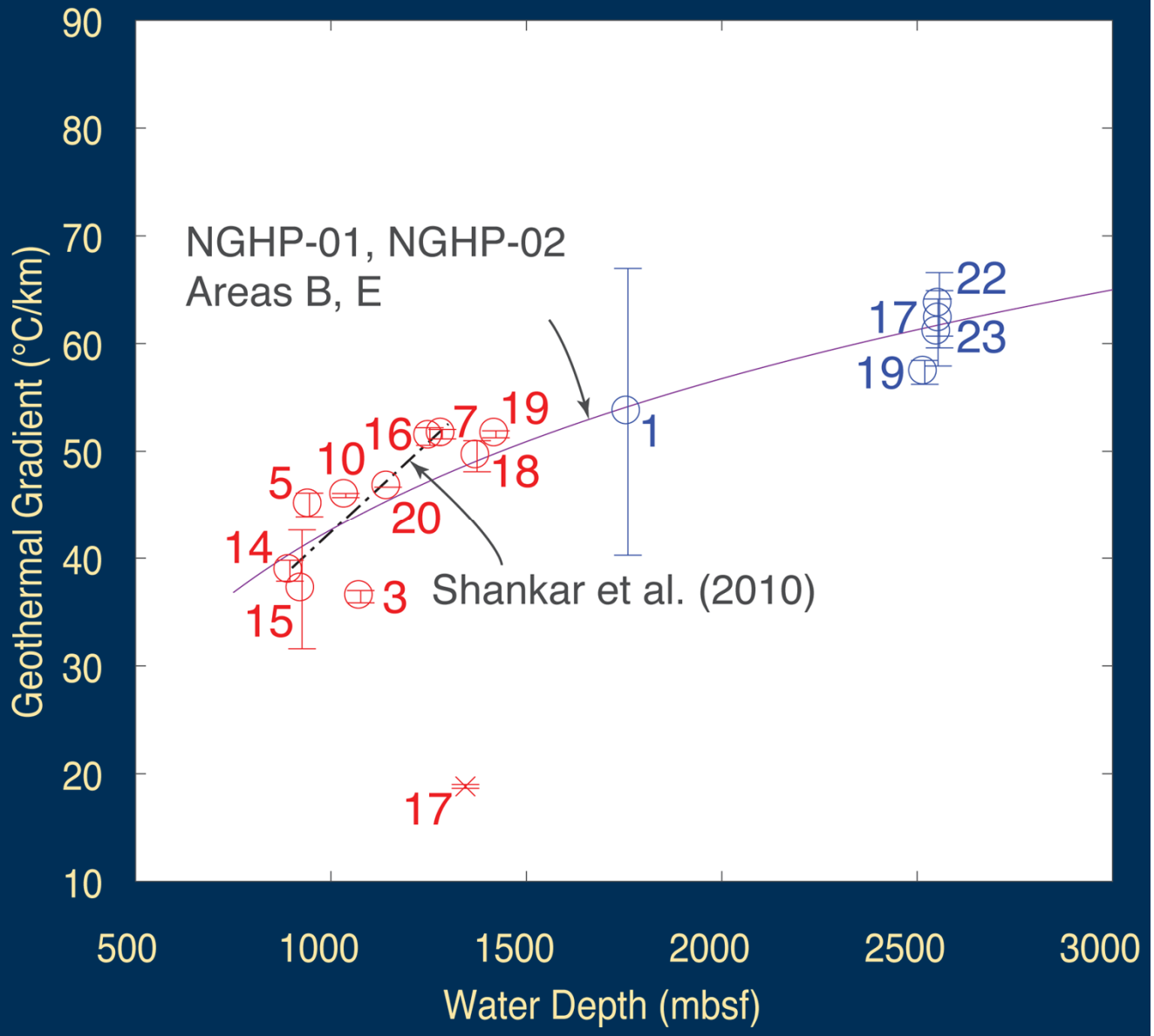
Guessing the temperature profile



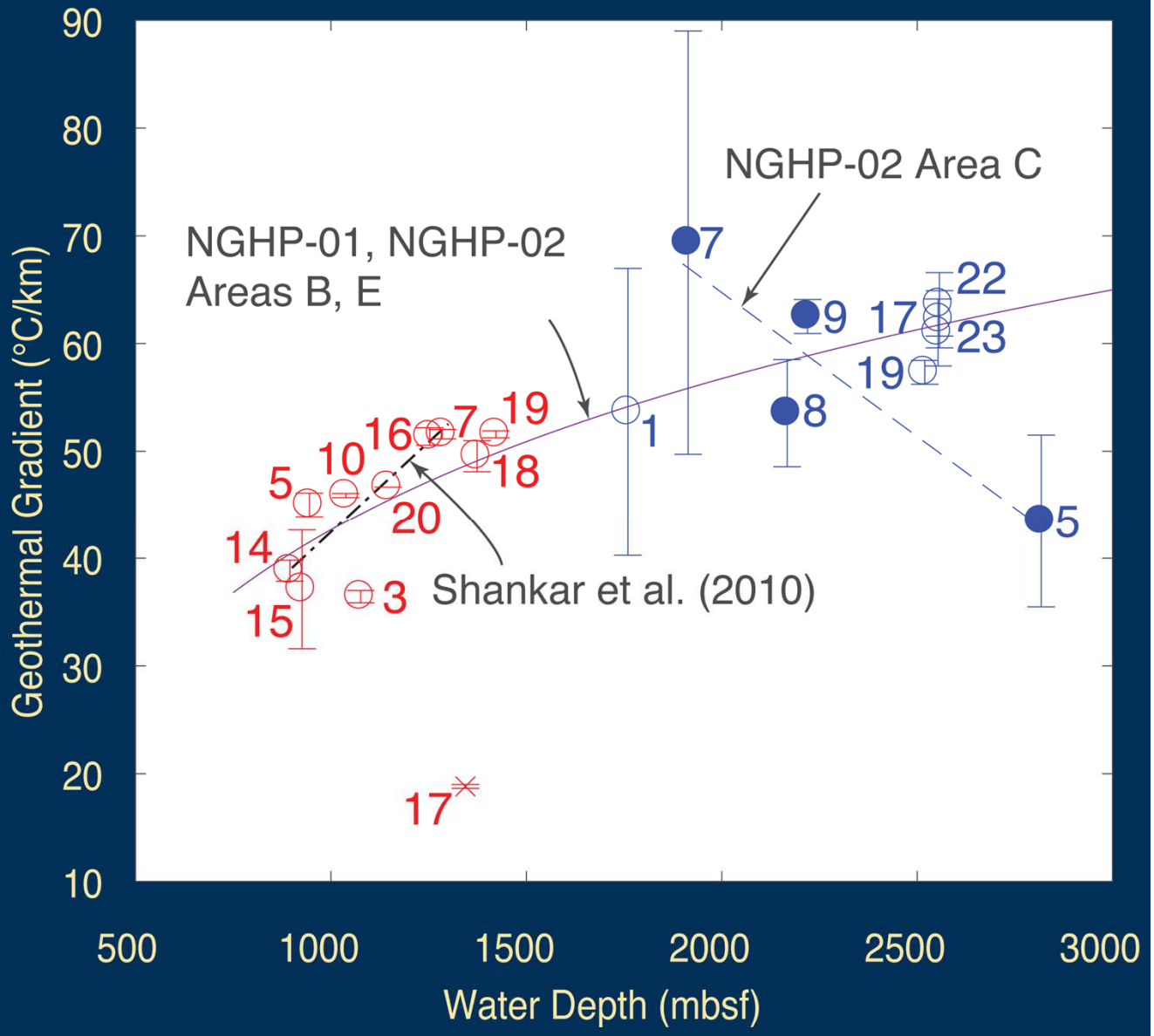
Geothermal gradient dependence on water depth



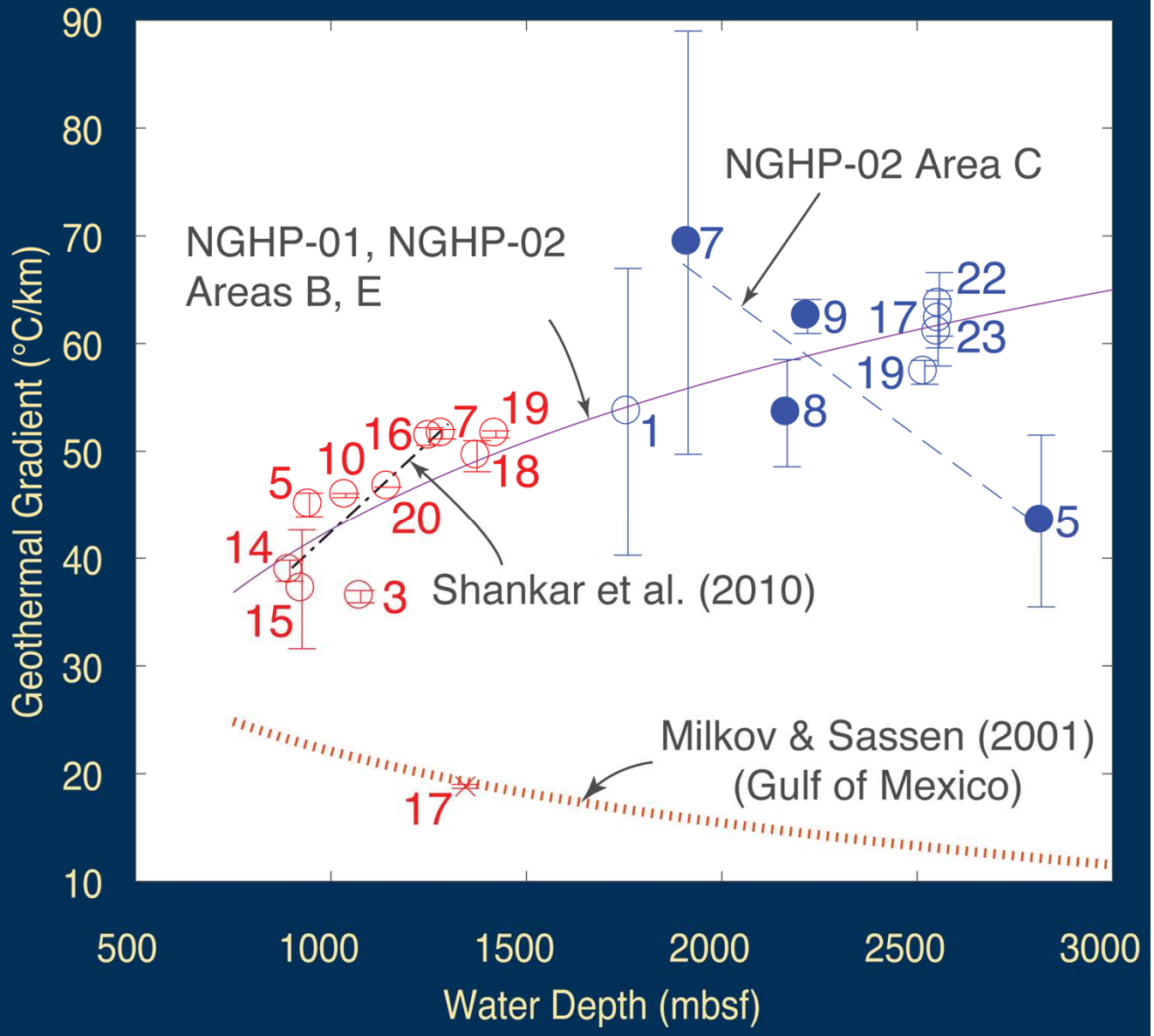
Geothermal gradient dependence on water depth



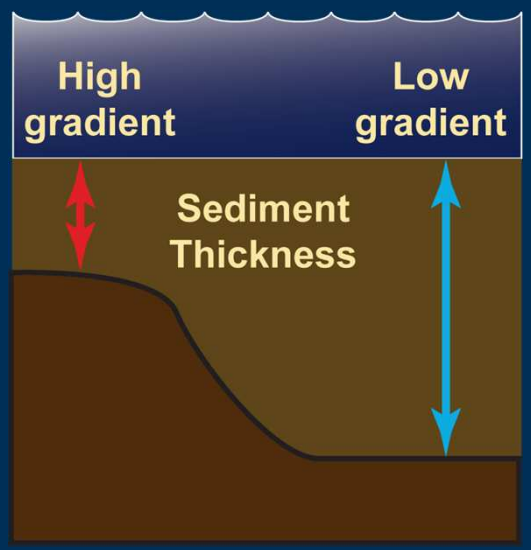
Geothermal gradient dependence on water depth

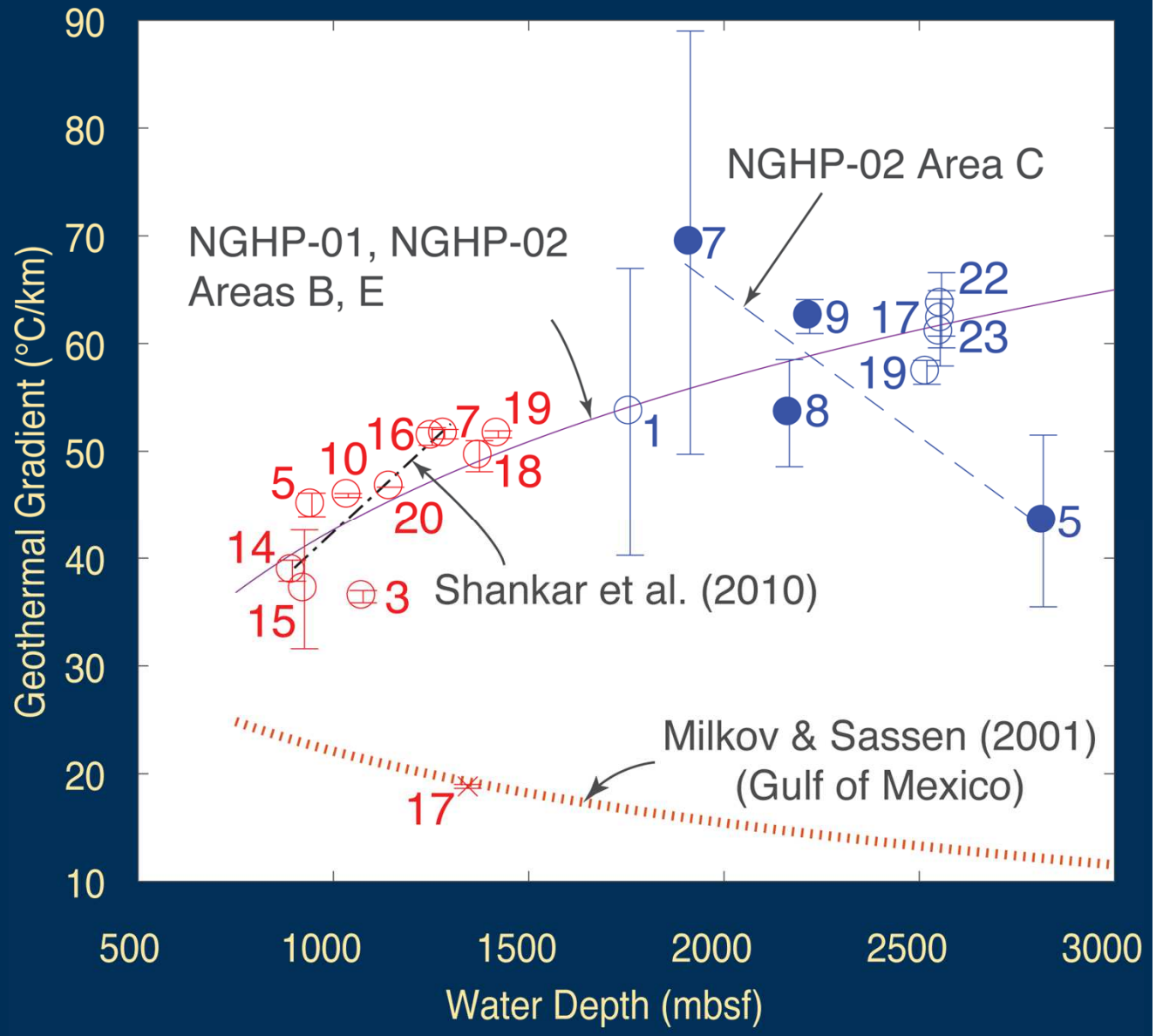


Geothermal gradient dependence on water depth



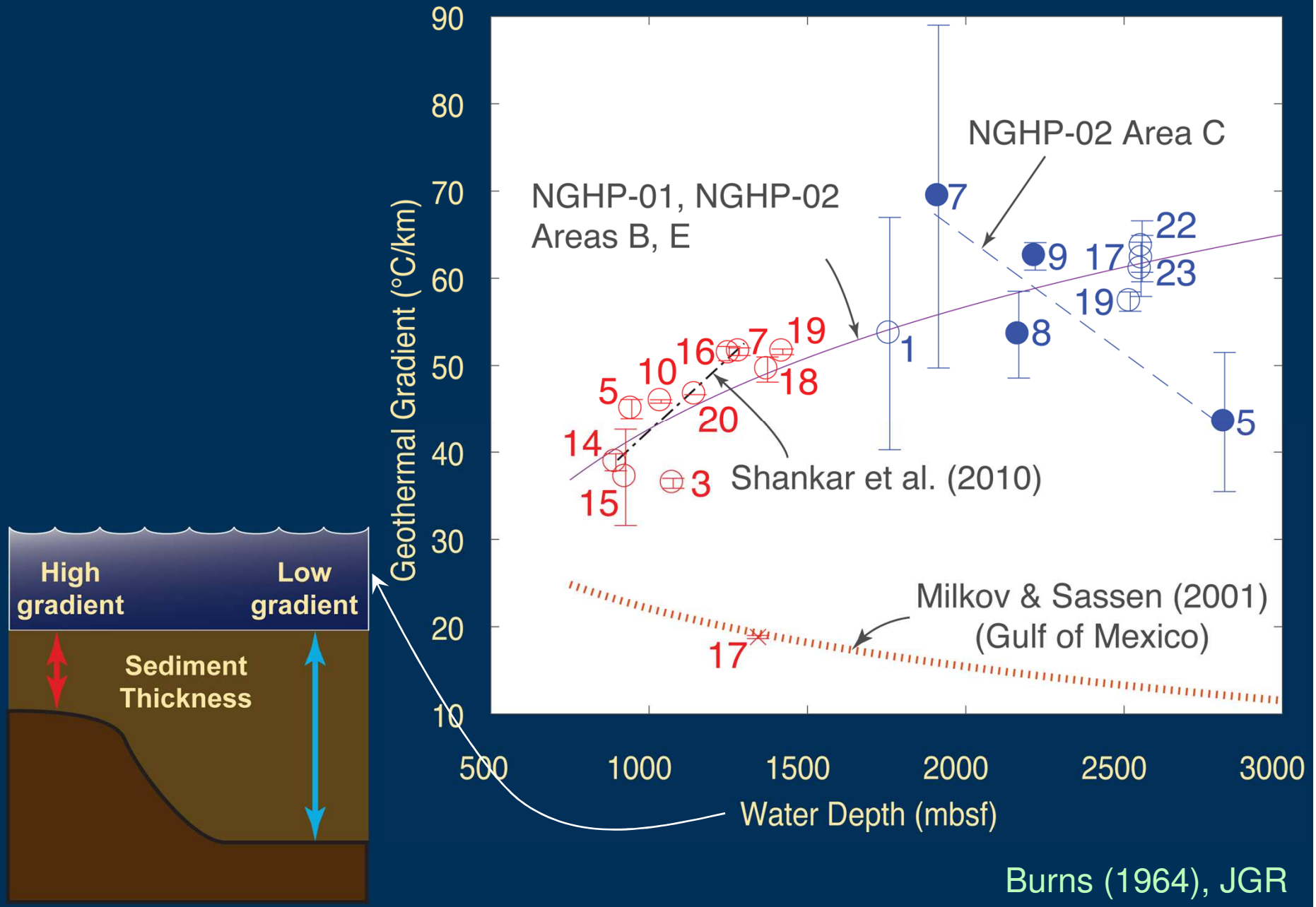
Geothermal gradient dependence on water depth





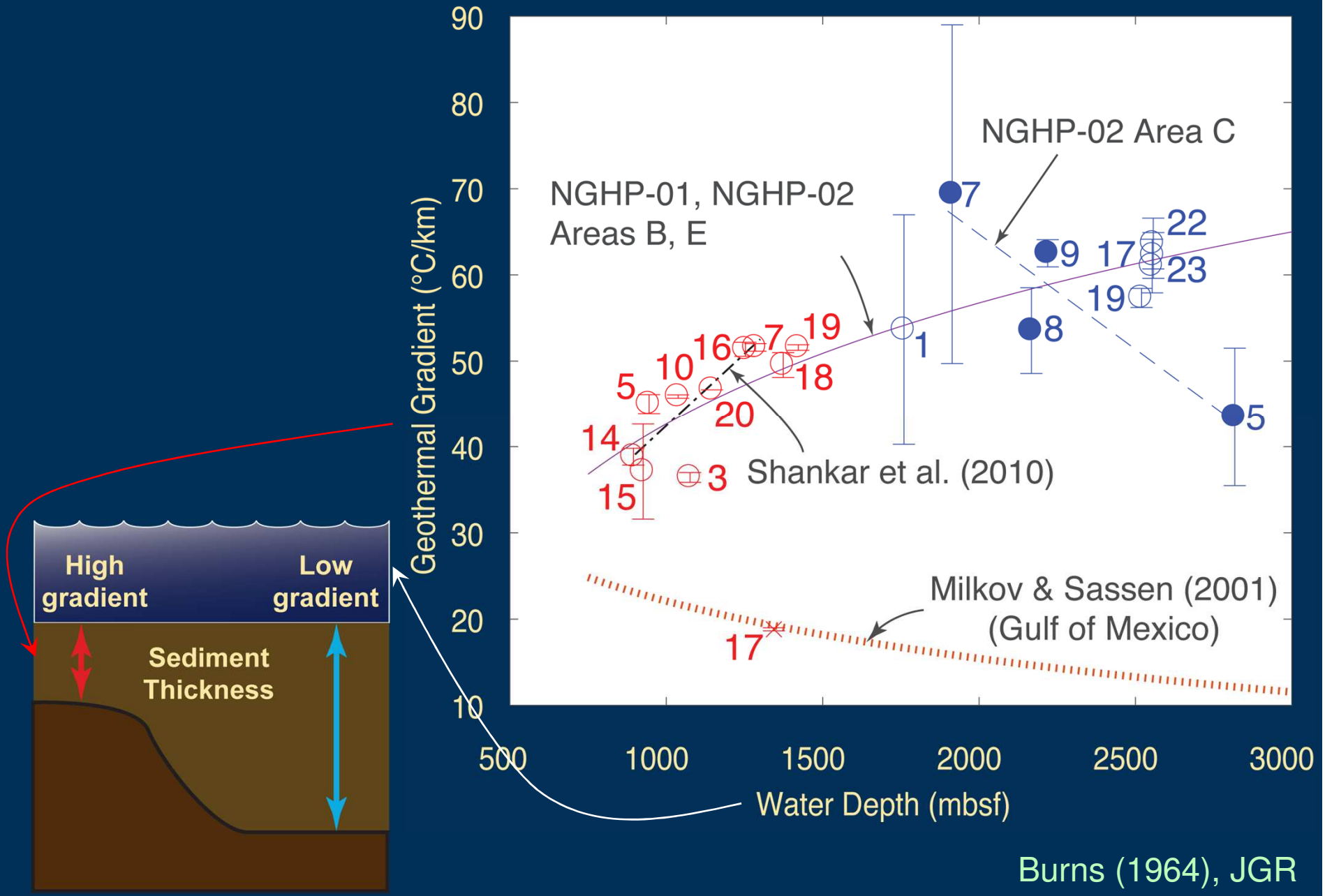
Burns (1964), JGR

Geothermal gradient dependence on water depth



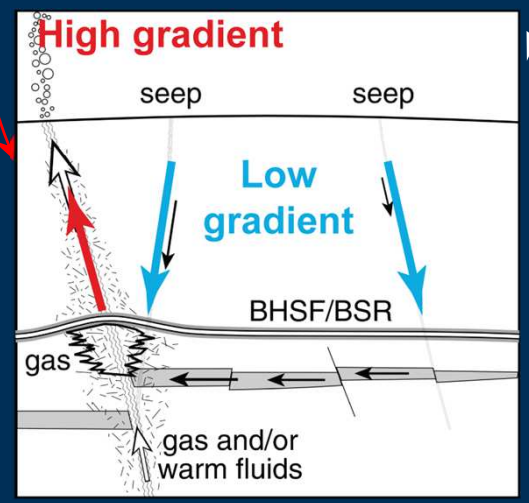
Burns (1964), JGR

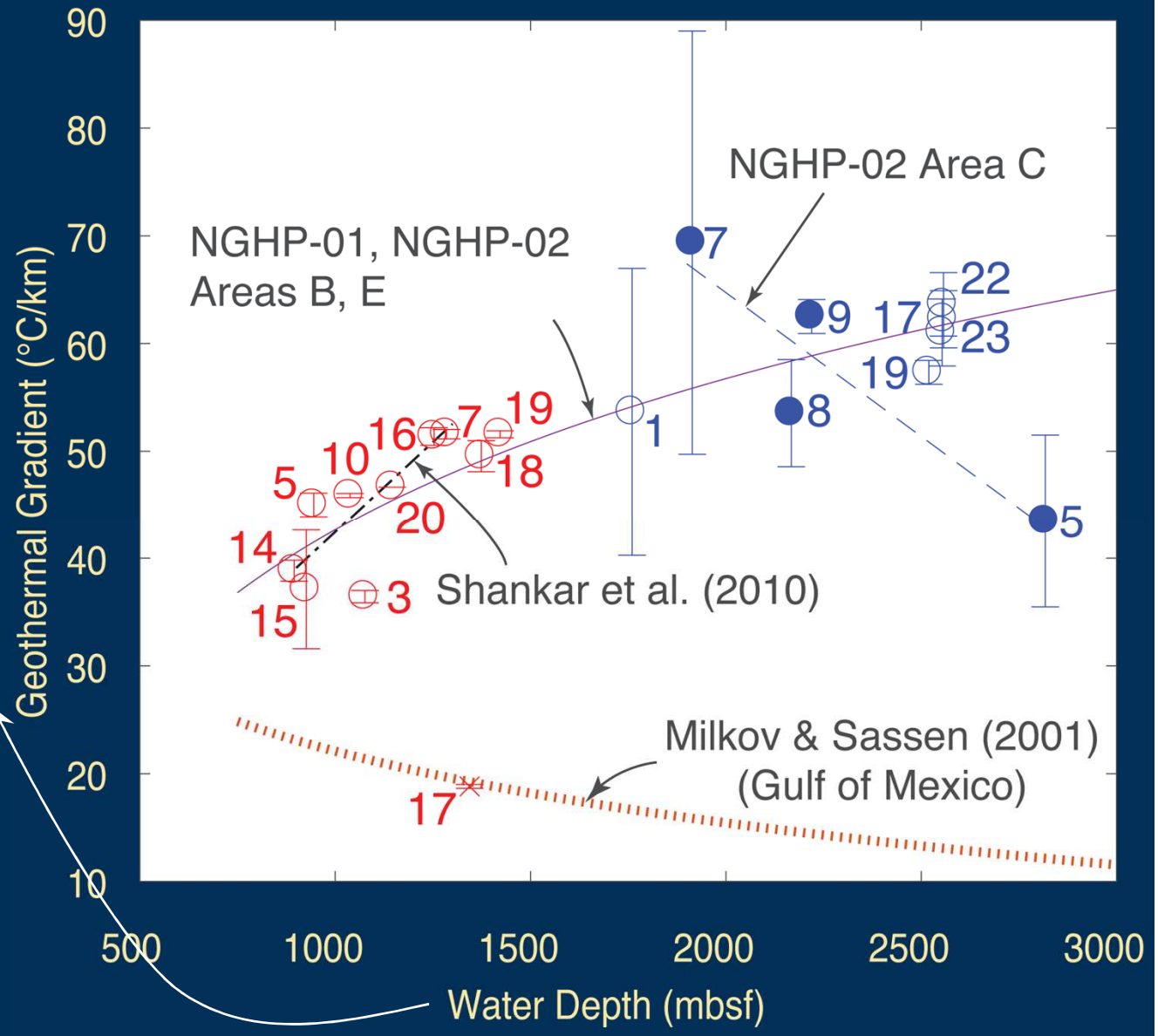
Geothermal gradient dependence on water depth



Burns (1964), JGR

Geothermal gradient dependence on water depth

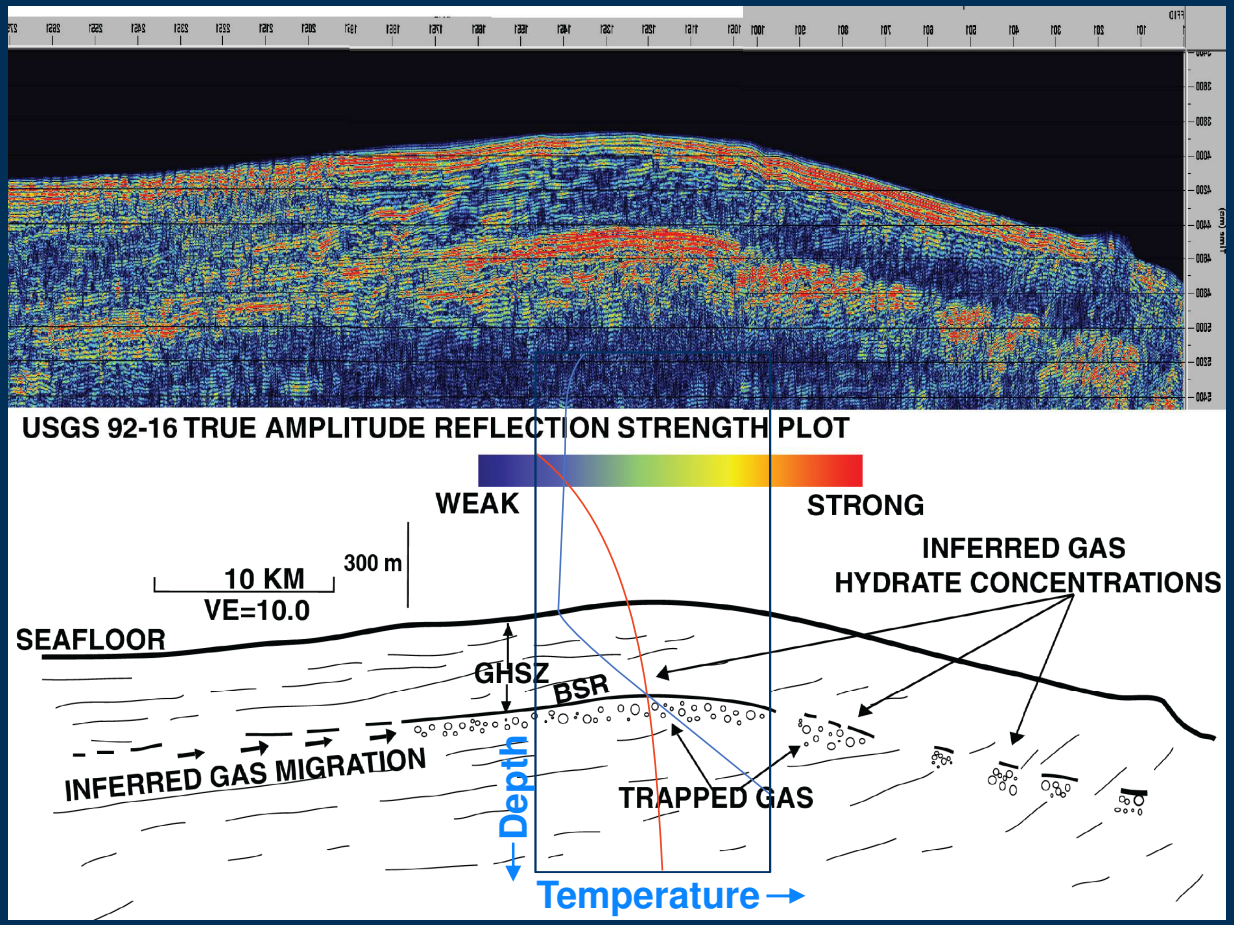




Tryon et al. (2002), EPSL

Using the BSR to guess the maximum hydrate depth

Blake Ridge (offshore USA)

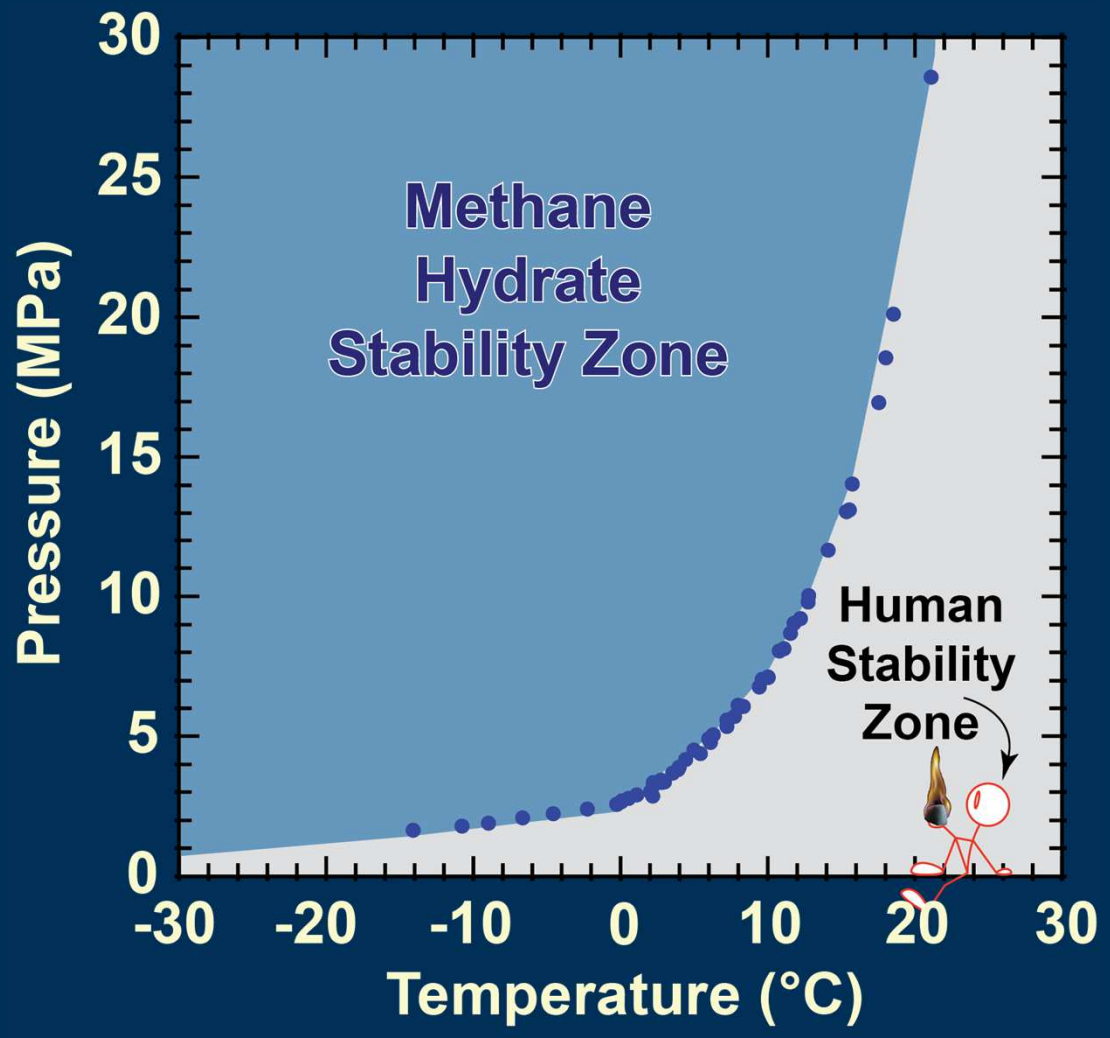


Need:

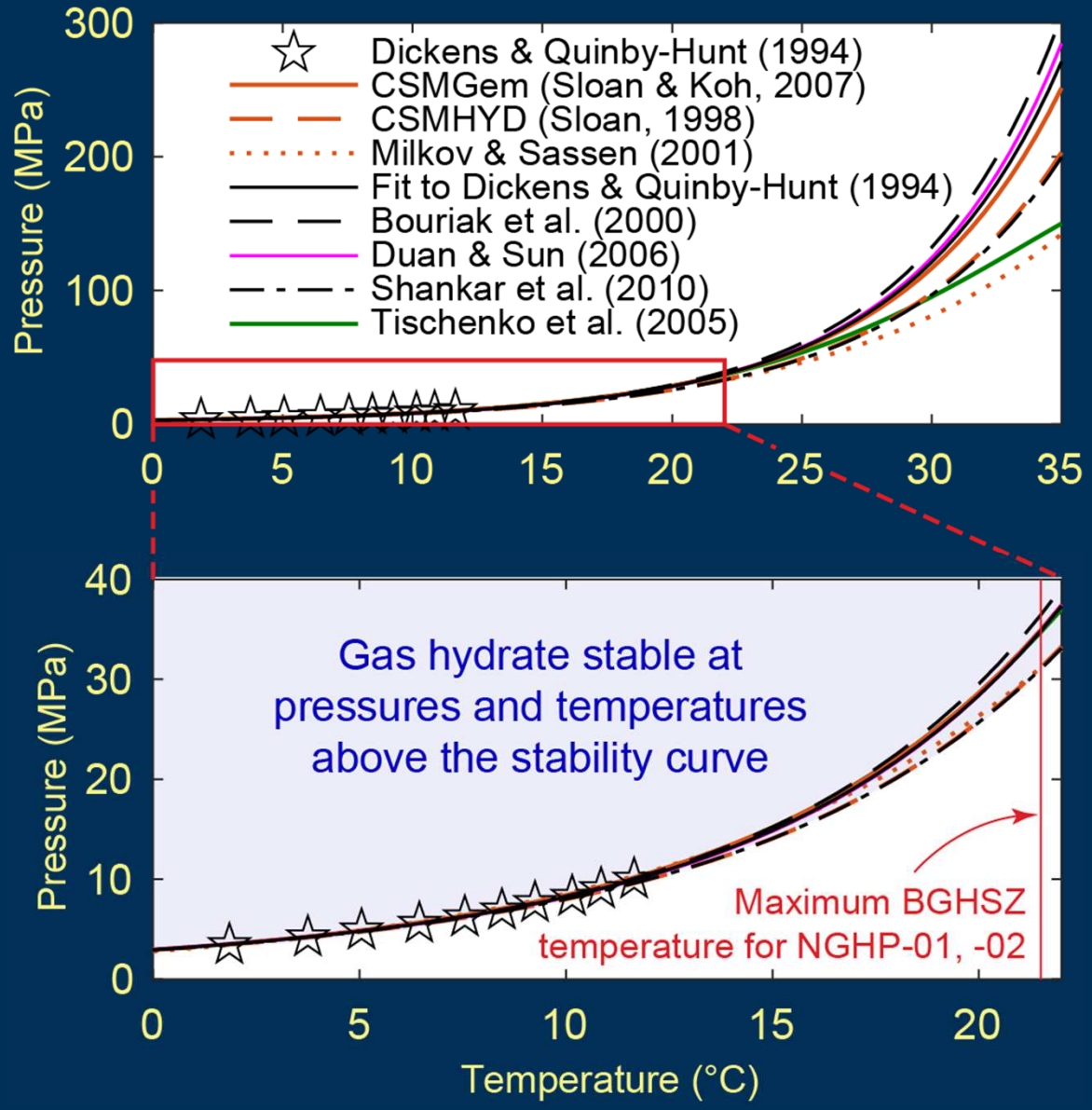
- Bottom Water Temperature
- Geothermal Gradient
- Stability Curve

Max and Dillon (1998), J. Petroleum Geology

How precisely do we actually know the stability curve?

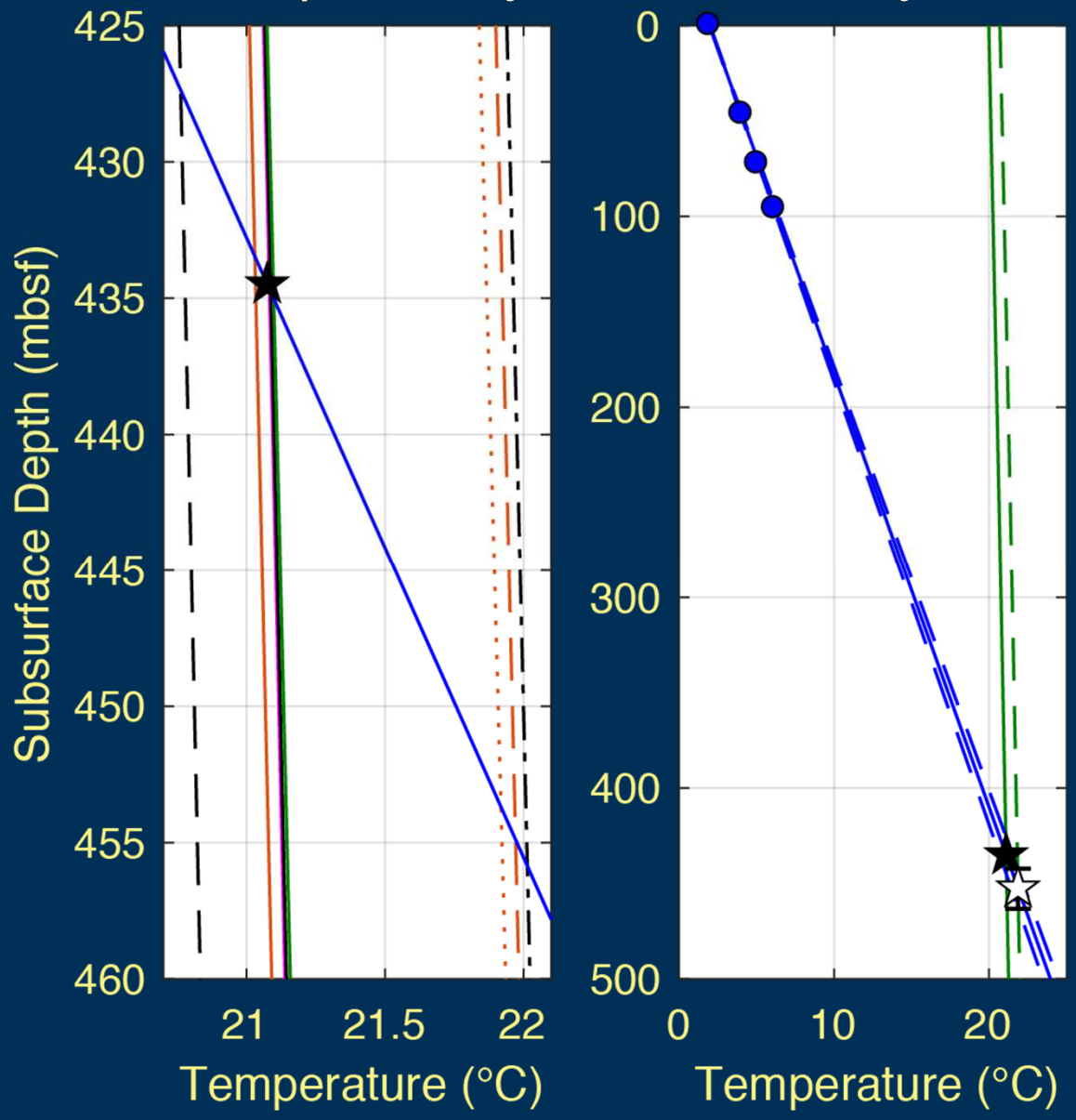


How precisely do we actually know the stability curve?



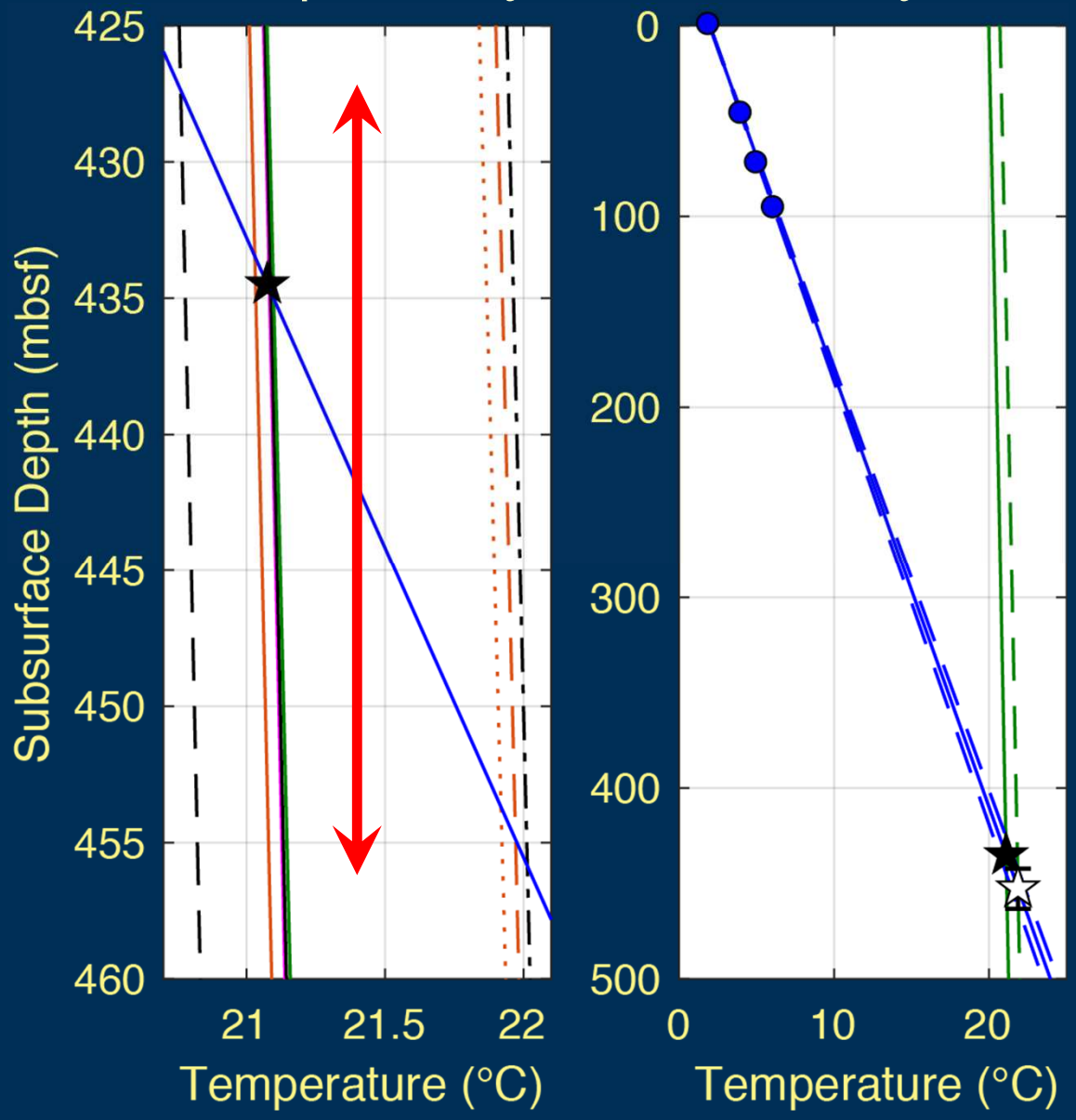
Waite et al. (2018), JMPG

How precisely do we actually know the stability curve?



Waite et al. (2018), JMPG

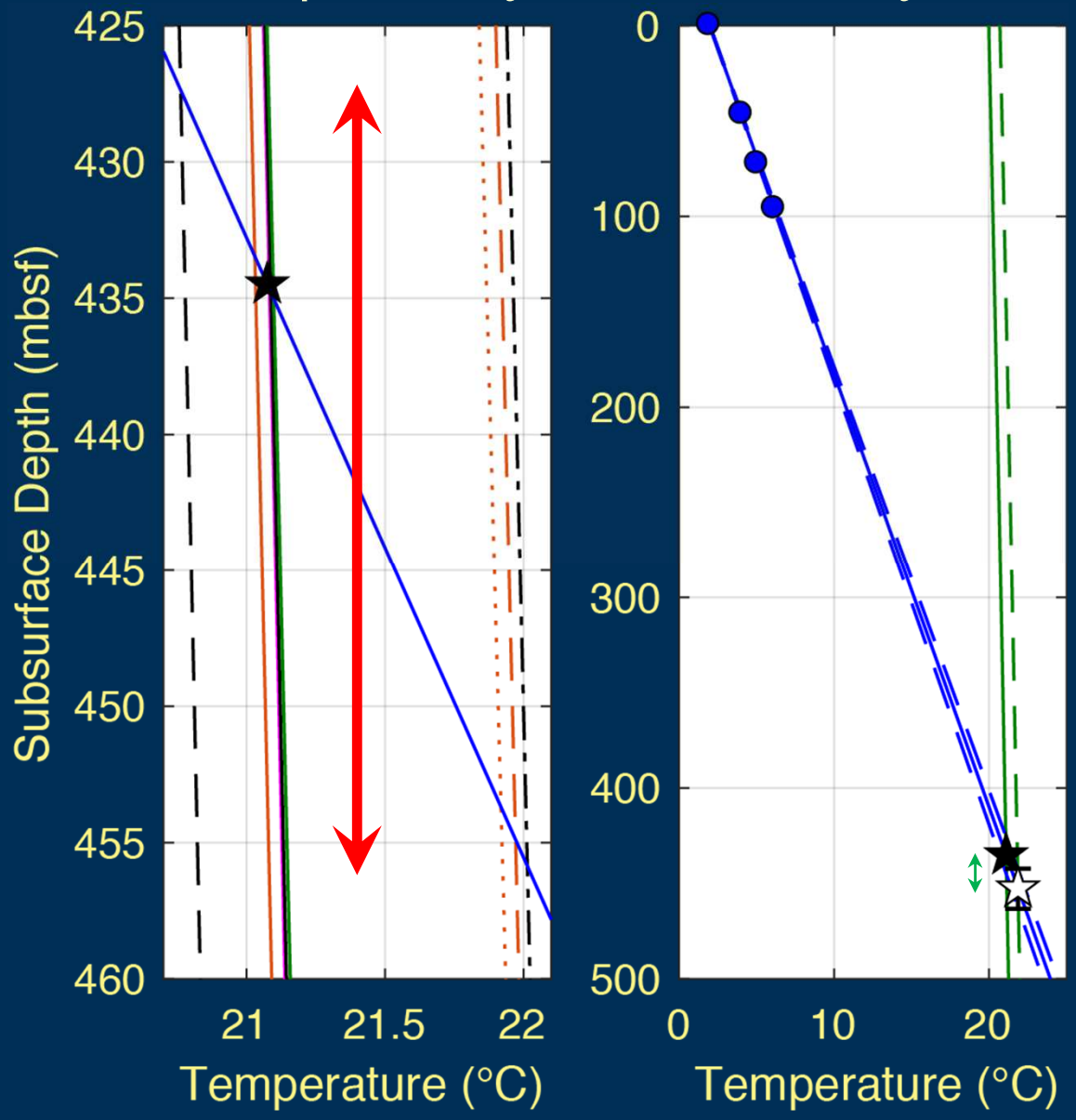
How precisely do we actually know the stability curve?



- Model choice alone can change BSR depth by **30 m**

Waite et al. (2018), JMPG

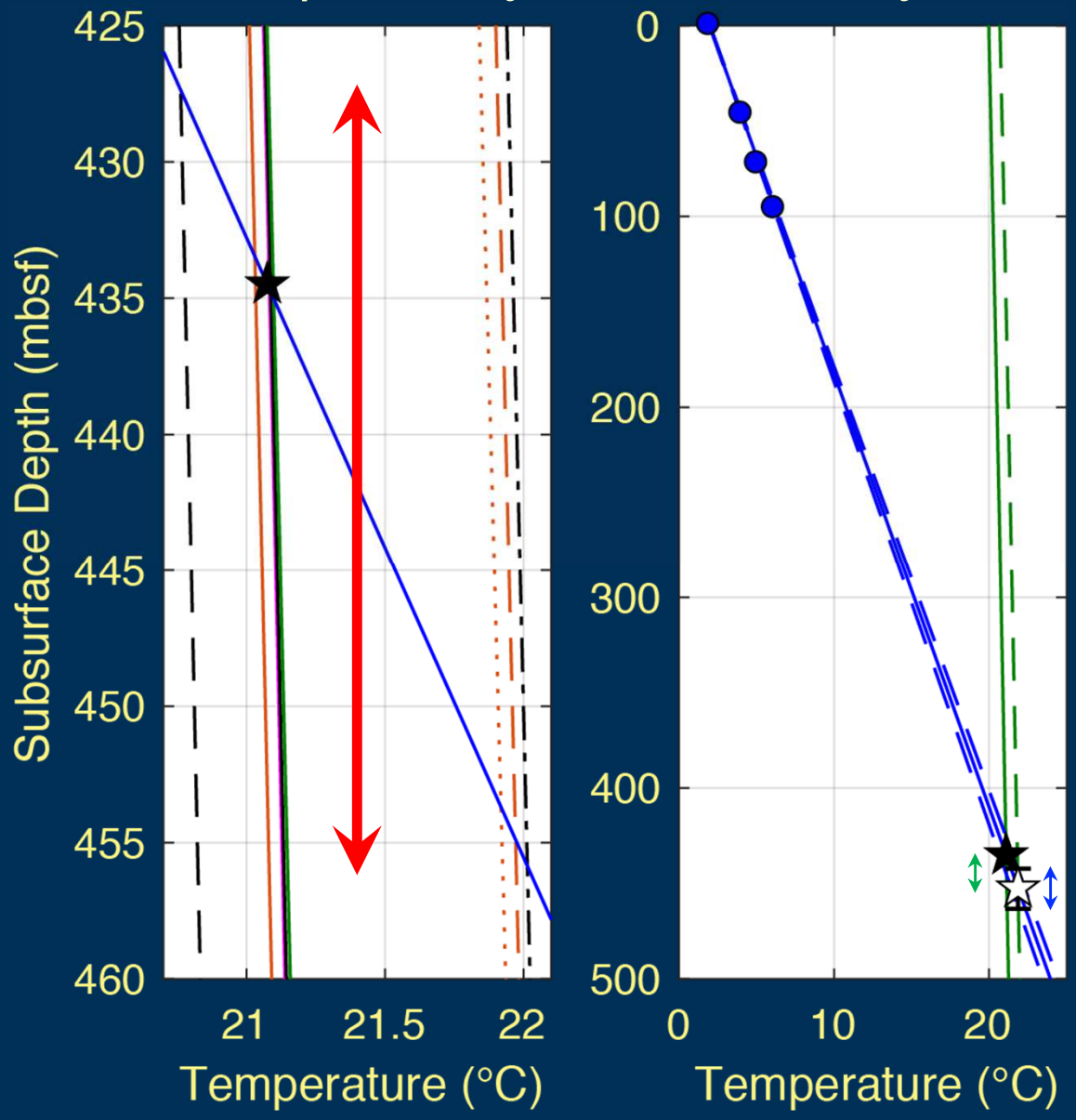
How precisely do we actually know the stability curve?



- Model choice alone can change BSR depth by **30 m**
- Salinity choice seawater, 33.5 ppt measured, 18.8 ppt can change BSR depth by **17 m**

Waite et al. (2018), JMPG

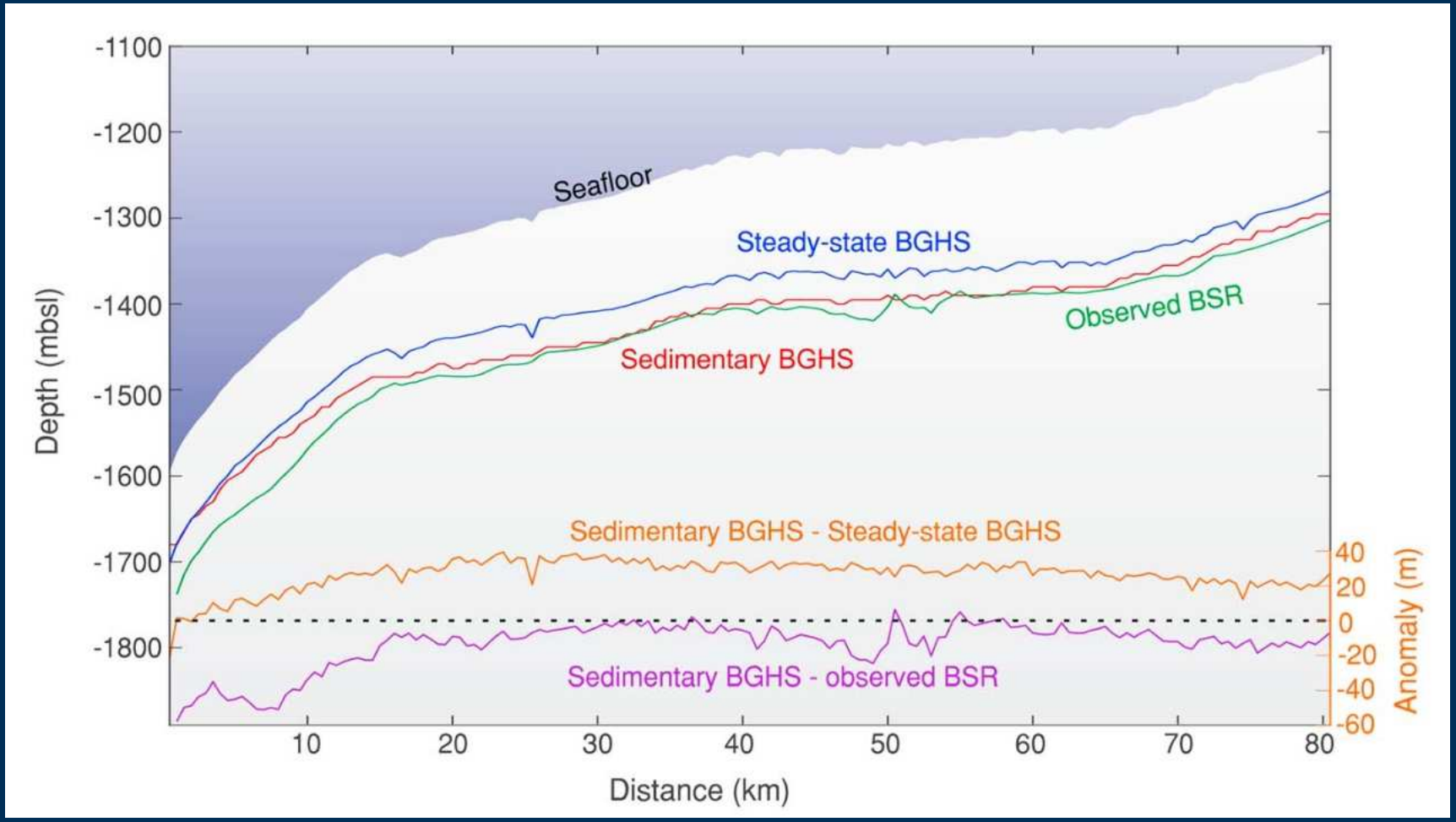
How precisely do we actually know the stability curve?



- Model choice alone can change BSR depth by **30 m**
- Salinity choice seawater, 33.5 ppt measured, 18.8 ppt can change BSR depth by **17 m**
- Temperature uncertainty can change BSR depth by **20 m**

Waite et al. (2018), JMPG

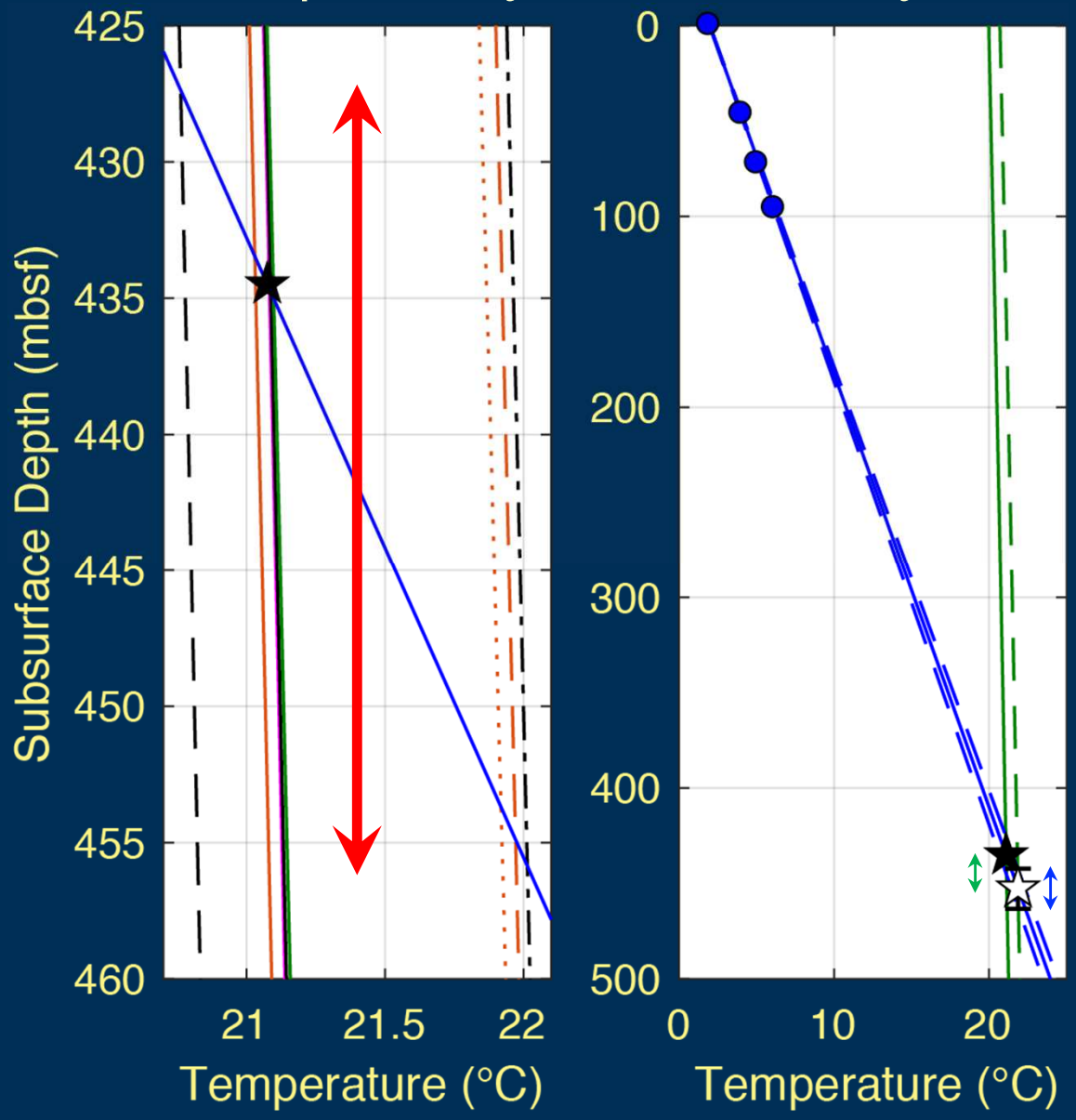
Nonlinear geothermal gradient: impact of sedimentation



Sedimentation (adding cool sediment) can make the sediment column cooler than expected, pushing the base of hydrate stability deeper.

Plaza-Faverola et al. (2017), JGR

How precisely do we actually know the stability curve?



- Model choice alone can change BSR depth by **30 m**
- Salinity choice seawater, 33.5 ppt measured, 18.8 ppt can change BSR depth by **17 m**
- Temperature uncertainty can change BSR depth by **20 m**

Waite et al. (2018), JMPG

Hydrate stability curve: Tishchenko equation

$$\ln(P) = \left[-1.6444866 \cdot 10^3 - 0.1374178 \cdot T + \frac{(5.4979866 \cdot 10^4)}{T} + 2.64118188 \cdot 10^2 \cdot ln(T)\right] +$$
$$S \cdot \left[1.1178266 \cdot 10^4 + 7.67420344 \cdot T - 4.515213 \cdot 10^{-3} \cdot T^2 - \frac{(2.04872879 \cdot 10^5)}{T} - 2.17246046 \cdot 10^3 \cdot ln(T)\right] +$$
$$S^2 \cdot \left[1.70484431 \cdot 10^2 + 0.118594073 \cdot T - 7.0581304 \cdot 10^{-5} \cdot T^2 - \frac{(3.09796169 \cdot 10^3)}{T} - 33.2031996 \cdot ln(T)\right]$$

Tishchenko et al. (2005), Chemical Geology

Hydrate stability curve: Tishchenko equation

$$\ln(P) = \left[-1.6444866 \cdot 10^3 - 0.1374178 \cdot T + \frac{(5.4979866 \cdot 10^4)}{T} + 2.64118188 \cdot 10^2 \cdot ln(T)\right] +$$
$$S \cdot \left[1.1178266 \cdot 10^4 + 7.67420344 \cdot T - 4.515213 \cdot 10^{-3} \cdot T^2 - \frac{(2.04872879 \cdot 10^5)}{T} - 2.17246046 \cdot 10^3 \cdot ln(T)\right] +$$
$$S^2 \cdot \left[1.70484431 \cdot 10^2 + 0.118594073 \cdot T - 7.0581304 \cdot 10^{-5} \cdot T^2 - \frac{(3.09796169 \cdot 10^3)}{T} - 33.2031996 \cdot ln(T)\right]$$

T = Temperature (K)

Tishchenko et al. (2005), Chemical Geology

Hydrate stability curve: Tishchenko equation

$$\ln(P) = \left[-1.6444866 \cdot 10^3 - 0.1374178 \cdot T + \frac{(5.4979866 \cdot 10^4)}{T} + 2.64118188 \cdot 10^2 \cdot ln(T)\right] +$$
$$S \cdot \left[1.1178266 \cdot 10^4 + 7.67420344 \cdot T - 4.515213 \cdot 10^{-3} \cdot T^2 - \frac{(2.04872879 \cdot 10^5)}{T} - 2.17246046 \cdot 10^3 \cdot ln(T)\right] +$$
$$S^2 \cdot \left[1.70484431 \cdot 10^2 + 0.118594073 \cdot T - 7.0581304 \cdot 10^{-5} \cdot T^2 - \frac{(3.09796169 \cdot 10^3)}{T} - 33.2031996 \cdot ln(T)\right]$$

T = Temperature (K); S = Salinity (ppt)

Tishchenko et al. (2005), Chemical Geology

Hydrate stability curve: Tishchenko equation

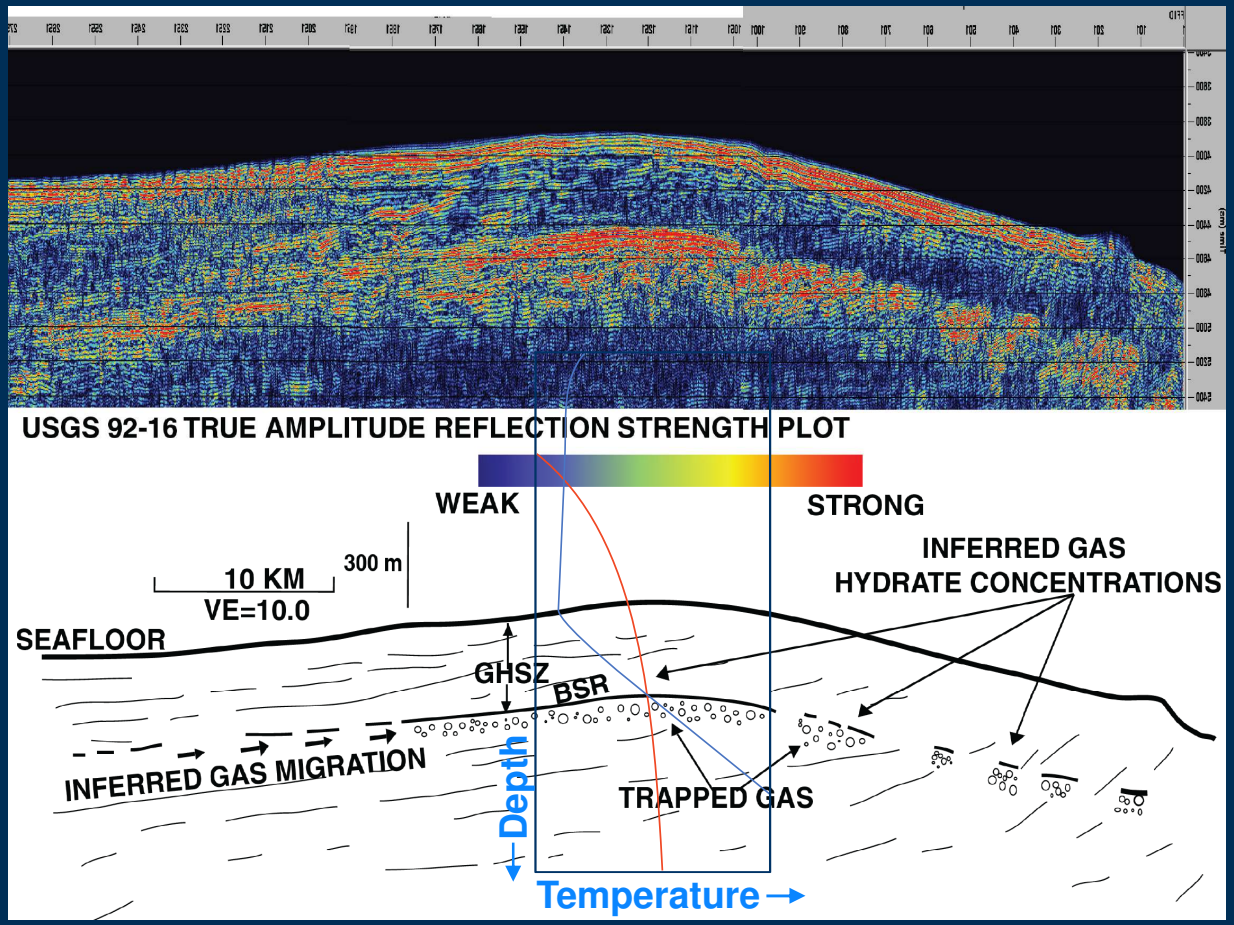
$$\ln(P) = \left[-1.6444866 \cdot 10^3 - 0.1374178 \cdot T + \frac{(5.4979866 \cdot 10^4)}{T} + 2.64118188 \cdot 10^2 \cdot ln(T)\right] +$$
$$S \cdot \left[1.1178266 \cdot 10^4 + 7.67420344 \cdot T - 4.515213 \cdot 10^{-3} \cdot T^2 - \frac{(2.04872879 \cdot 10^5)}{T} - 2.17246046 \cdot 10^3 \cdot ln(T)\right] +$$
$$S^2 \cdot \left[1.70484431 \cdot 10^2 + 0.118594073 \cdot T - 7.0581304 \cdot 10^{-5} \cdot T^2 - \frac{(3.09796169 \cdot 10^3)}{T} - 33.2031996 \cdot ln(T)\right]$$

T = Temperature (K); S = Salinity (ppt); P = Pressure (MPa)

Tishchenko et al. (2005), Chemical Geology

Using the BSR to guess the maximum hydrate depth

Blake Ridge (offshore USA)



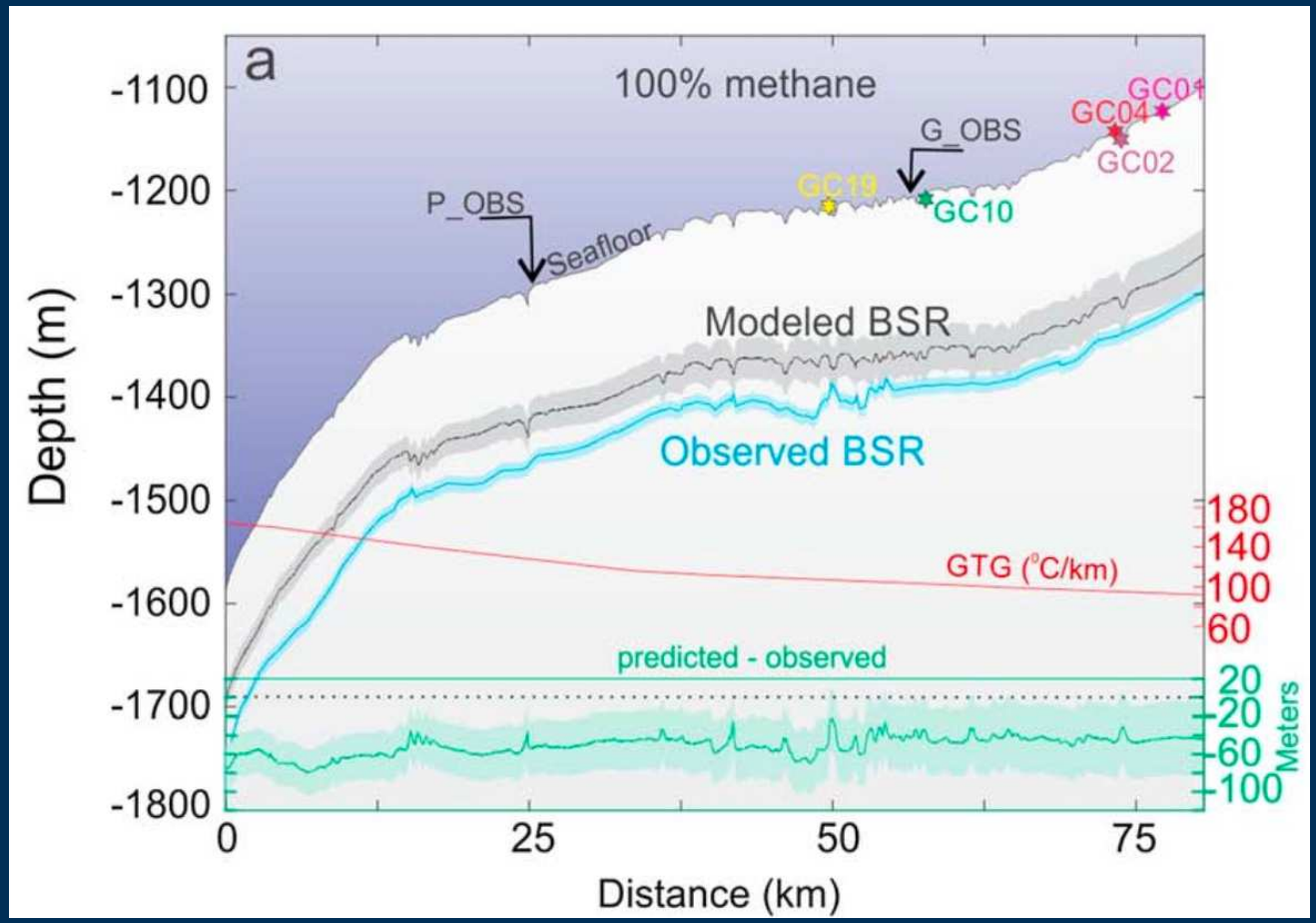
Need:

- Bottom Water Temperature
- Geothermal Gradient
- Stability Curve

Max and Dillon (1998), J. Petroleum Geology

Using the BSR to guess the maximum hydrate depth

Vestnesa Ridge (offshore Svalbard)



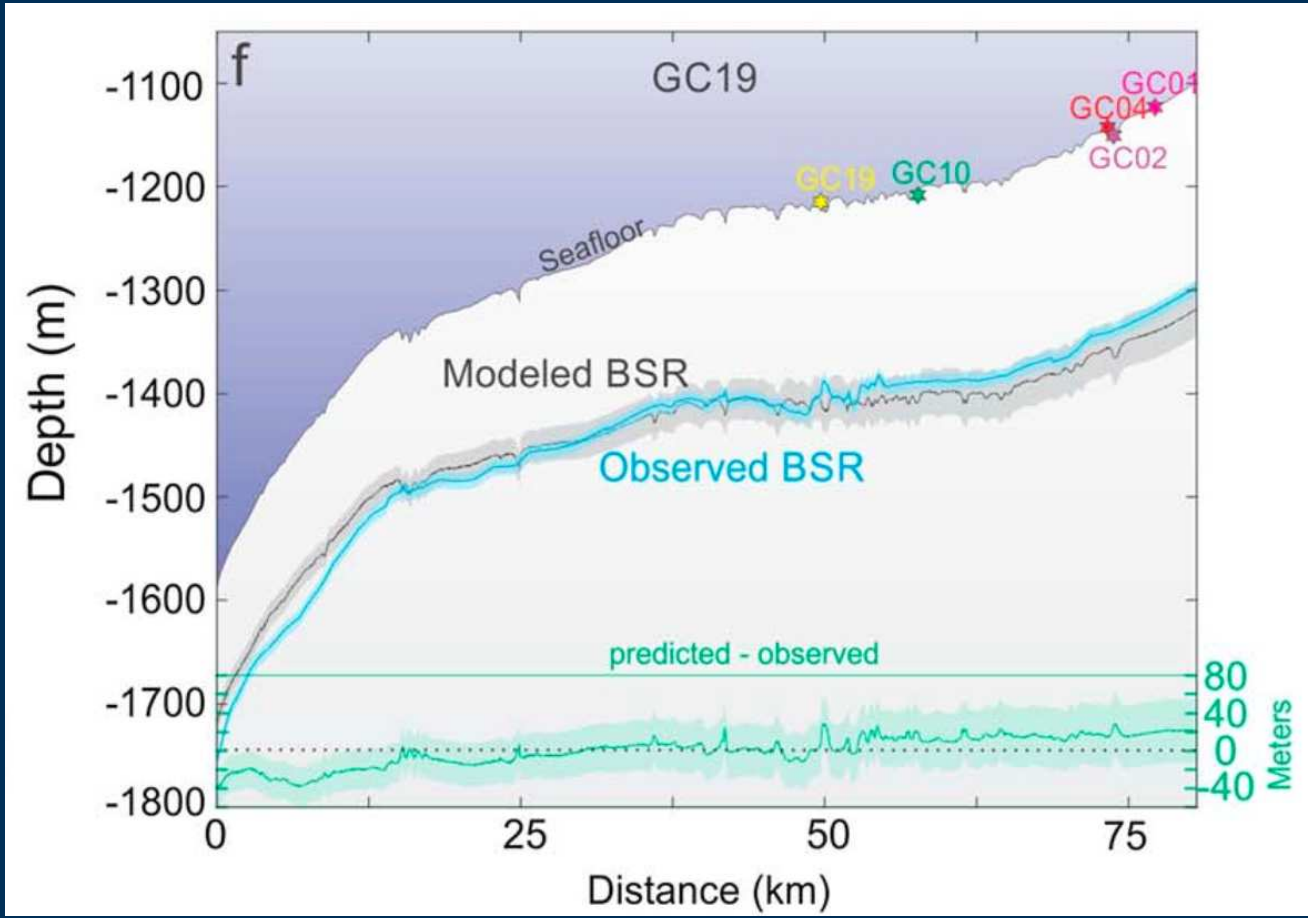
Need:

- Bottom Water Temperature
- Geothermal Gradient
- Stability Curve

Plaza-Faverola et al. (2017), JGR

Using the BSR to guess the maximum hydrate depth

Vestnesa Ridge (offshore Svalbard)



Need:

- Bottom Water Temperature
- Geothermal Gradient
- *Appropriate* Stability Curve

Plaza-Faverola et al. (2017), JGR

Big Ideas: general approach, and finding gas hydrate

Big Ideas: general approach, and finding gas hydrate

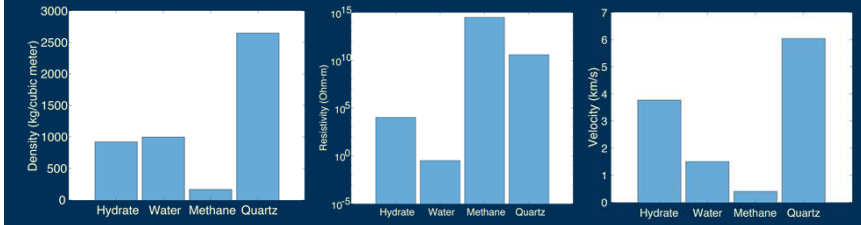
Guess Test Learn

- To learn more, be willing to “fail” more. Every outcome is a chance to learn!

Big Ideas: general approach, and finding gas hydrate

Guess Test Learn

- To learn more, be willing to “fail” more. Every outcome is a chance to learn!



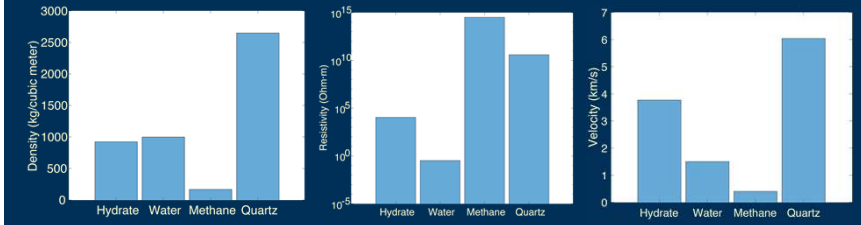
Density Resistivity Velocity

- To find things, use properties that are very different from what you are *not* looking for.

Big Ideas: general approach, and finding gas hydrate

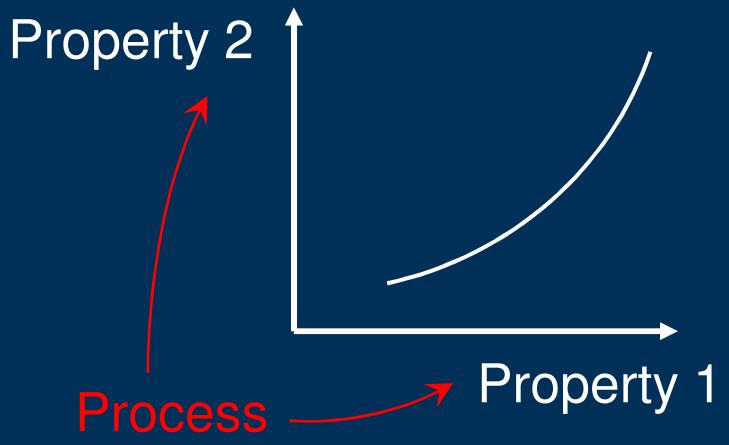
Guess Test Learn

- To learn more, be willing to “fail” more. Every outcome is a chance to learn!



Density Resistivity Velocity

- To find things, use properties that are very different from what you are *not* looking for.



- Correlations have real power (good and bad). Make sure you understand the *process* that connects your properties.