Fire from Ice: Methane Hydrate Petroleum Systems and Resources*+

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Introduction and Overview

Methane hydrates occur in polar permafrost regions and marine outer continental margins and represent a potentially enormous energy resource.

Hydrates are naturally occurring crystalline compounds of natural gas enclosed within a cage-like lattice of water ice. Chemists call such structures clathrates. In methane hydrates, water crystallizes in the cubic system, rather than in the hexagonal structure of normal ice. The resulting compound packs a lot of methane in its dense organization. One cubic foot of hydrate contains about 164 cubic feet of methane gas.

With adequate gas concentrations, methane hydrates form and are stable under moderate- to high pressure, low temperature conditions. This Methane Hydrate Stability Zone (MHSZ) typically occurs: 1) on continental margins at water depths greater than about 300 m and bottom water temperatures close to 0° C, where gas hydrate is found from the sediment surface to depths of about 1100 m below the seafloor, and 2) in polar continental regions, where gas hydrate can be present in sediment and permafrost at depths between about 150 and 2000 m.

Early estimates of the total resource were as speculative as they were impressive. Current work using geology-based Total Petroleum System (TPS) assessments still yields very large numbers.

The USGS recently estimated that there are about 85.4 trillion cubic feet (Tcf) of undiscovered, technically recoverable gas resources within methane hydrates in northern Alaska alone (Collett, 2009). The Minerals Management service conducted an evaluation of the petroleum system for the Gulf of Mexico and estimated a mean value of 21,444 Tcf with 6,717 Tcf in place in sandstone reservoirs (Frye, 2008). Mean estimated resource of domestic methane hydrate in place is about 200,000 Tcf (NETL, site accessed 4/28/11).

Compare this to proved conventional U.S. reserves of about 273 Tcf shale gas reserves of 687 Tcf and a total natural gas resource (including CBM but excluding hydrates) of about 2,170 Tcf (Potential Gas Committee, 2011; EIA, 2010).

Hydrate Petroleum Systems

Source

Two primary source mechanisms have been recognized based on carbon and hydrogen isotopic analysis (Uchida, et al, 2009): microbial decay of organic matter within the gas-hydrate stability zone and thermogenic methane. Thermogenic methane may migrate from thermally mature, deep-seated organic shales, or by leakage from deeper, conventional free gas reservoirs (Lorenson, 2011).

Reservoir

An important difference between methane hydrate accumulations and more conventional gas fields is the nature of the reservoir beds containing the gas: methane hydrate deposits occur in young, relatively unconsolidated sediments where the ice-like hydrate structure holds the gas in place. Methane hydrates occur within a range of reservoir facies, from mudstones to gravels. Sandy siliciclastic reservoirs are considered to be the most favorable for commercial exploitation.

Seal

The seal is provided by the clathrate structure itself. In fact, it is increasingly recognized that the hydrate accumulations may provide a top and lateral seal for deeper free-gas reservoirs outside the methane hydrate stability zone (MHSZ).

Trap

The trapping mechanism, too, is attributed to the arrangement of methane within the clathrate structure. As free gas migrates into the MHSZ, it is chemically trapped within the crystalline configuration of the naturally formed clathrate.

Exploration Technologies

Recent efforts have shifted from resource assessment to evaluating exploration methods for recognizing and mapping commercial hydrate-bearing zones, and production technologies for safe, commercial extraction.

Early exploration methods used seismic signatures known as "bottom-simulating reflectors" (BSR) to identify potential hydrate occurrence. The BSR is the result of an impedance contrast between gas hydrate-filled sediments in the MHSZ and water-filled and/or potentially free gas zones beneath the interface. BSRs are not always evident, and are not universally considered an accurate predictor of commercial-scale accumulations.

Ongoing research has identified other geological models and geophysical characteristics which support the existence of potential high gas hydrate saturations in reservoir-quality sands. For example, successful drilling projects in the Gulf of Mexico have demonstrated that the seismic character of sands are phase reversed across the base of the MHSZ with the phase reversal caused by high velocity gas hydrate pore fill (USGS, 2009).

Production Methods

Research into producing methane from hydrates has focused on two primary methodologies: 1) reducing the pressure, and/or 2) increasing the temperature within the deposit.

As the temperature/pressure curve shifts outside the MHSZ, the gas naturally disassociates from the clathrate structure. Recent short-term production tests have demonstrated the viability of commercial hydrate production through depressurization, the first time this had been accomplished on the North Slope (MH21 Research Consortium, 2011). A relatively new idea involves the injection of carbon dioxide (CO_2) into the deposit, which has the potential to displace methane from the hydrate structure in-situ. This would help to stabilize the reservoir as the methane disassociates, while at the same time providing the added benefit of carbon sequestration.

Additional Research

Other areas of hydrate research include slope stability studies and drilling hazards associated with methane disassociation and seabed collapse.

Finally, methane hydrates must play a significant role in the global carbon cycle, and researchers are studying their port in global climate processes and climate change.

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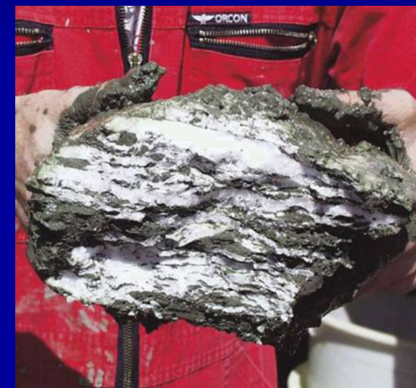
Fire from Ice: Methane Hydrate Petroleum Systems and Resources

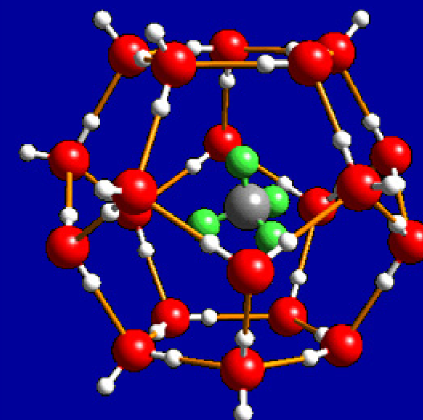
Paul H. Pausé

Southwest Section AAPG Annual Meeting
Ruidoso, New Mexico
June 7, 2011

What is Methane Hydrate?

- **Methane hydrates are naturally occurring icy solids composed of gas molecules trapped in a cage-like structure of water ice.**





- **Stable at low temperature and high pressure**
- **Occurs abundantly in continental margin sediments and Arctic permafrost**
- **Other natural gases may form hydrate compounds, but methane is by far the most abundant**

“Significant Gas Resource Discovered in U.S. Gulf of Mexico”

“ … for the first time … we were able to predict hydrate accumulations before drilling, and we discovered thick, gas hydrate-saturated sands that actually represent energy targets.”

USGS news release, 5/29/2009
http://www.usgs.gov/newsroom/article.asp?ID=2227

“. . . this US expedition has potentially changed the face of the petroleum industry as it exists now.”

US Gas Hydrates Find Has Worldwide Implications
Rigzone
June 12, 2009

Hydrate Petroleum System

Methane source

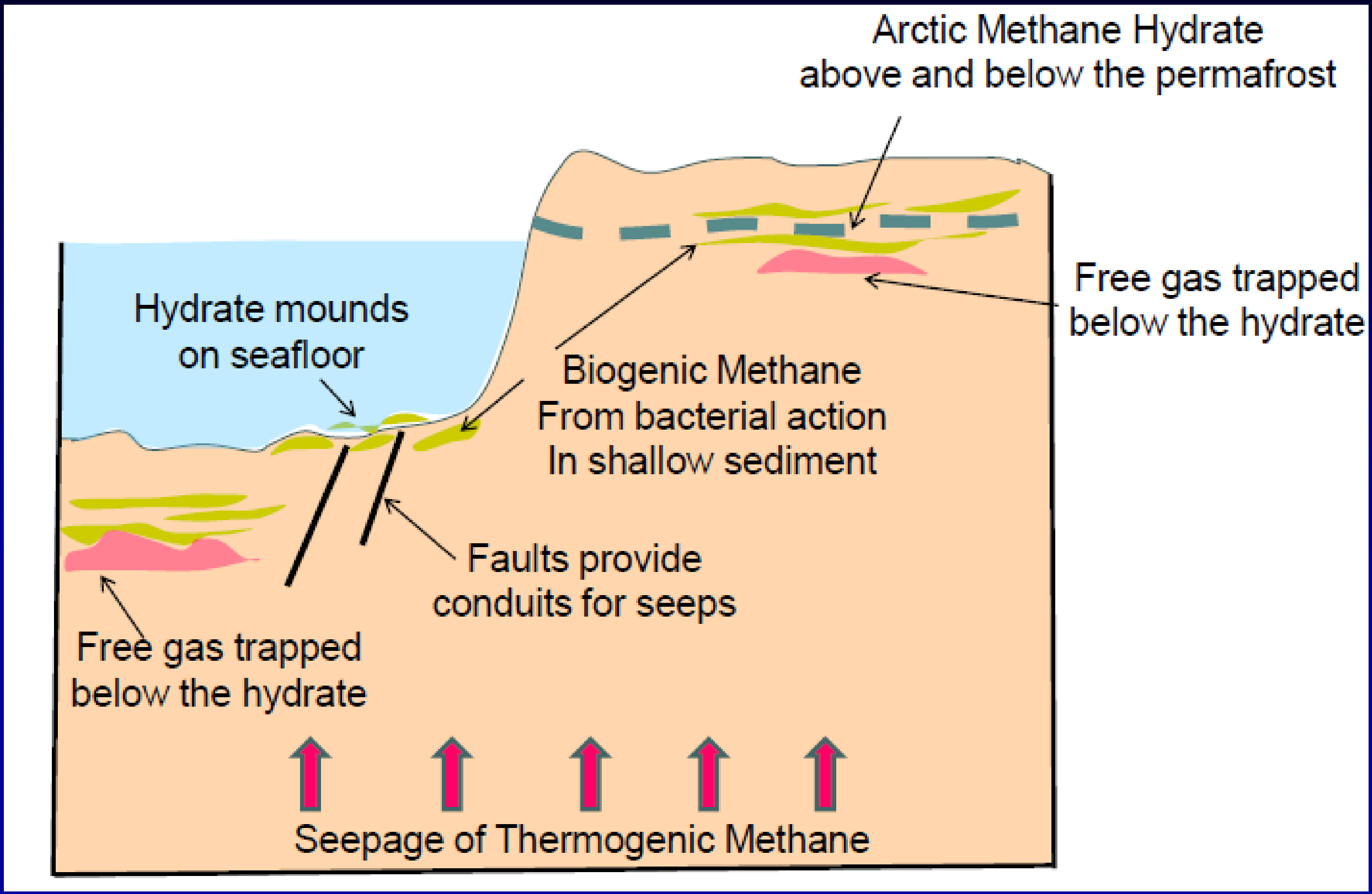
Reservoir lithologies, traps, and seals

Migration into reservoir facies

Timing

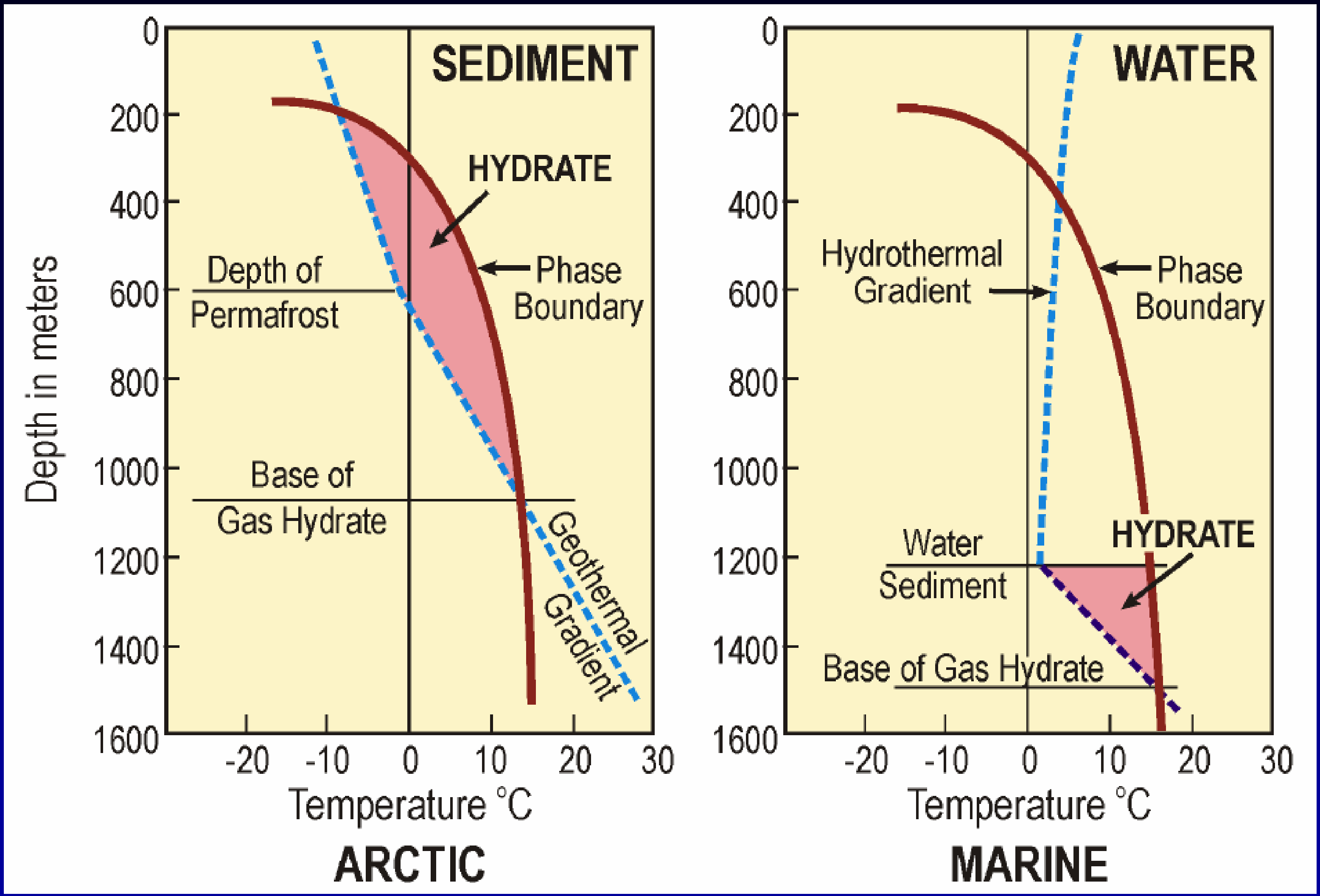
Hydrate stability conditions

Methane origin and hydrate formation



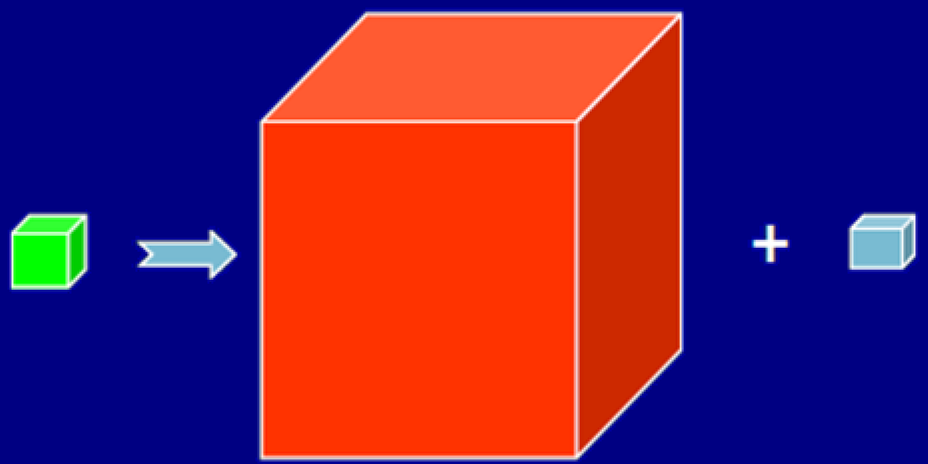
http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2011Reports/MH_Primer2011.pdf
February 2011

Methane Hydrate Stability Zones



Collett and Johnson, 2009

Hydrate Dissociation



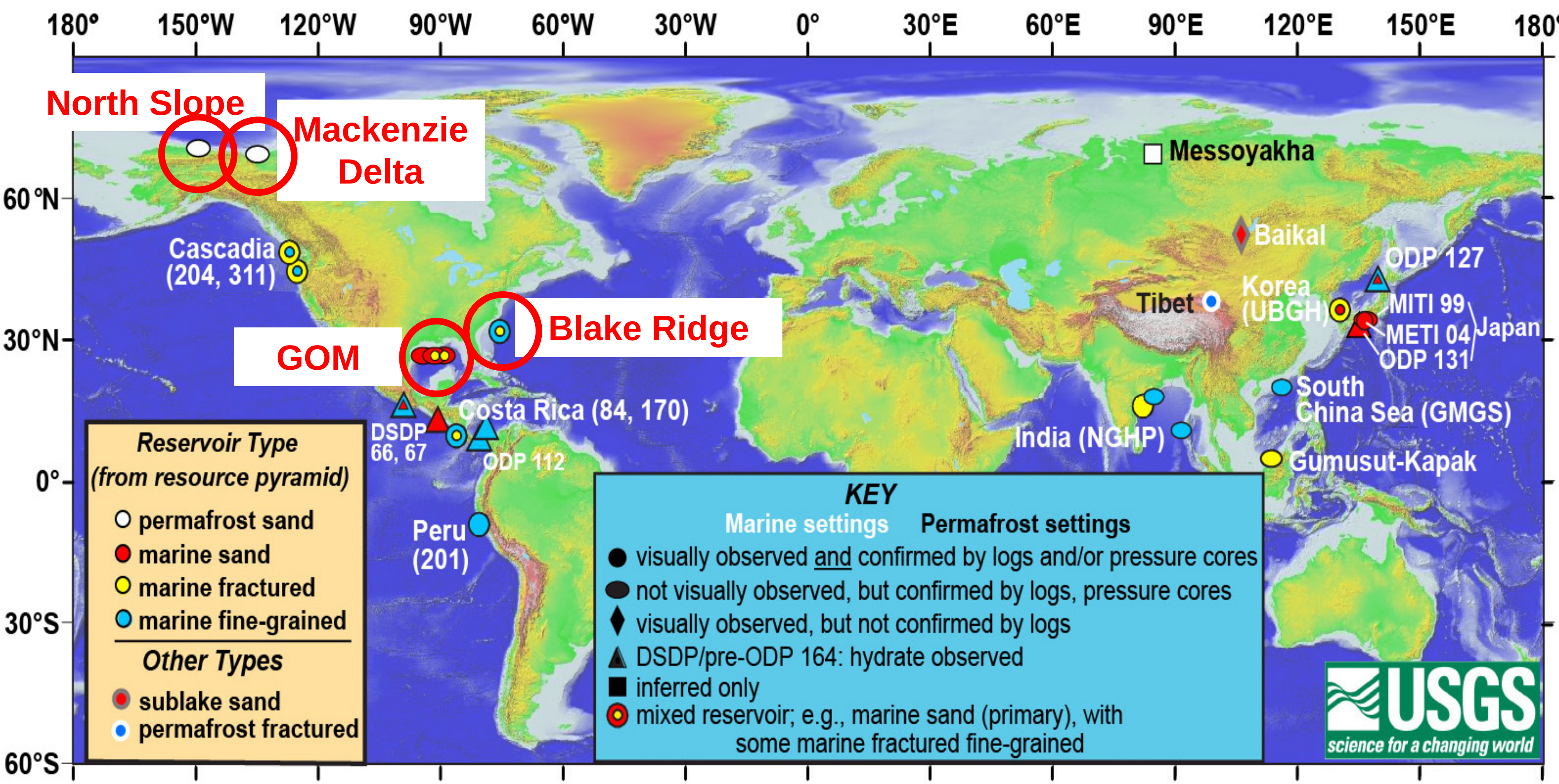
1 ft^3 **Methane hydrate**

164 ft^3 **Methane gas**

0.8 ft^3 **Water**

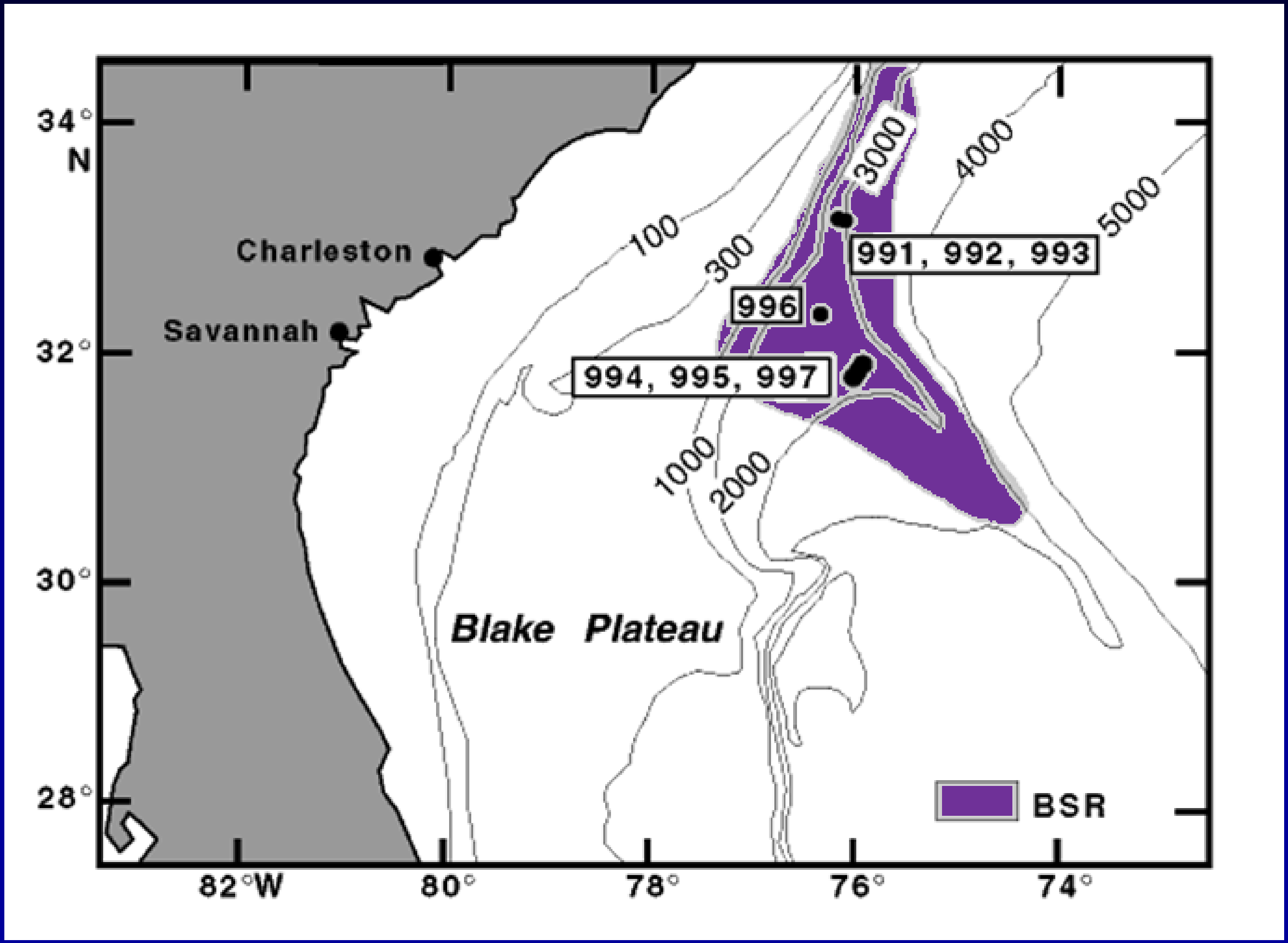
after Shelander et al, 2010

Hydrate Resource Map



Ruppel et al, 2011

ODP Leg 164 Sites
Blake Ridge

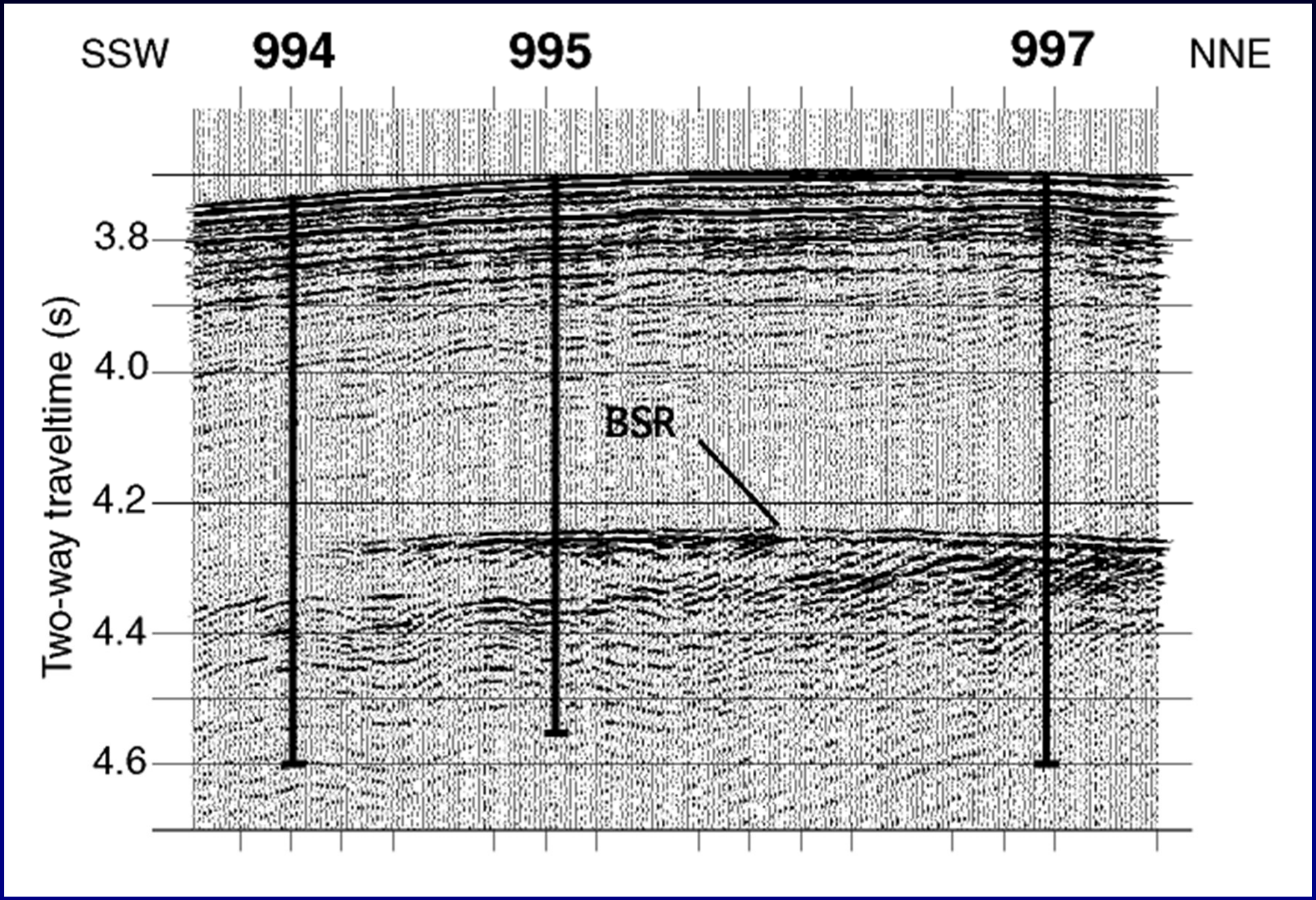


after Paull and Matsumoto, 2000, Fig. 1

Blake Ridge Hydrate Core

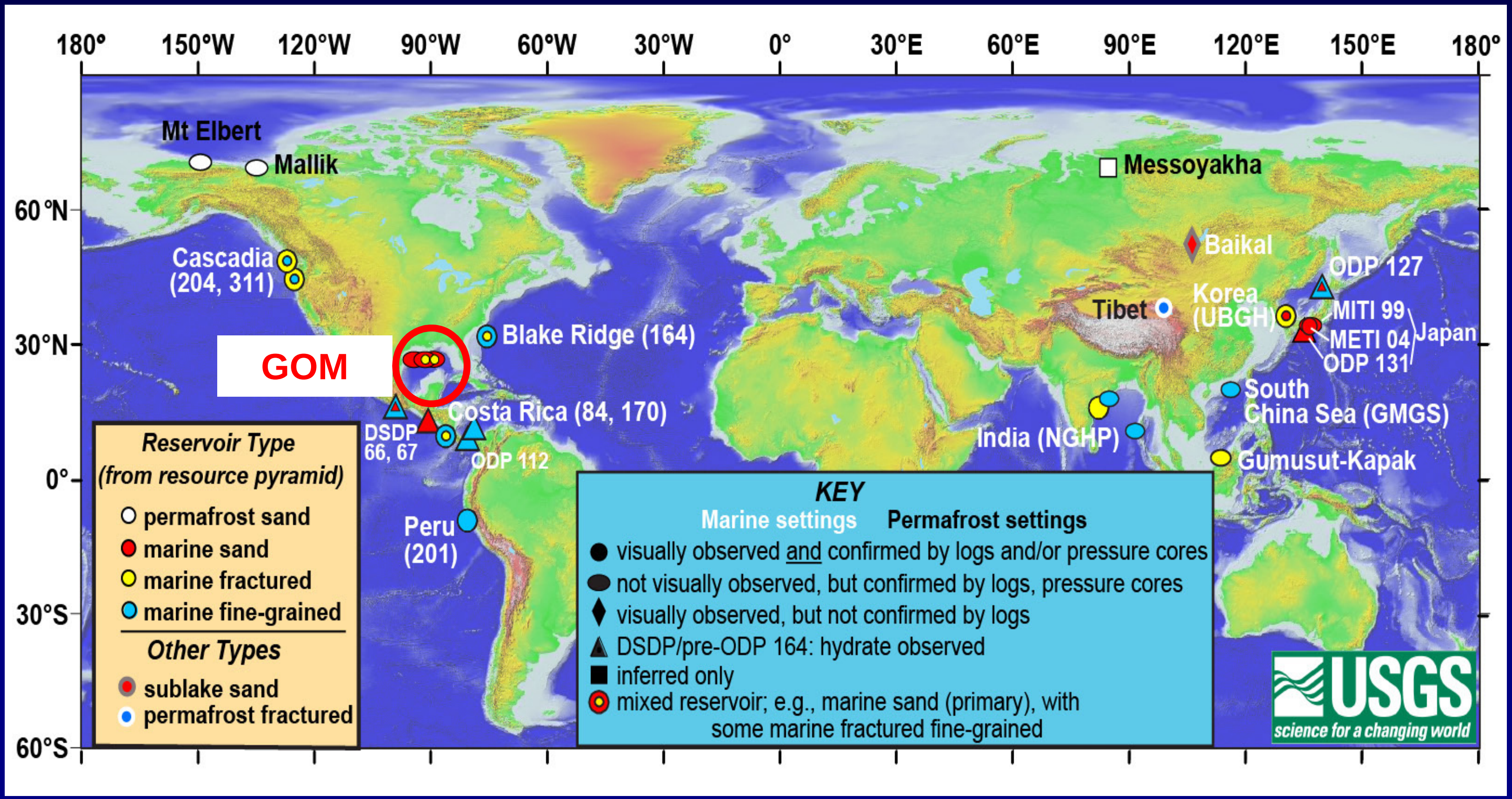
from Ruppel, 2008

Bottom Simulating Reflector (BSR)



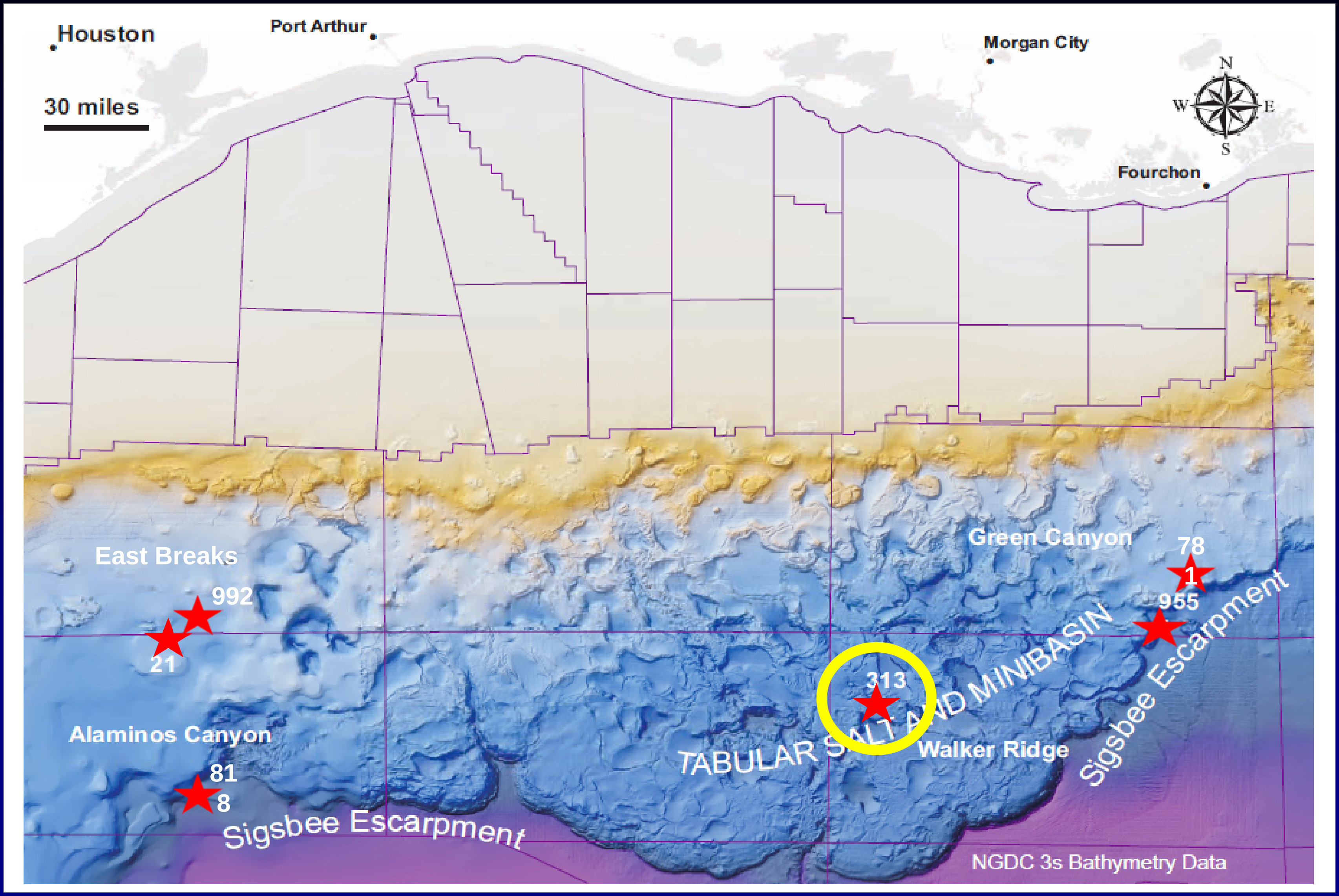
Paull and Matsumoto, 2000

Hydrate Resource Map

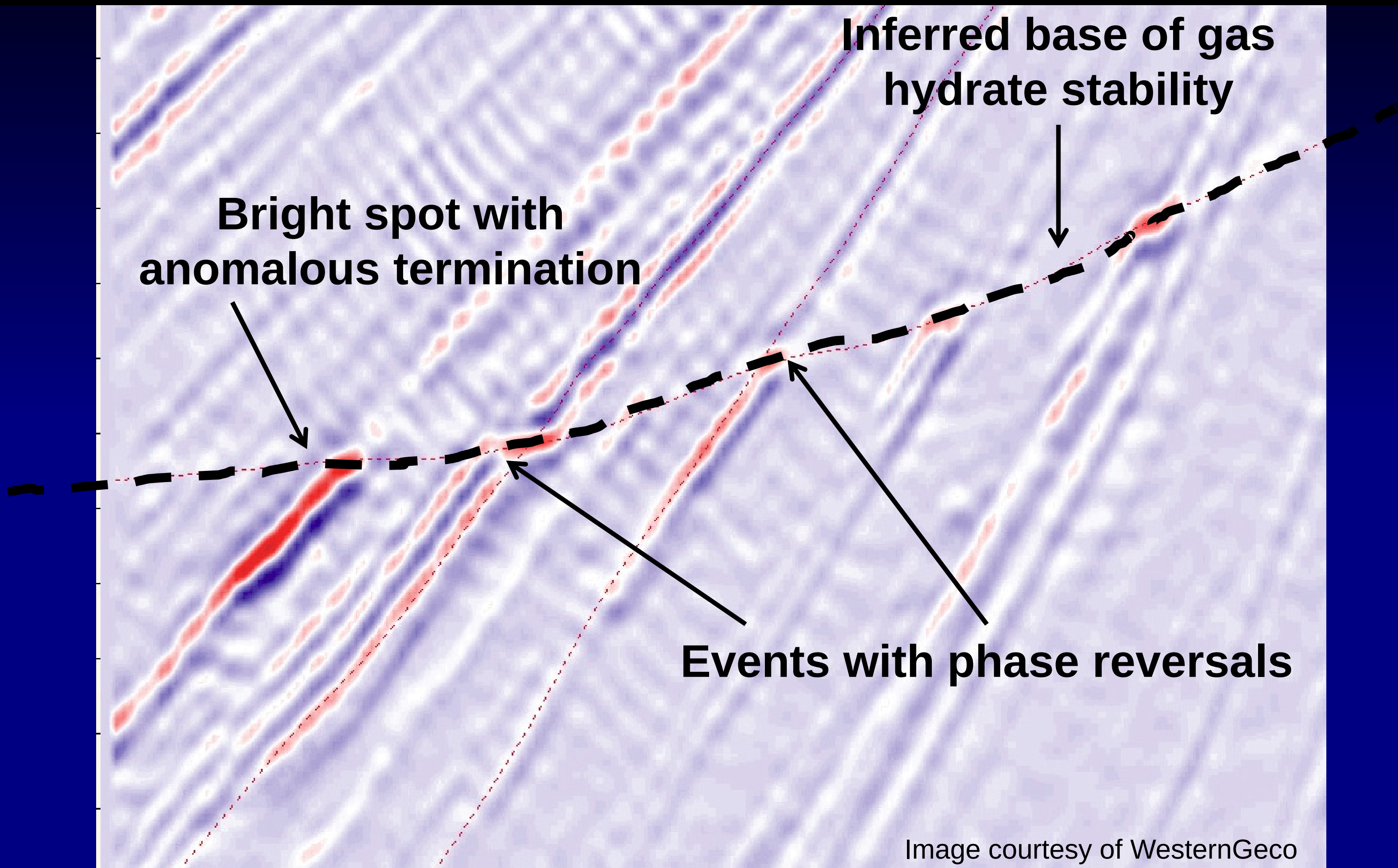


Ruppel et al, 2011

JIP Leg II field sites



Walker Ridge 313 Seismic



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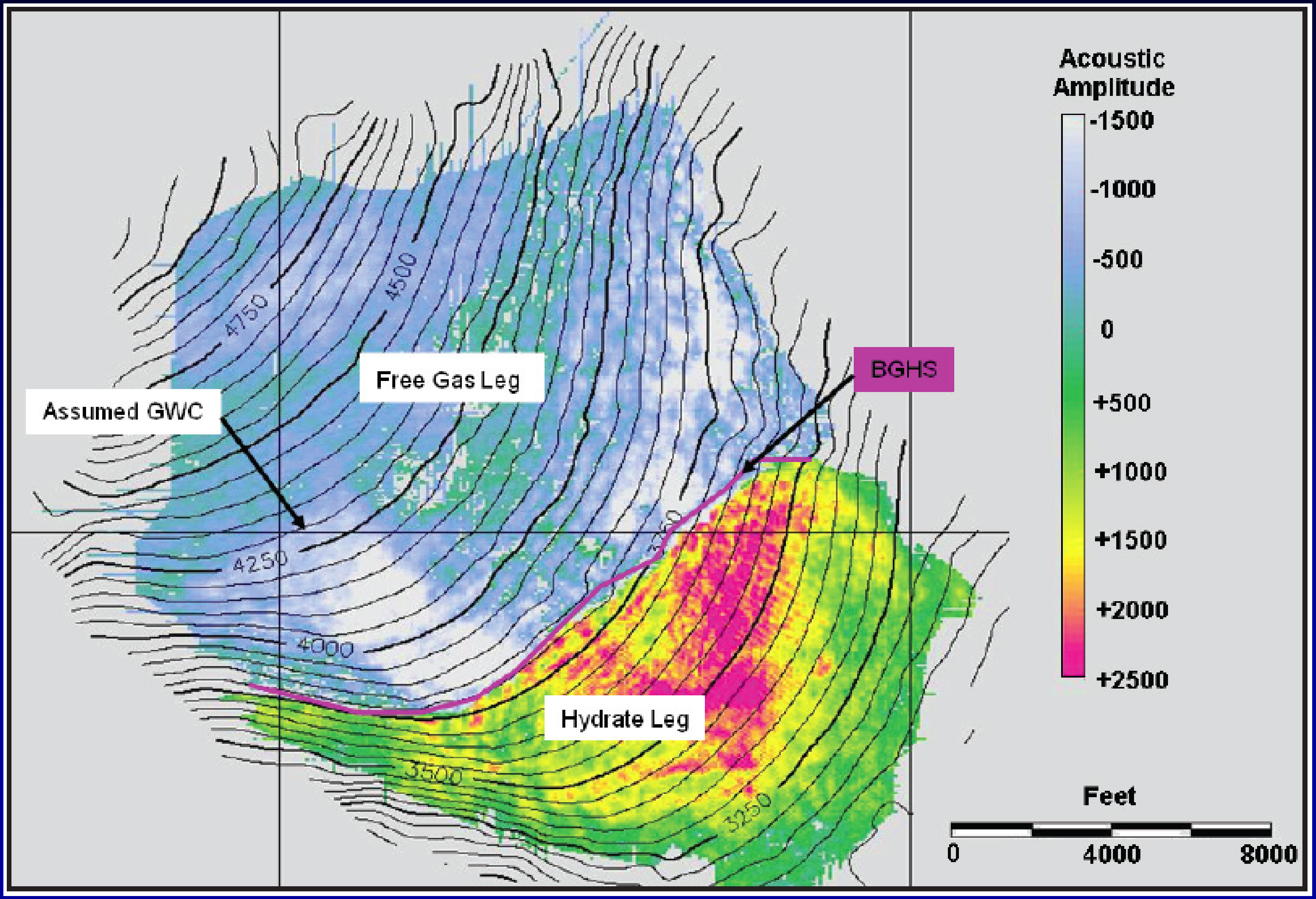
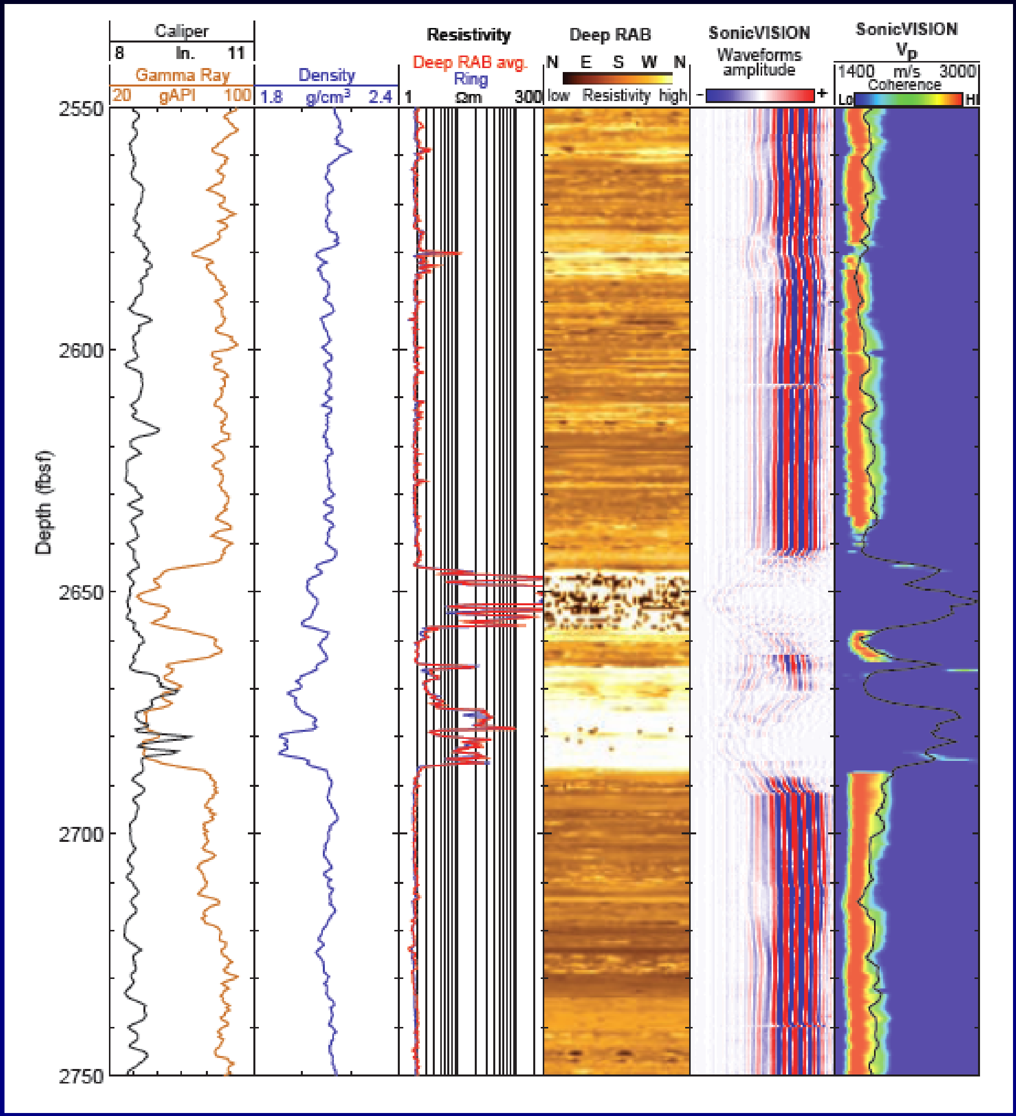
Time structure on prospective gas hydrate horizon in WR313



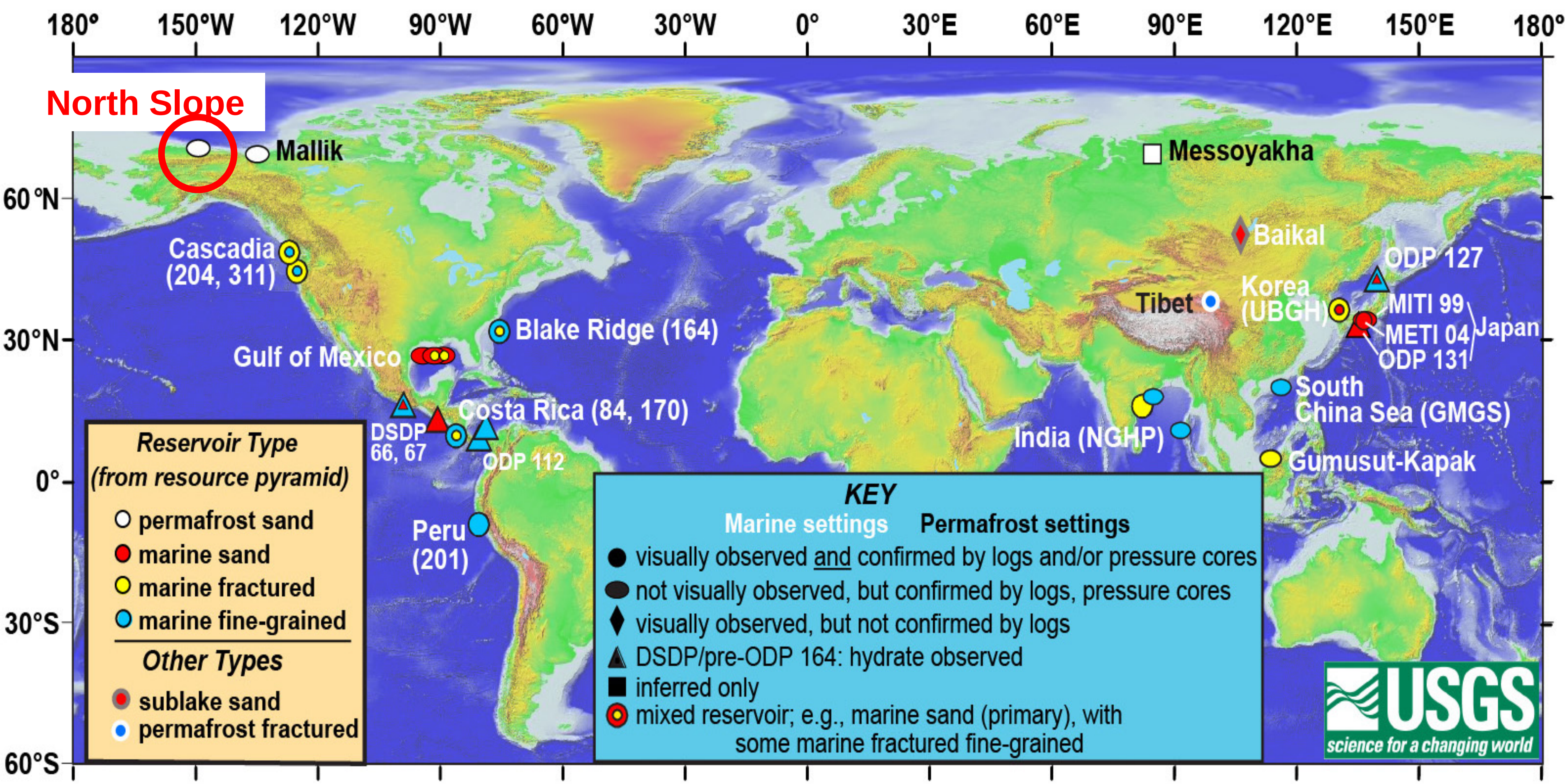
Modified after Shedd, *et al* (2009)

Gas hydrate confirmed on logs



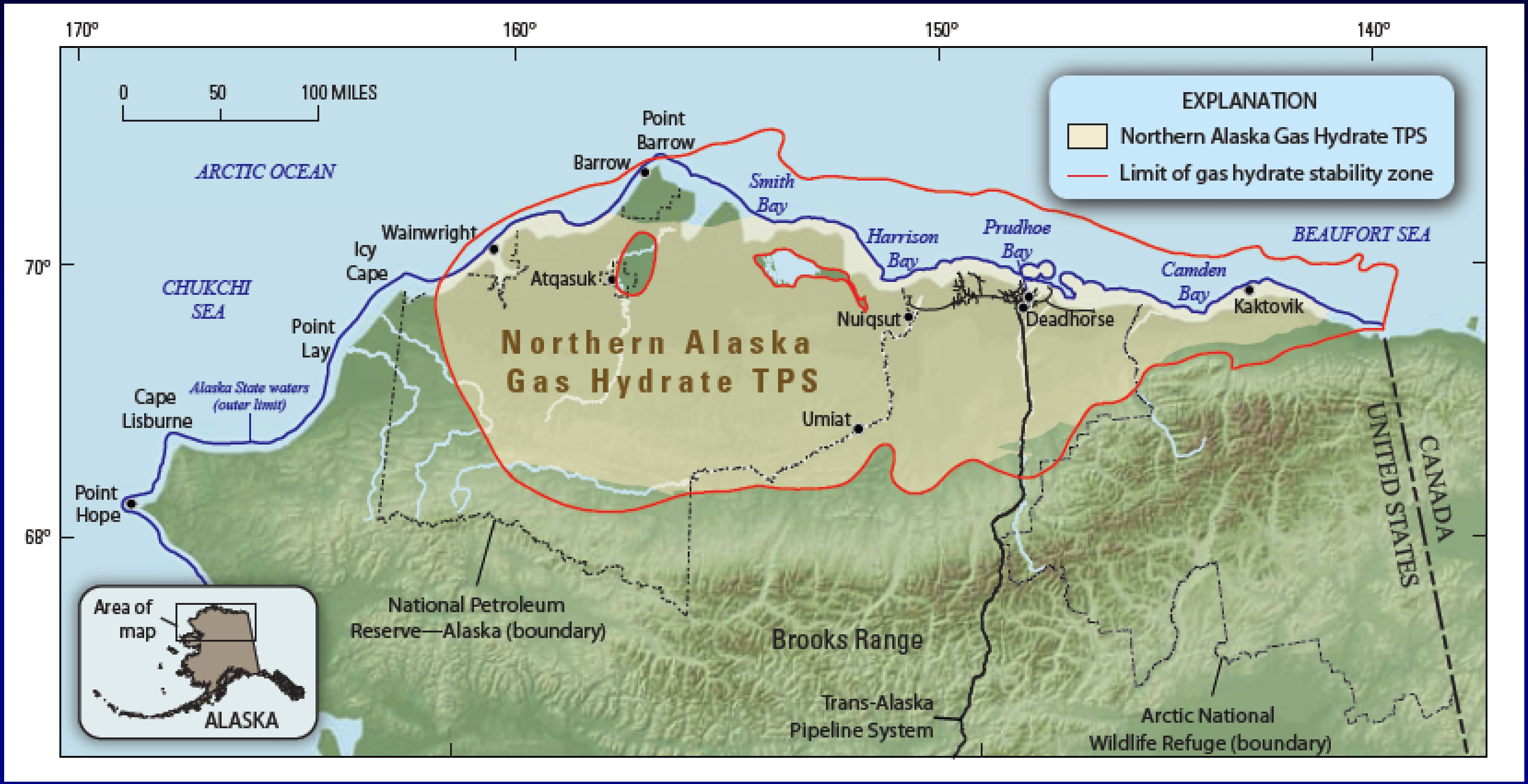
WR 313-H

Hydrate Resource Map



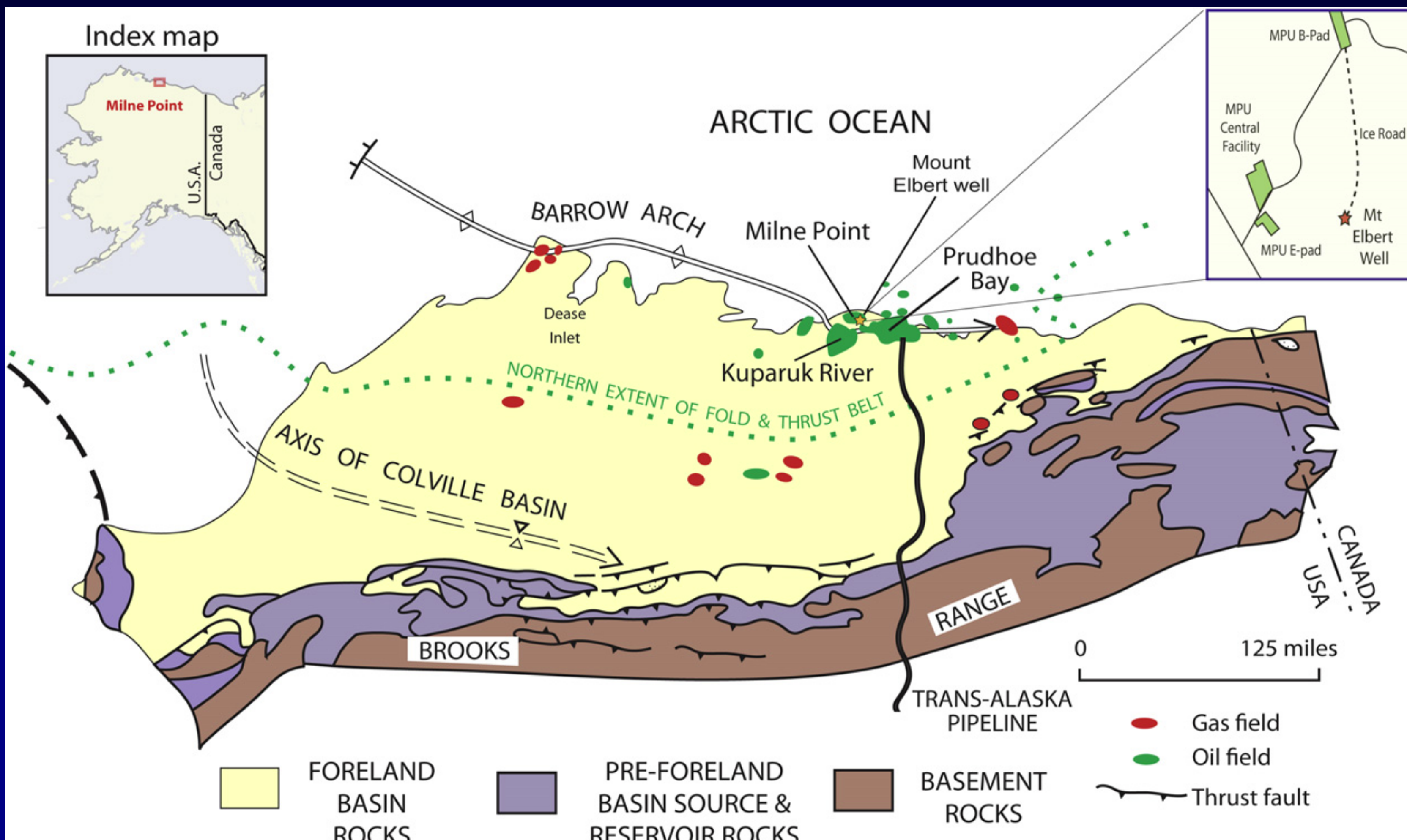
Ruppel et al, 2011

Gas-hydrate stability zone in northern Alaska – 85 Tcf

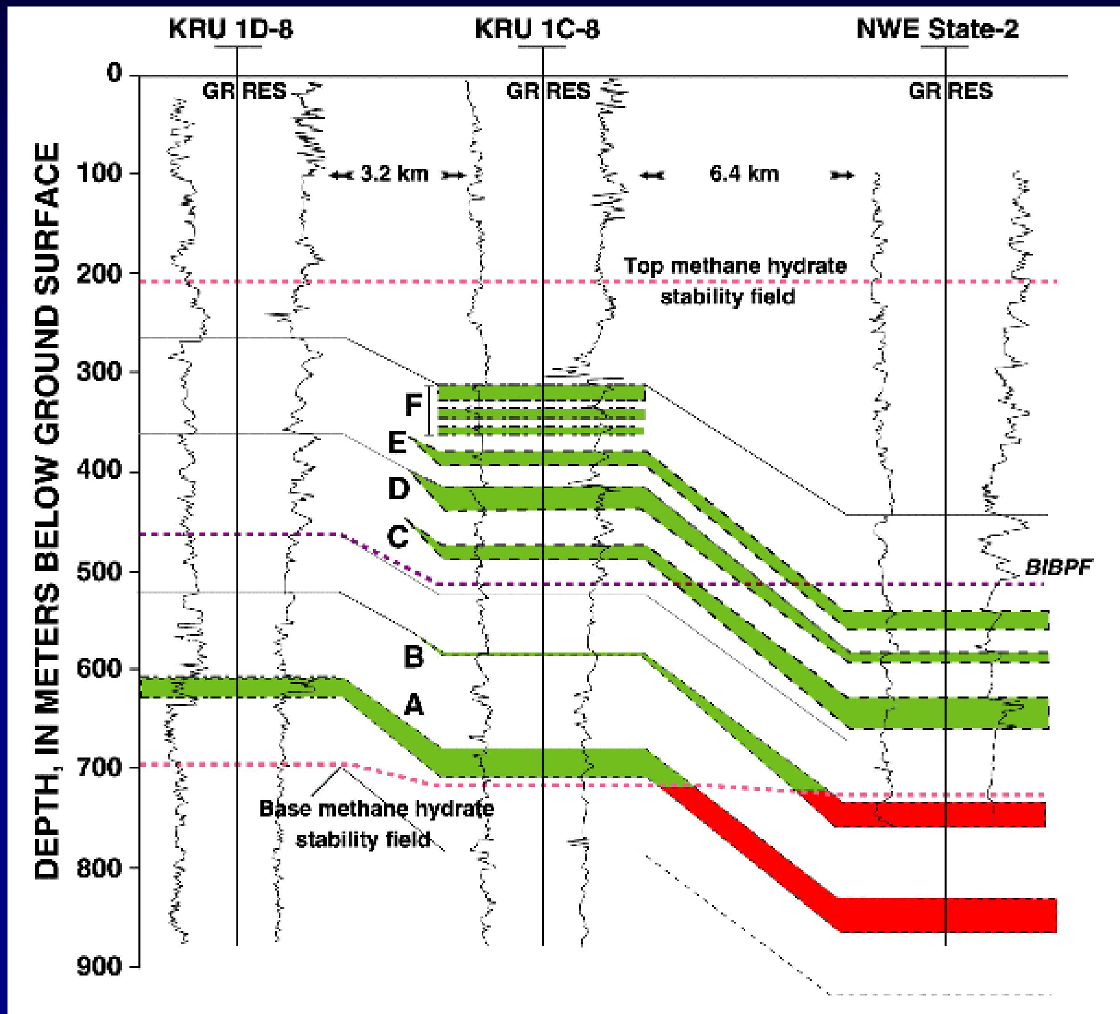


Collett et al., 2008

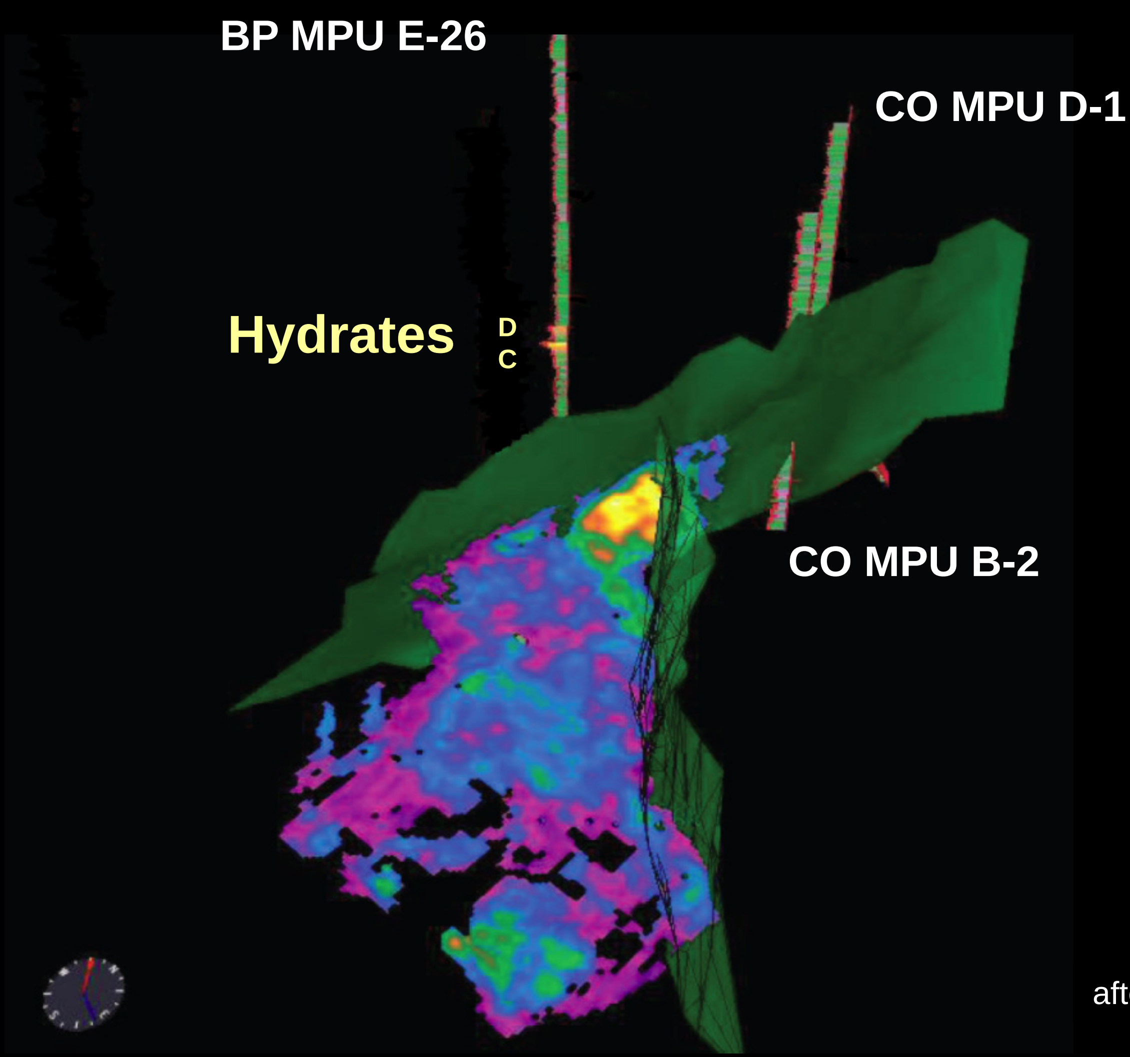
Mount Elbert well
Milne Point Unit (MPU)



Southern Milne Point Unit Gas Hydrate Accumulation

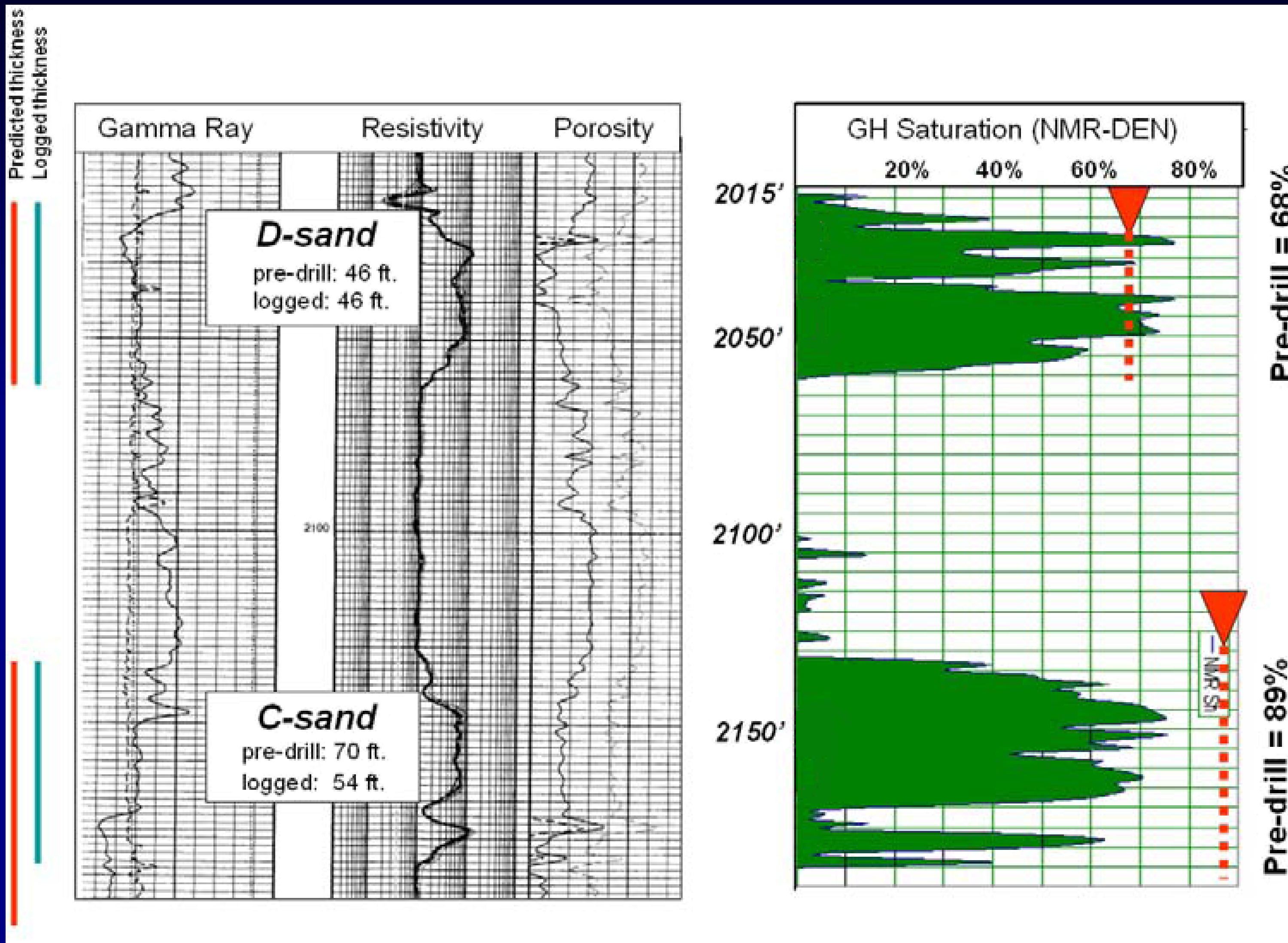


Milne Point gas-hydrate prospect

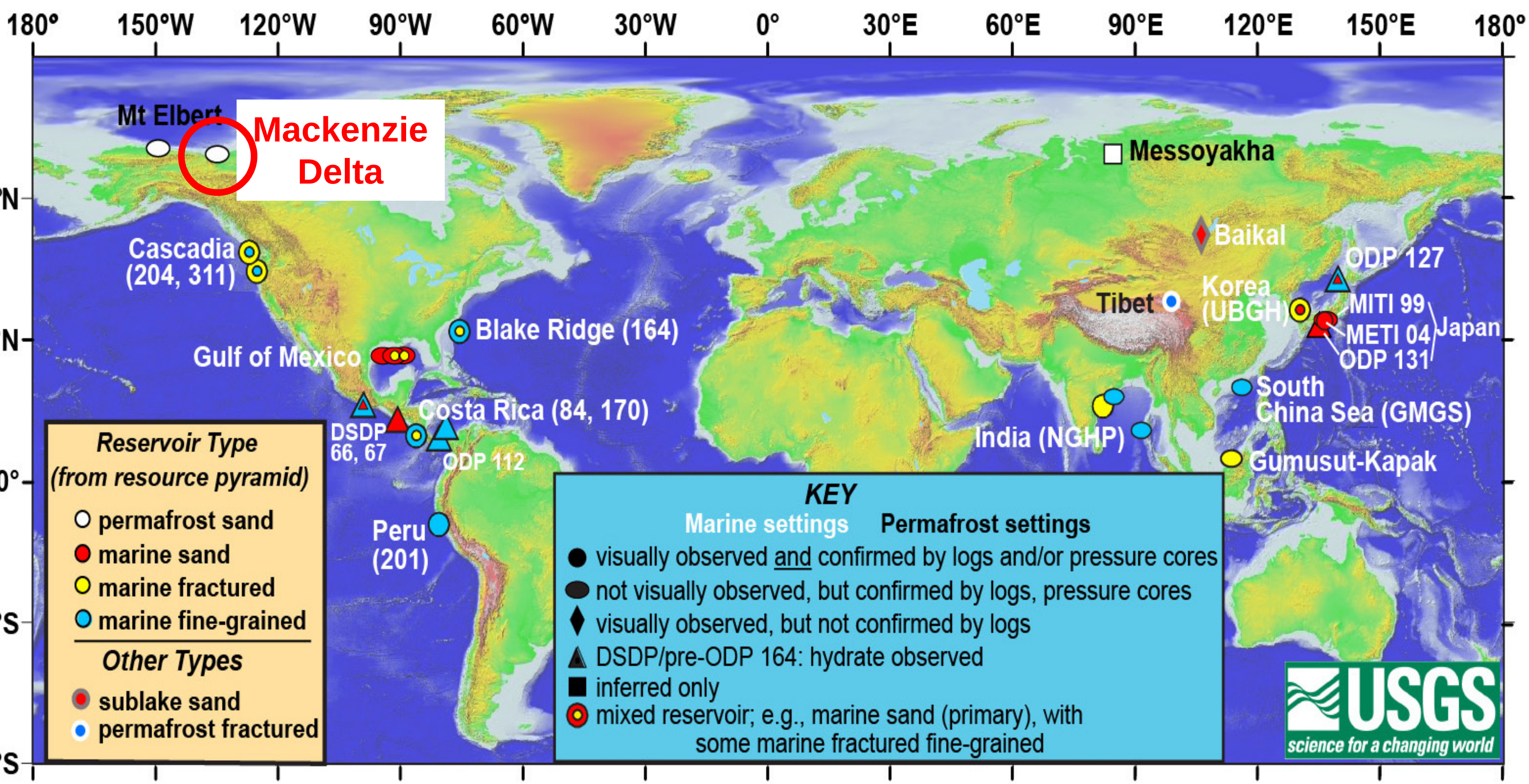


after Inks et al., 2009

Mt. Elbert well log



Hydrate Resource Map

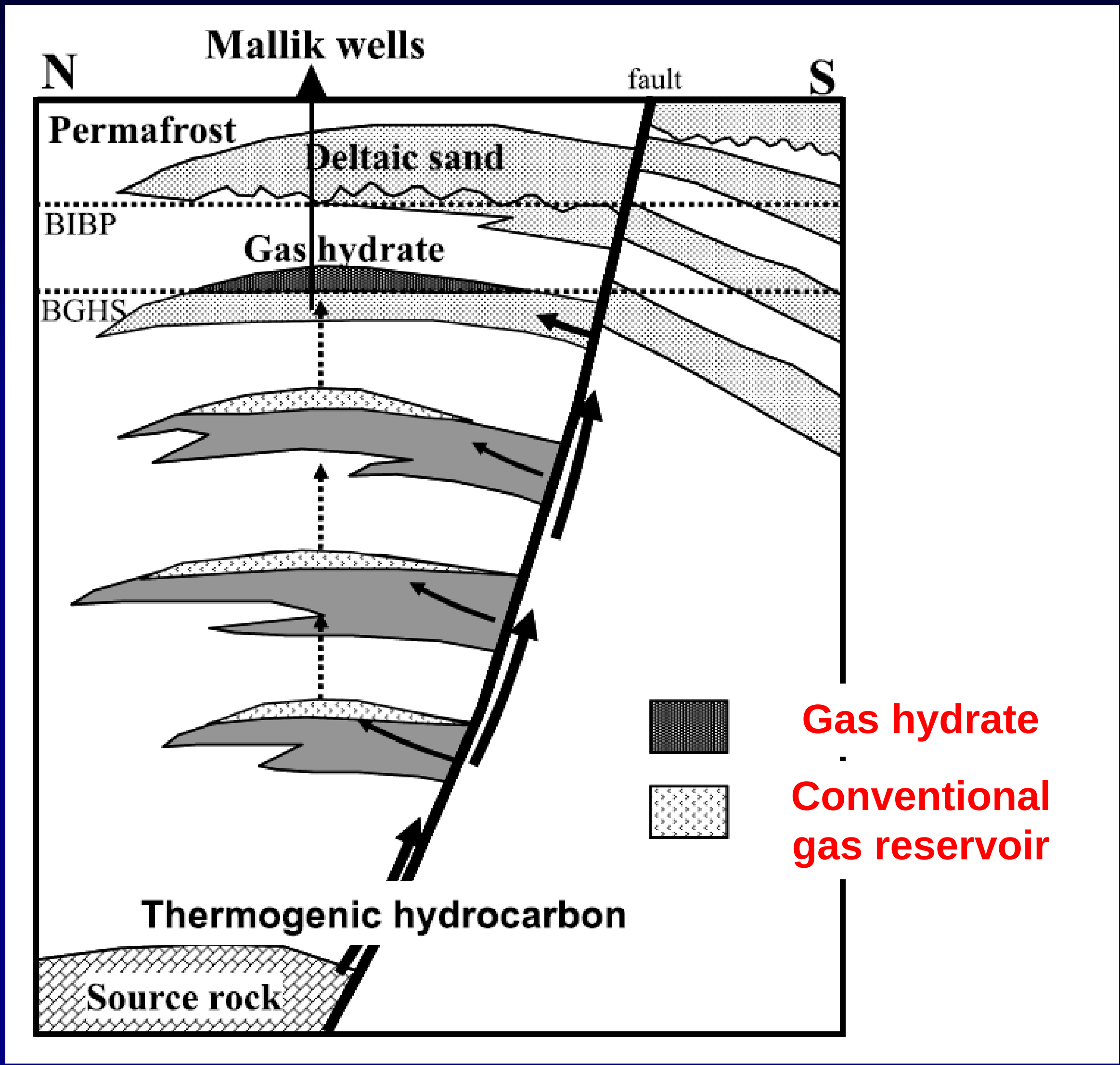


Ruppel et al, 2011

Mallik well location
Canadian Northwest Territories

http://energy.usgs.gov/other/gashydrates/mallikmap.html
06/05/11

Gas sources and migration pathways, Mallik area, Mackenzie delta



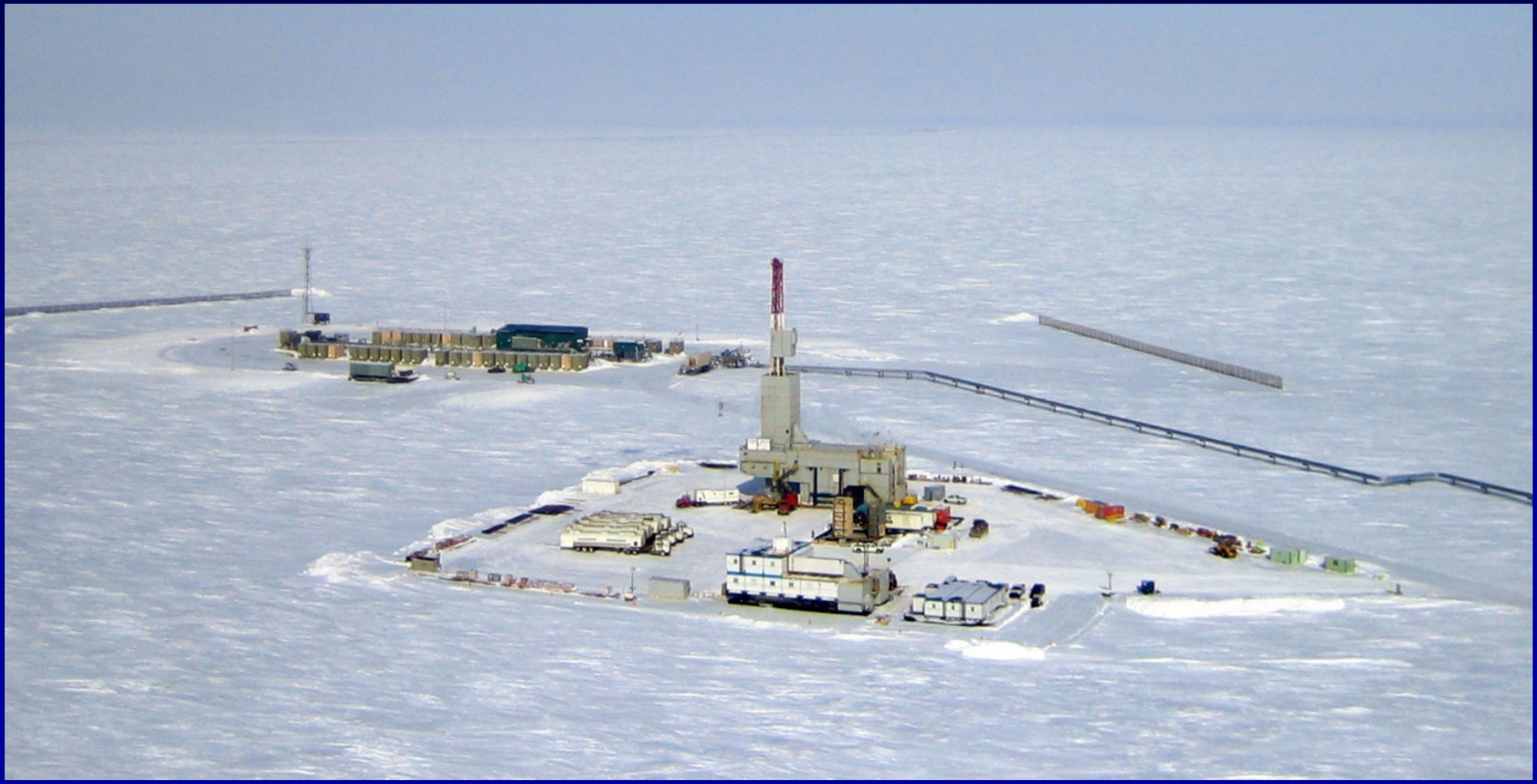
Uchida et al, 2010

Mallik 5L-38
Mackenzie Delta, Canadian Arctic

Iġnik Sikumi #1

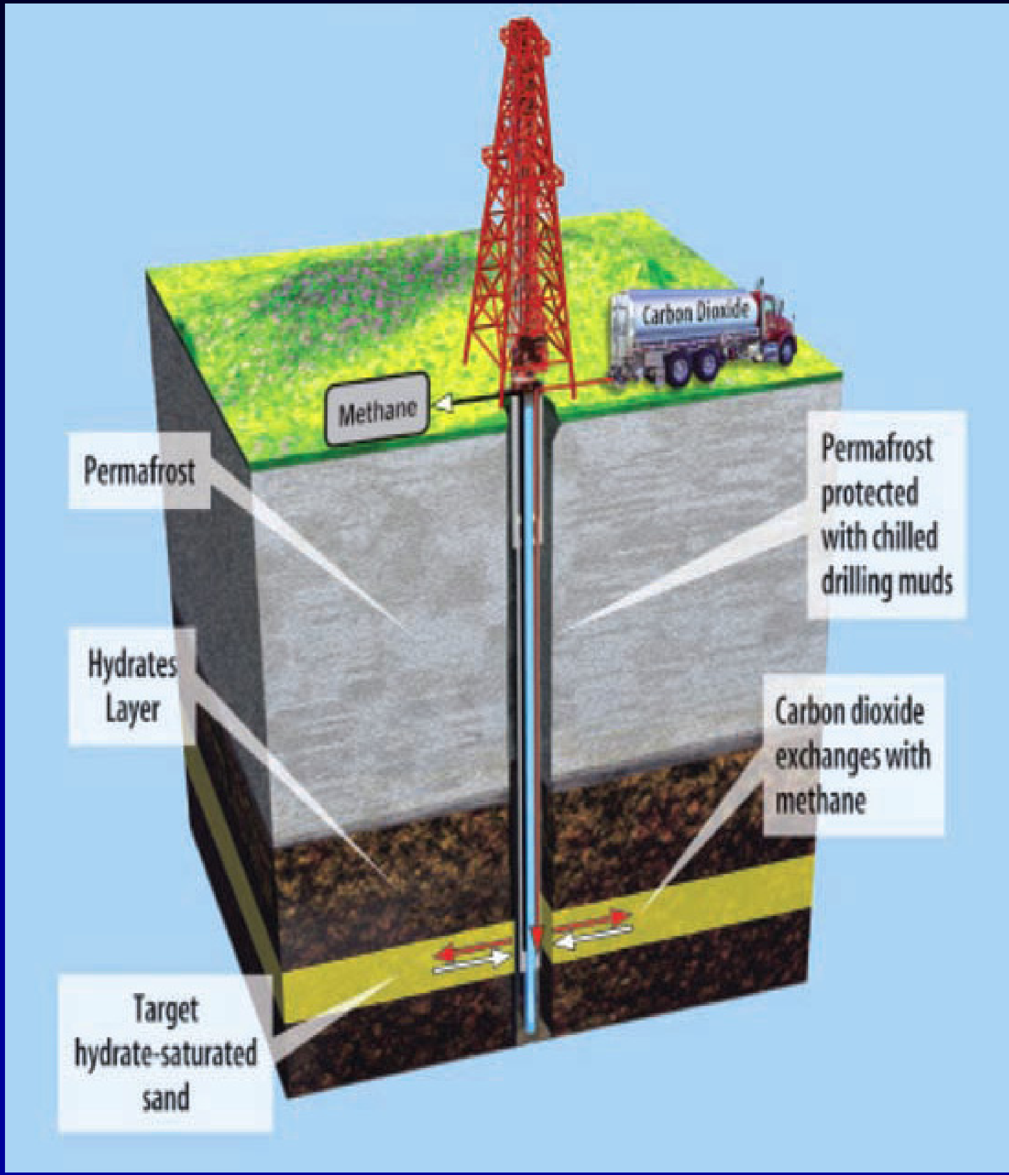
Prudhoe Bay, Alaska

TD 2,597 ft



ConocoPhillips, April 2011

CO_2 - CH_4 exchange



ConocoPhillips, 2010

Gas reserve comparisons: GOM

GOM conventional gas:

proved : 12 Tcf *
resources: 506 Tcf **

TOTAL: **518 Tcf**

GOM hydrates (mean):

sands: 6,717 Tcf *

TOTAL: **21,444 Tcf ***

* EIA, 2010
** Potential Gas Committee, 2011

* USGS, 2010

Hydrate reserve estimates

U.S. conventional gas:

proved : 284 Tcf*
resources: 1,898 Tcf **

TOTAL: **2,182 Tcf**
(incl. shale gas at ~ 850 Tcf)

U.S. hydrates (mean):

TOTAL: **318,000 Tcf ***

* EIA, 2010
** Potential Gas Committee, 2011

* USGS, 2010

Hydrate reserve estimates

Global conventional gas:

proved : 6,621 Tcf *

TOTAL: **15,500 Tcf ****

Global hydrate resources:

TOTAL: ??? – **4,200,000 Tcf ***

* Congressional Research Service, 2010
** USGS 2011

* USGS, 2010

Conclusions

- Methane hydrates represent a potentially vast domestic and global resource of natural gas
- Seismic techniques combined with Petroleum System analysis will drive prediction, identification, and evaluation of hydrate resources

National Research Council Canada, 2008

- Methane hydrates will be an important component of America's future energy security and will position natural gas as the fuel of choice for years to come