Geophysikalische Untersuchungen zu maritimen Gashydratvorkommen

Michael Riedel

FB4 Marine Geodynamik, GEOMAR

HELMHOLTZ
SPITZENFORSCHUNG FÜR
GROSSE HERAUSFORDERUNGEN

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Geophysikalische Untersuchungen zu maritimen Gashydratvorkommen

- Gas Hydrate – was ist das?
- Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?
  - Seismische Verfahren
  - Elektromagnetische Verfahren
- Die wichtigsten Meilensteine in der Gashydrat-Exploration
  - Akademischen Forschung und semi-kommerzielle Projekte
- Kommerzielle Nutzung von Gas Hydraten – ist das Möglich?
  - Gas Hydrate Produktionstests (Technische Herausforderungen)
  - Die Vision von CO_2-neutraler Nutzung

Gas Hydrate – was ist das?

A solid, ice-like chemical substance made out of water and natural gas (mainly CH_4).

$1m^3$ gas hydrate

= 160 m^3 gas

Photo credit: GEOMAR

Photo credit: U. of Victoria

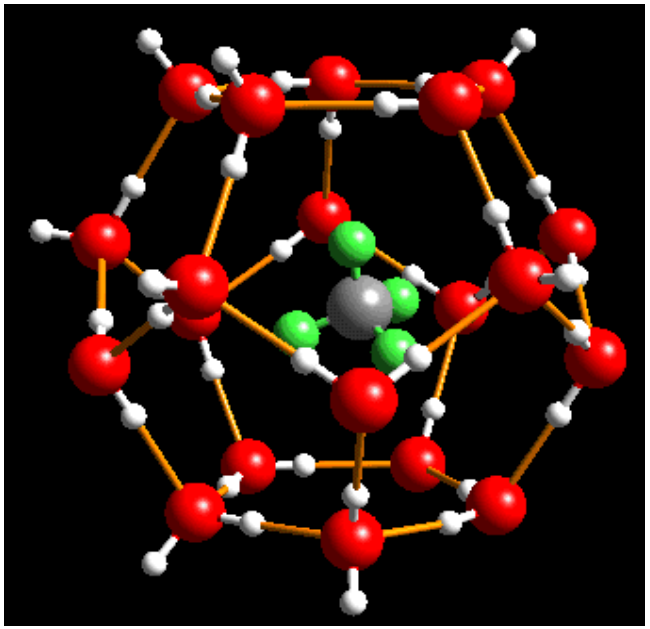

Photo credit: USGS

Gas Hydrate – was ist das?

Stable under special conditions of low temperatures (5-20°C) and high pressure.


Photo credit: GEOMAR, Kiel


Photo credit: GEOMAR, Kiel

It can be found naturally along all continental slopes in water depths exceeding ~600 m as well as in Arctic regions below permafrost.

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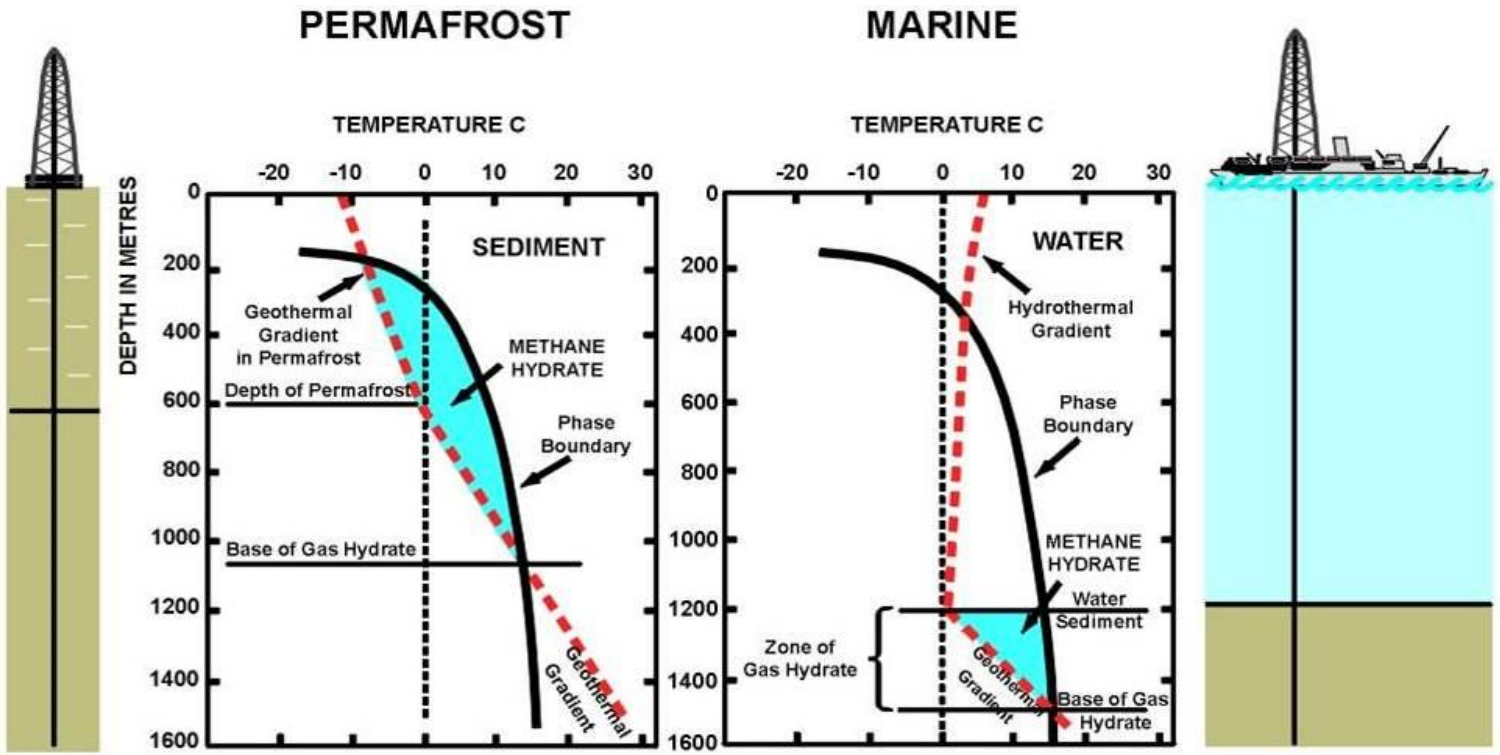
Das Phasen-Diagramm

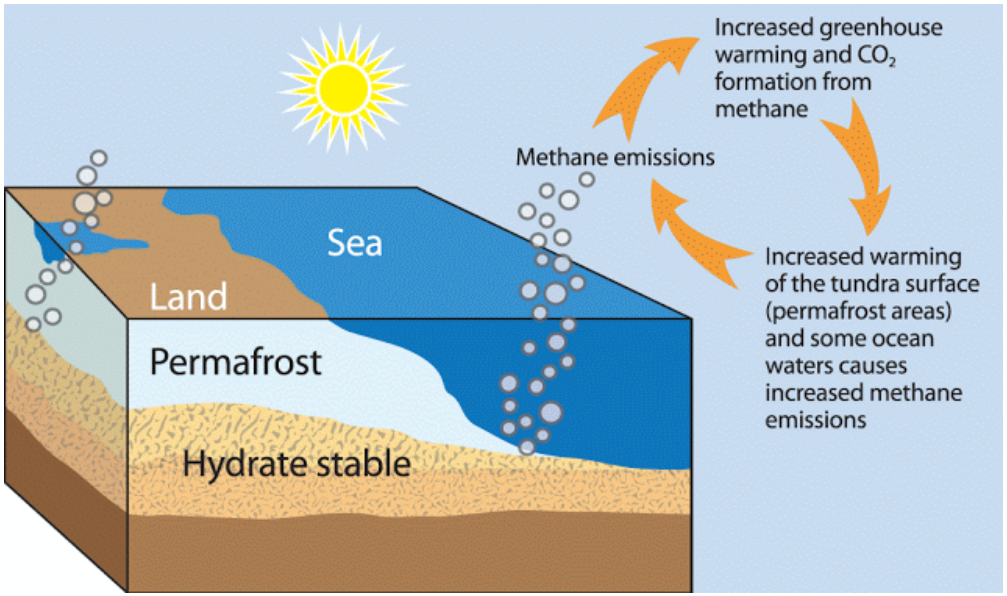
Gas Hydrat Stabilität ist abhängig von
Druck, Temperatur, Gas-Zusammensetzung, Salzgehalt



Modified from Kvenvolden 1988a

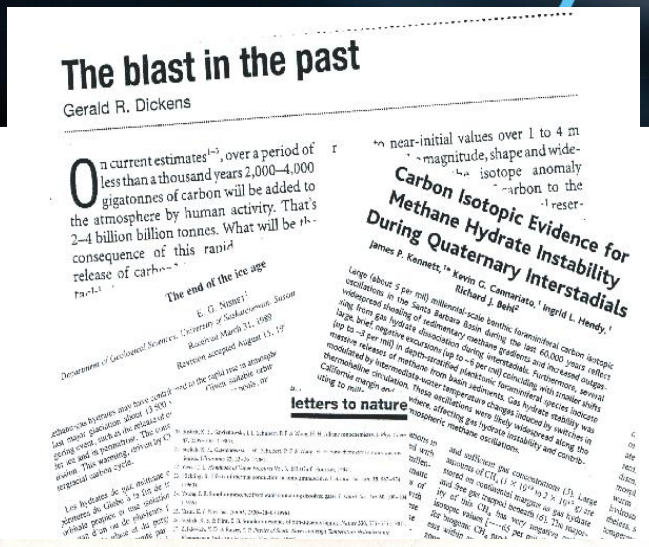
Gas Hydrate – Methan - Klima

Methan ist ein stärkeres Treibhausgas als CO_2 (bei Faktor ~25) aber verweilt kürzere Zeit in der Atmosphäre



http://globalclimatechangenow.blogspot.com/p/clathrate-gun-hypothesis.html

https://en.wikipedia.org/wiki/Clathrate_gun_hypothesis


The blast in the past

Gerald R. Dickens

On current estimates[1–3], over a period of less than a thousand years 2,000–4,000 gigatonnes of carbon will be added to the atmosphere by human activity. That's 2–4 billion billion tonnes. What will be the consequence of this rapid release of carbon

The end of the ice age

Carbon Isotopic Evidence for Methane Hydrate Instability During Quaternary Interstadials

James P. Kennett,* Kevin G. Cannariato,† Ingrid L. Hendy,† Richard J. Behl*

letters to nature

near-initial values over 1 to 4 m magnitude, shape and wide- isotope anomaly carbon to the reser-


New Scientist 6 May 1989

Methane: the hidden greenhouse gas

Methane from cows, rubbish tips and rice fields is warming the Earth. Car exhausts may help the process. But methane from the Arctic tundra could be most damaging of all

Fred Pearce

IT IS hard to measure the methane in a cow's farts. But Dieter Ehhalt has made an estimate. It is hardly an easy task to count how many cattle there are in the world. But the West German chemist has tried to do that too. Ehhalt's answers are, respectively, 200 grams per day and 1300 million. Together, they suggest that the world's cattle emit into the atmosphere approaching 100 million tonnes of methane each year, enough to warm up the planet.

Public concern about the greenhouse effect and its potential to warm the Earth's atmosphere has so far focused on carbon dioxide, unleashed into the air as we burn coal and oil and chop down trees. But methane is also a greenhouse gas, second in importance to carbon dioxide. Like carbon dioxide,

Kennett et al., 2003

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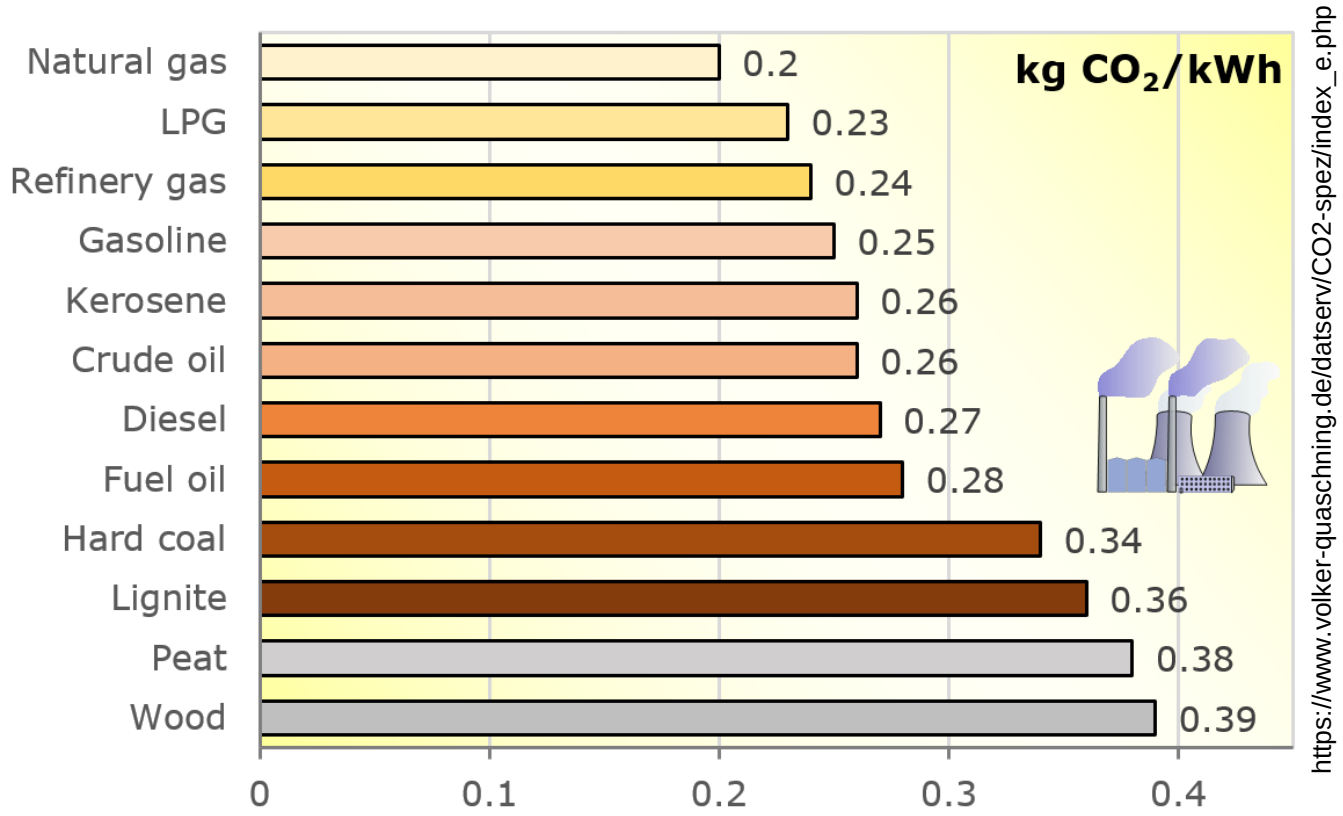
Gas Hydrate – Methan - Klima



Ist Erdgas aus Hydraten ein “sauberer” fossiler Brennstoff ?

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Flow-Assurance – Plugs in Pipelines

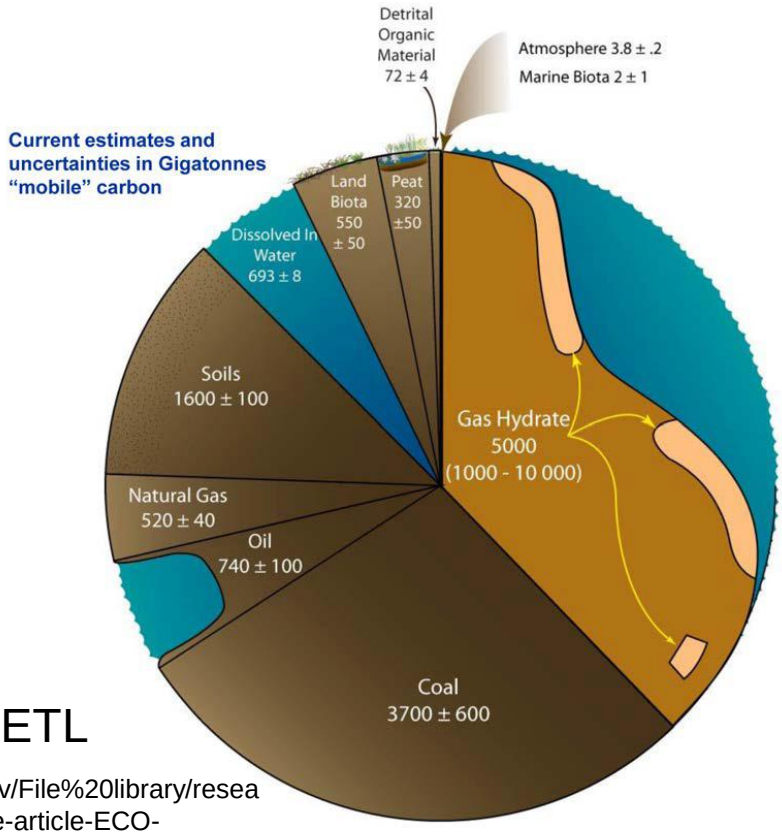
Photo credit: Centre for gas hydrate research, Heriot Watt University

Photo credit: Centre for gas hydrate research, Heriot Watt University

Seit den 1930’er and 40’er Jahren wurde viel an der Thermodynamik von GH geforscht (Dendy Sloan)

Gas Hydrate – was ist das?

Energy resource and emissions



Source: NETL

https://netl.doe.gov/File%20library/research/oil-gas/hydrate-article-ECO-Digital.pdf

11,000 Gt C
(Kvenvolden, 1988a)
Nach ersten Bohrergebnissen

Oder doch nur 1800 GT C
(Milkov, 2004) … ???

Die Zahl schwankt stark und ist nur schlecht abzuschätzen

Ausserdem:
Wieviel von diesem "Kohlenstoff" kann überhaupt kommerziell gefördert werden?
(siehe dazu auch Diskussion bei Boswell and Collett, 2011)

See also: Ruppel and Kessler, 2017

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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Physikalische Eigenschaften der Sedimente

	Vp	Vs	Elektr. Widerstand	Porosität	Dichte	Gamma	Permeabilität	Attenuation
Sediment + Hydrat	↑	↑	↑	—	+* —	+* —	↓	↑
Sediment +Karbonat	↑	↑	↑	↓	↑	↘	↓	↘
Sediment + Gas	* ↓	* —	↑	↓	↓	↓	* —	↑

*: < 25% Hydrate
+: Hydrat als Porenfüllung

Was eignet sich? → Seismik
→ Elektromagnetik

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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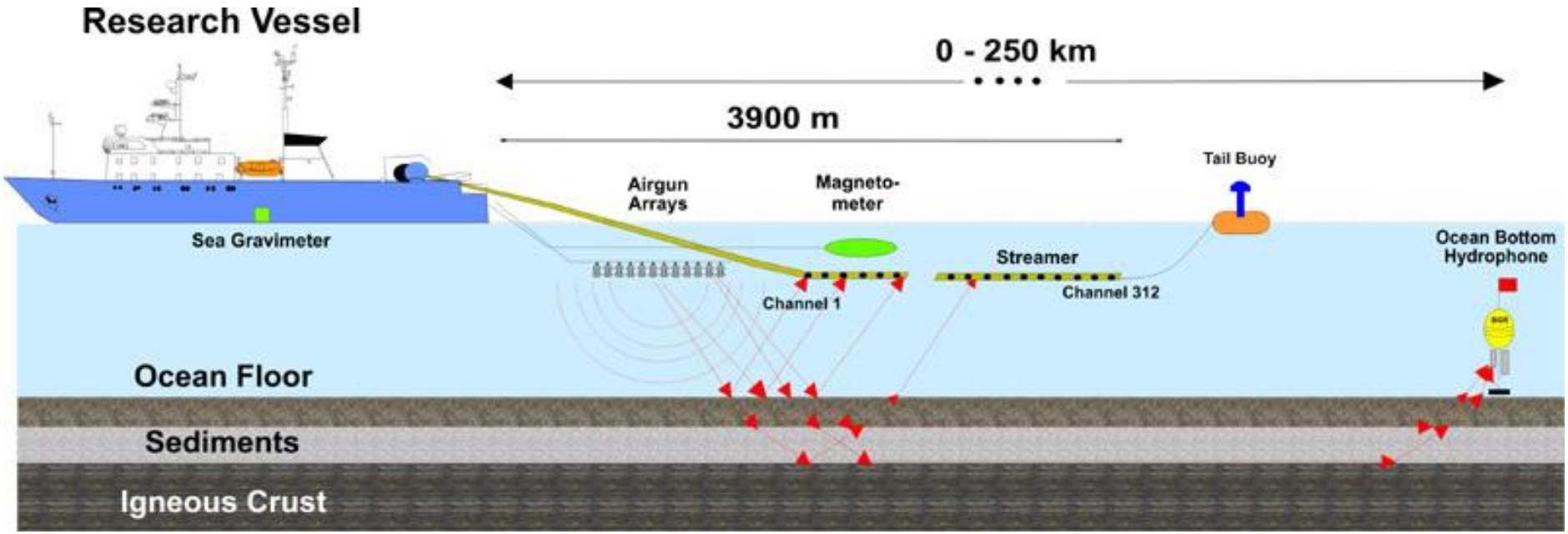
Seismik – akustische Abbildung des Untergrundes



https://www.bgr.bund.de/EN/Themen/GG_Geophysik/Marine_Geophysik/Seismik/Bilder/erfassung_p_en.html

Schematische Darstellung
Marine Mehrkanal-Seismik

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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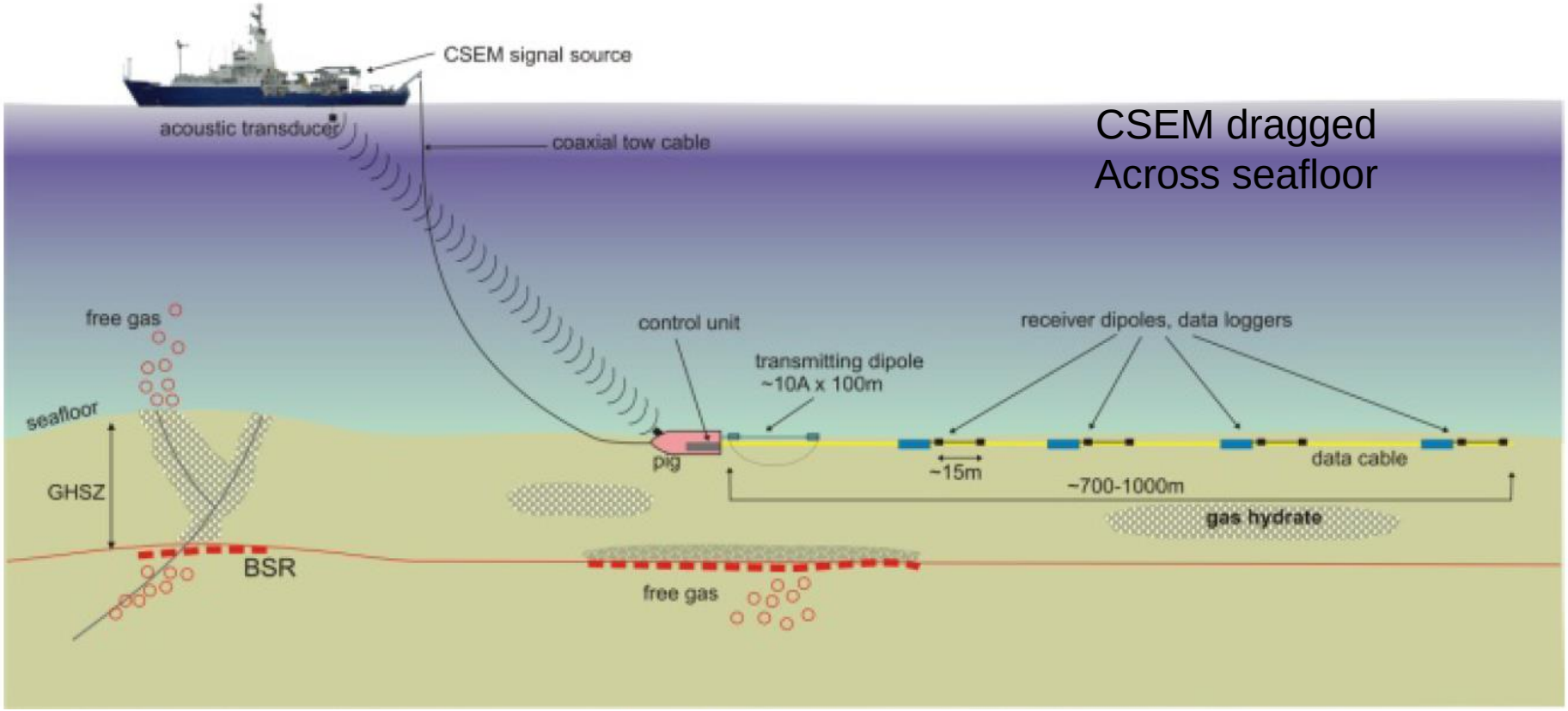
Controlled-Source Electromagnetic (CSEM) – resistivity imaging



Schwalenberg and Engels, 2011

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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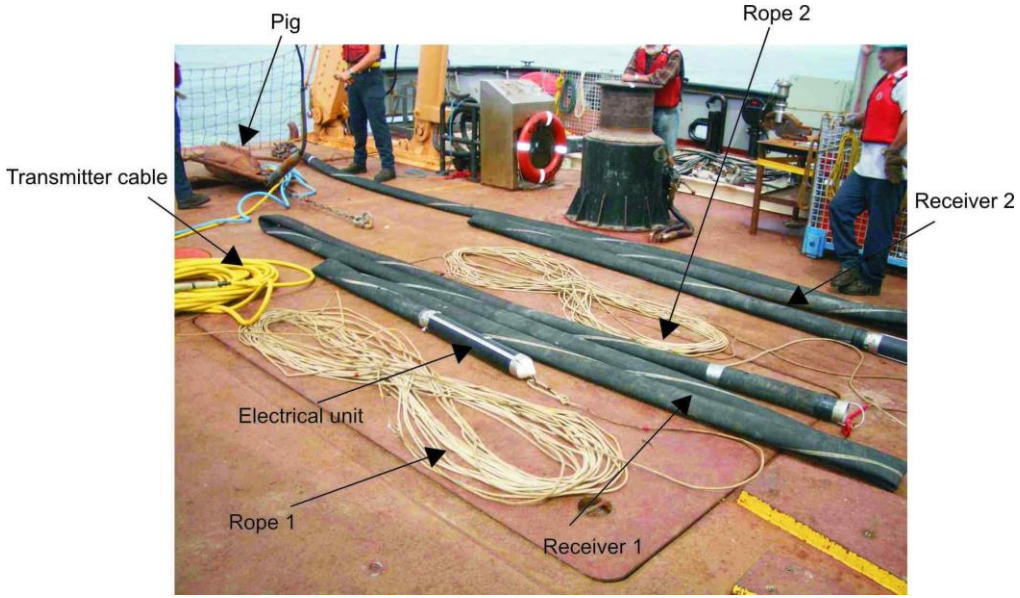
Controlled-Source EM



Schwalenberg and Engels, 2011

Report of Cruise PGC04-08
C.C.G. Vessel John P. Tully
22 July – 10 August 2004
(unpublished, by G.D. Spence & E.C. Willoughby)

www.geopotenzial-nordsee.de

Contact: **Dr. Katrin Schwalenberg**

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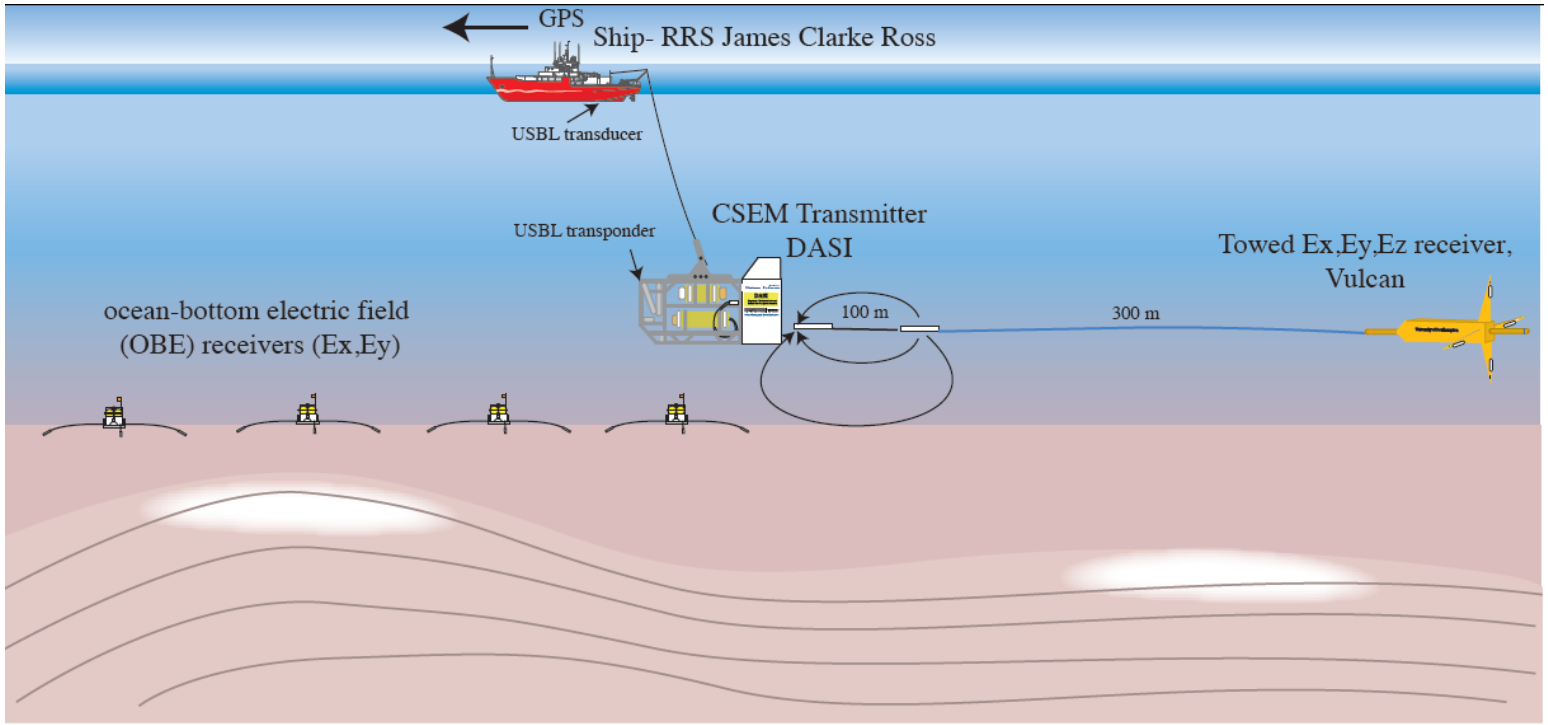
Controlled-Source EM

Towed System

Used by *SOC* + *SCRIPPS*



E. Attias, A. Best, T. Minshull, K. Weitemeyer, Southampton Ocean. Centre
https://www.southampton.ac.uk/oes/research/projects/integration_of_csem_and_seismic_data.page

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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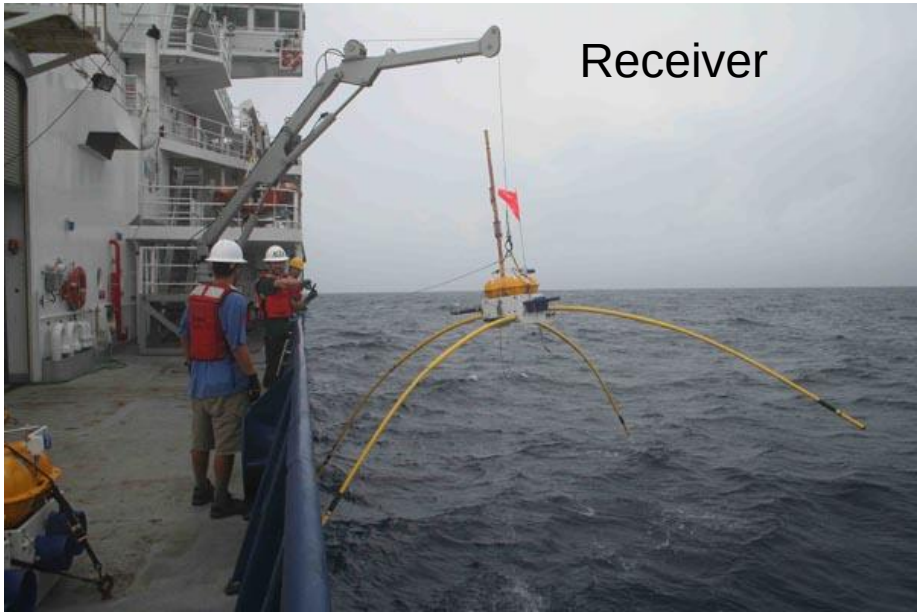
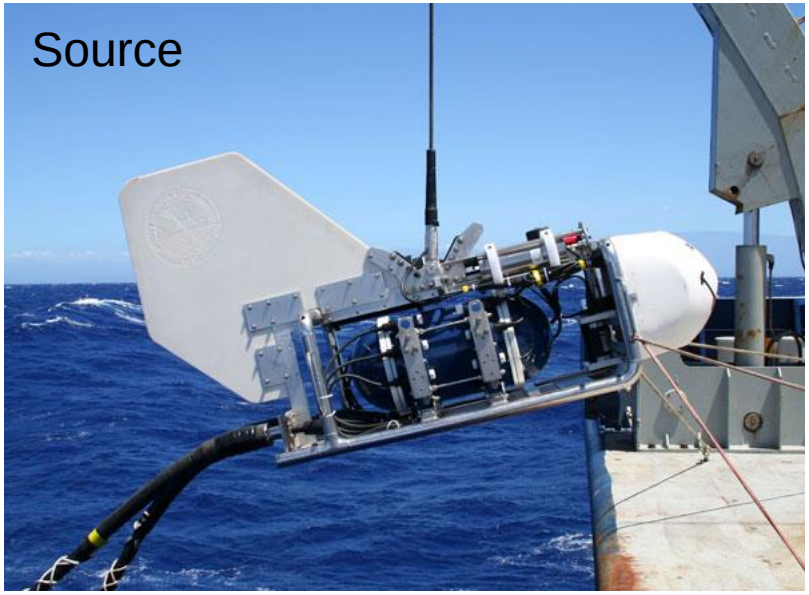
Controlled-Source EM



http://marineemlab.ucsd.edu/Projects/GoMHydrate/index.html



http://marineemlab.ucsd.edu/instruments/suesi_images.html

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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Bisher haben sich **seismische Methoden** durchgesetzt

→ hohe Auflösung des Untergrundes (1-5 Meter, je nach Frequenz)

→ Gas Hydrat Konzentration gut abschätzbar (+/- 5%)

CSEM noch eher “experimentell”

→ geringe Auflösung (10-50 Meter vertikal und >500 m lateral)

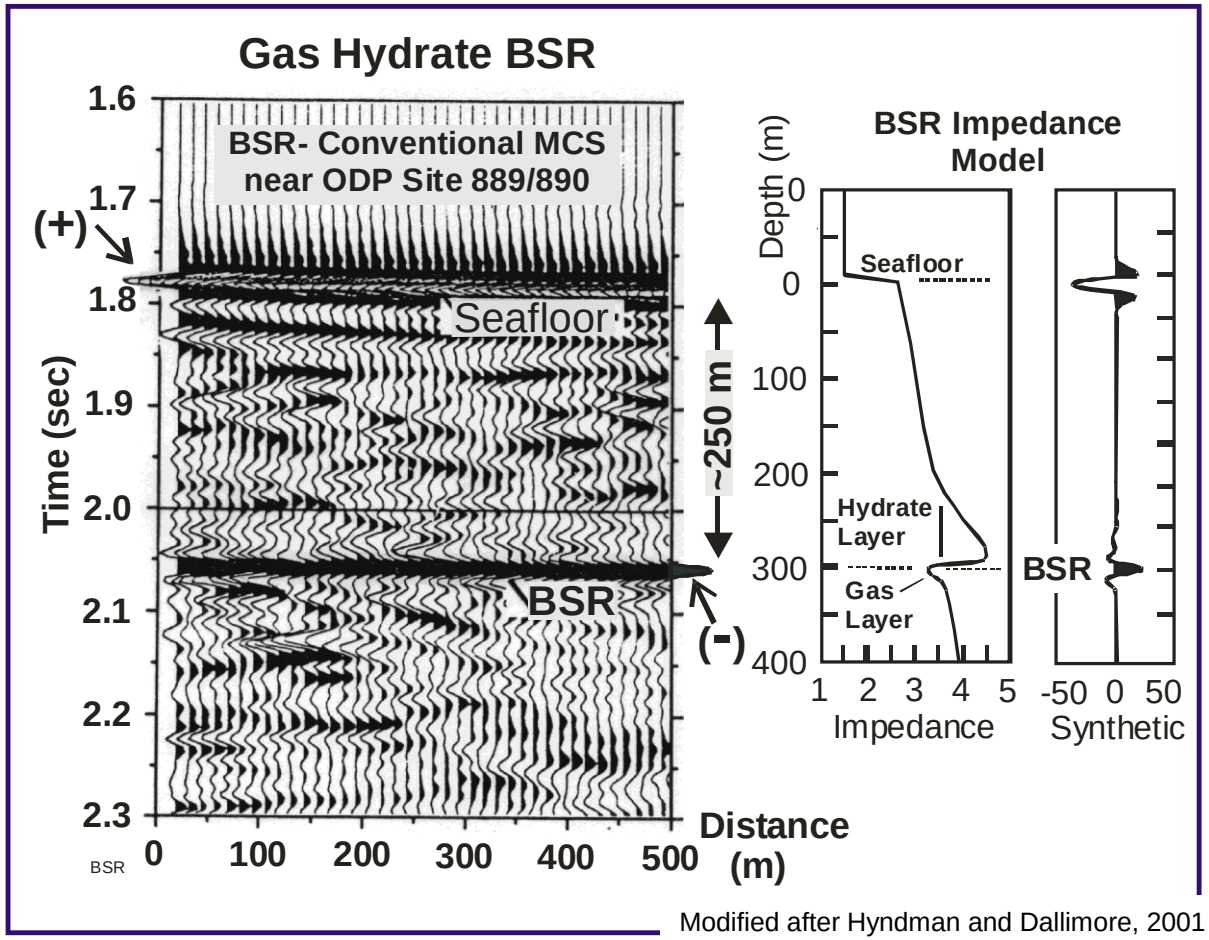
→ Gas Hydrat Konzentration schlecht abschätzbar (+/- 10-20%)

→ Kein Unterschied im Abbild zwischen freiem Gas und Gas Hydrat (beide haben hohen elektrischen Widerstand)

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

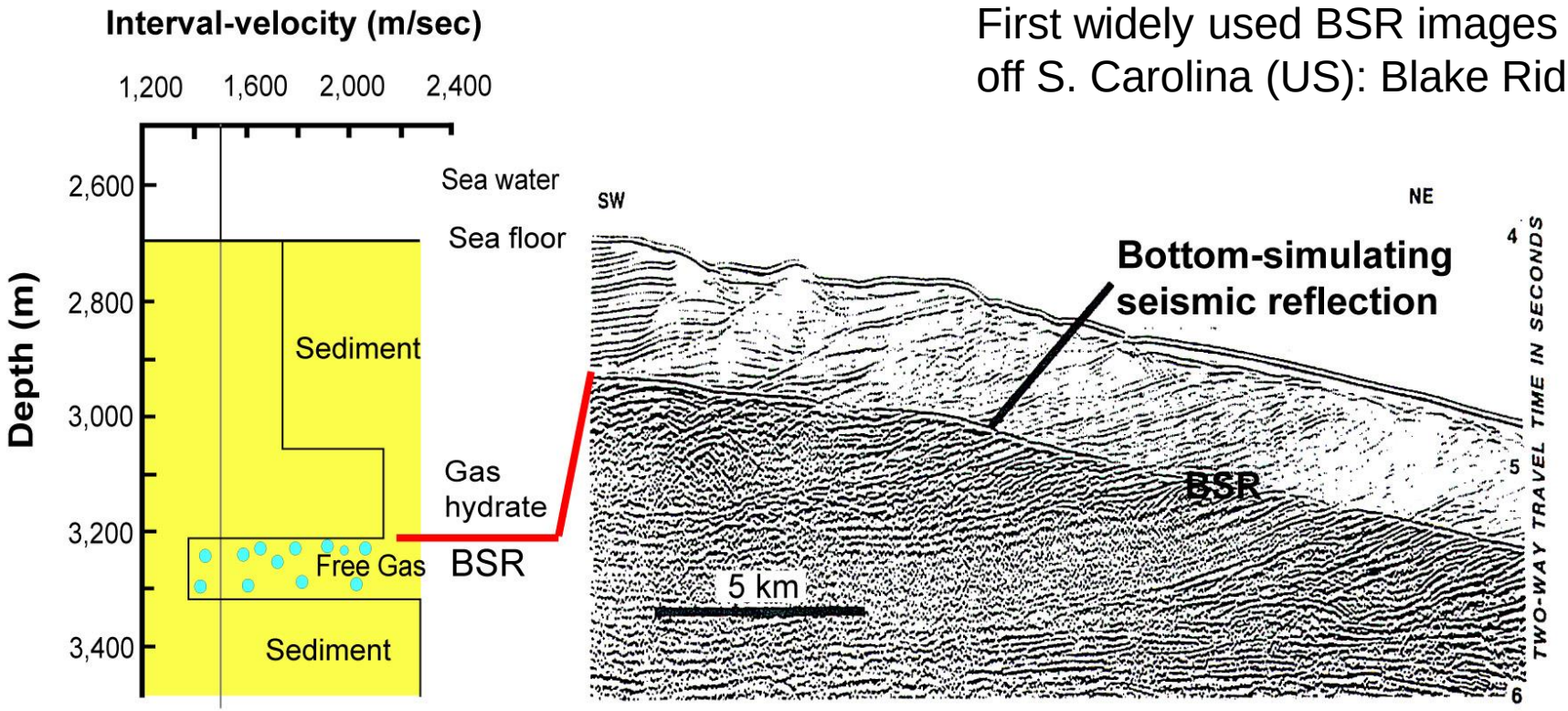
Seismik – der Klassiker

Bottom-Simulating Reflektor “BSR”



Modified after Hyndman and Dallimore, 2001
Hyndman et al., 2001

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

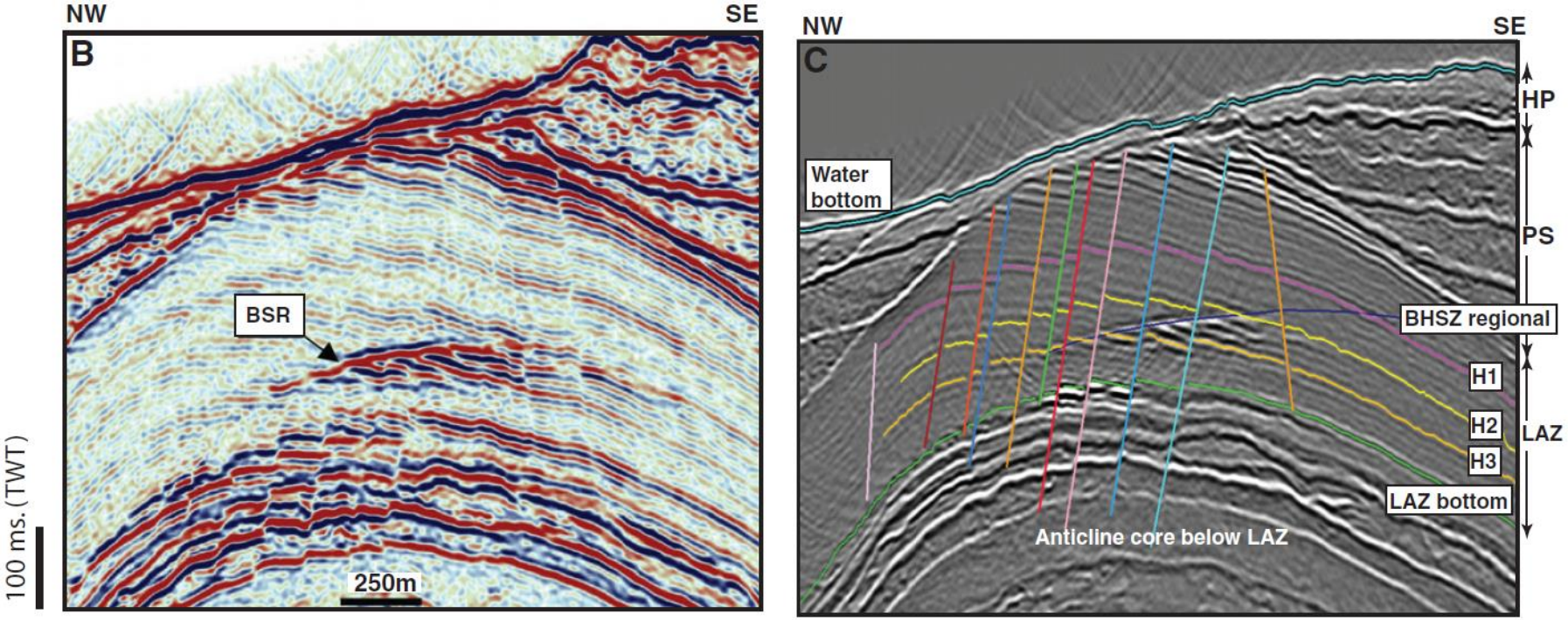


First widely used BSR images off S. Carolina (US): Blake Ridge

Shipley et al., 1979
Bohrmann & Torres, 2006

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

BSR can be cutting stratigraphy



Laird and Morley, 2011

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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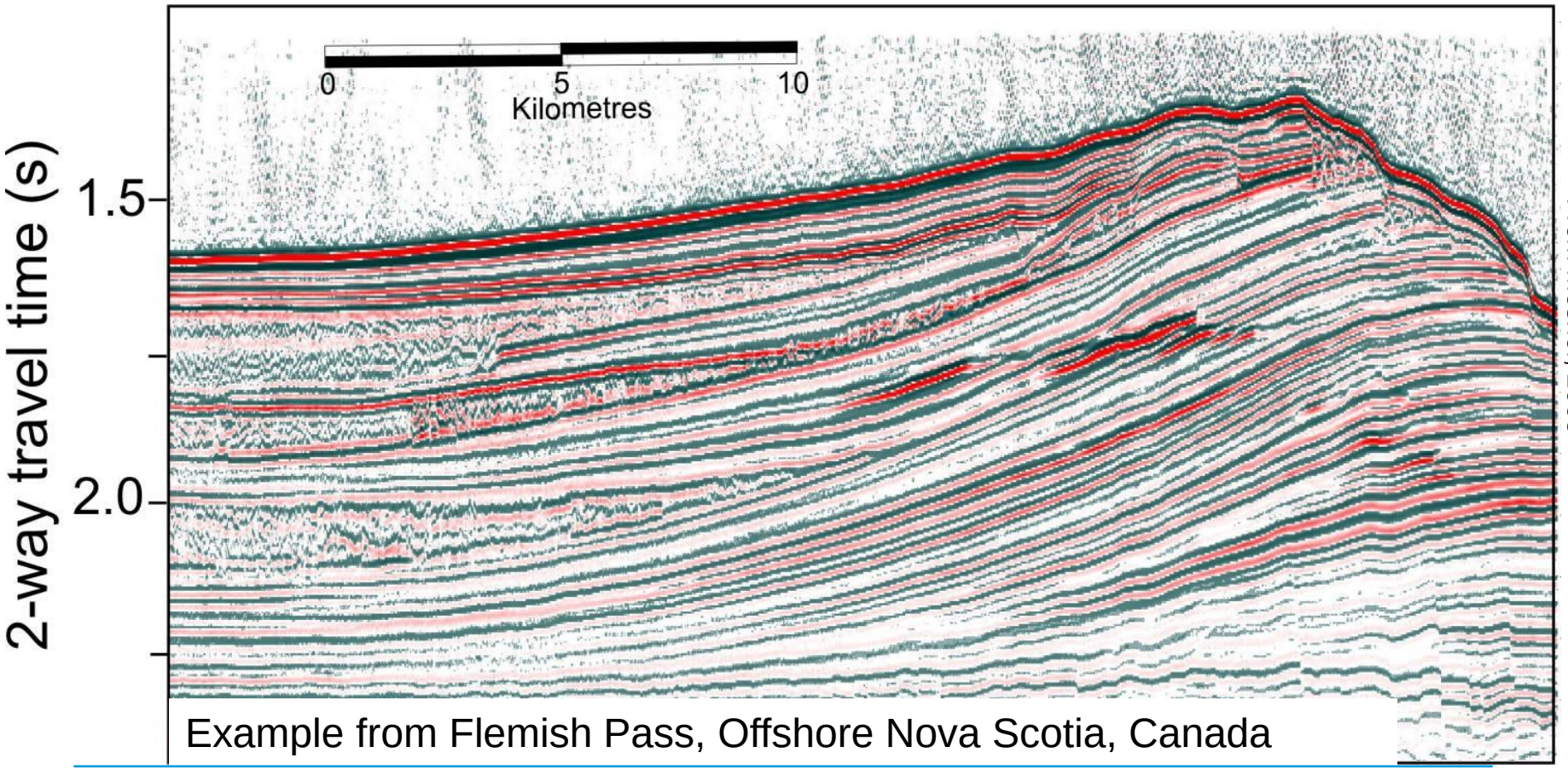
BSR can be discernable by upper truncations of bright-spots



From Mosher, 2005

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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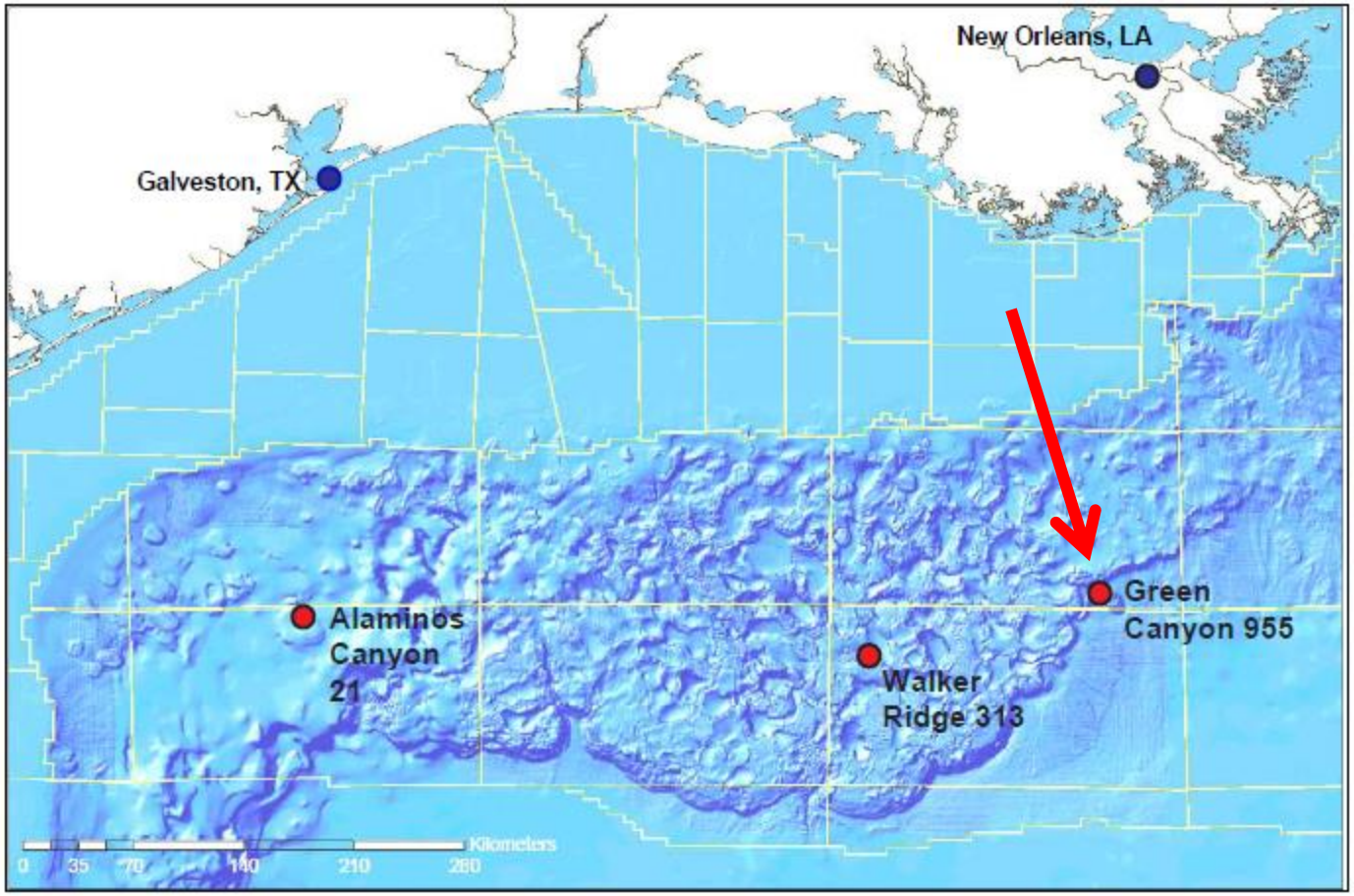
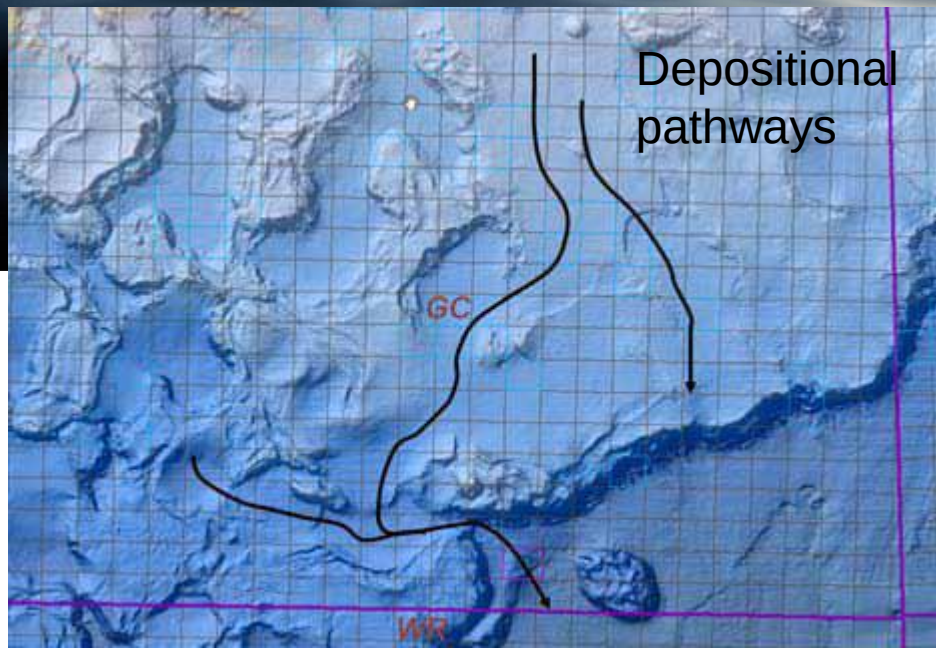
Some examples on how GH deposits have been mapped

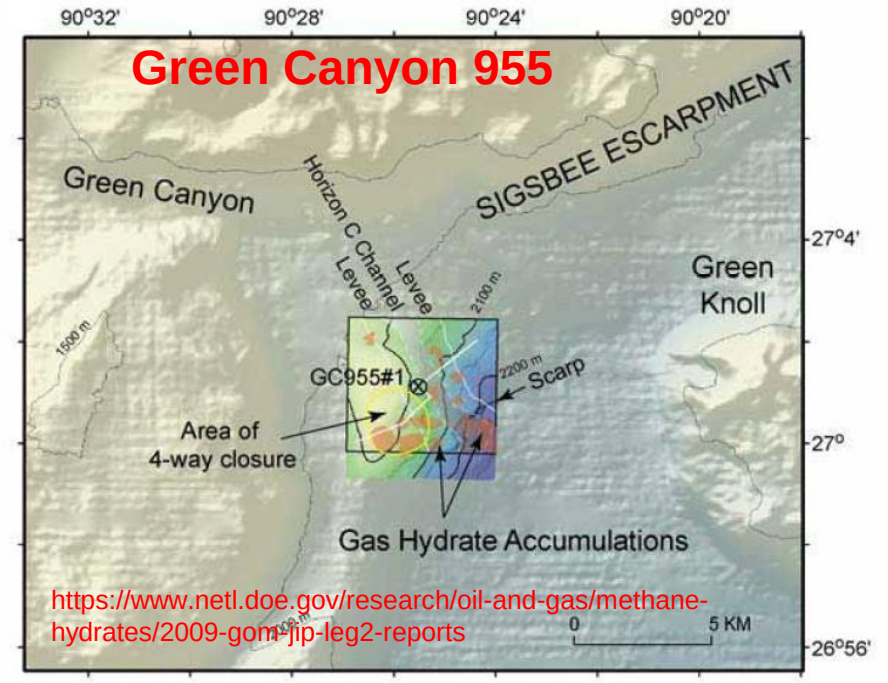
Gulf of Mexico Joint-Industry-Project (JIP)



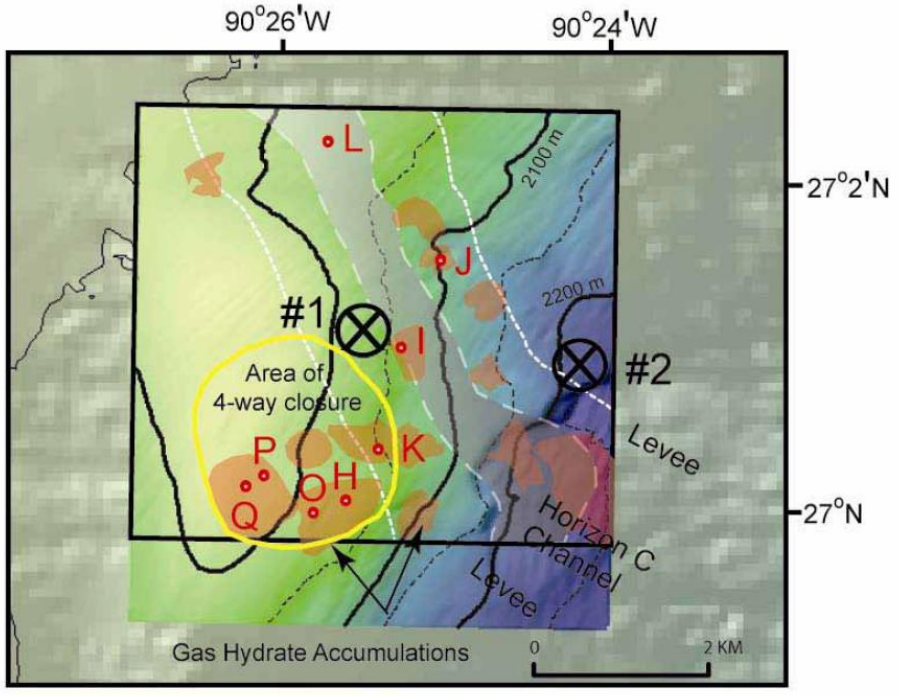
Map taken from Frye et al., 2009

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?



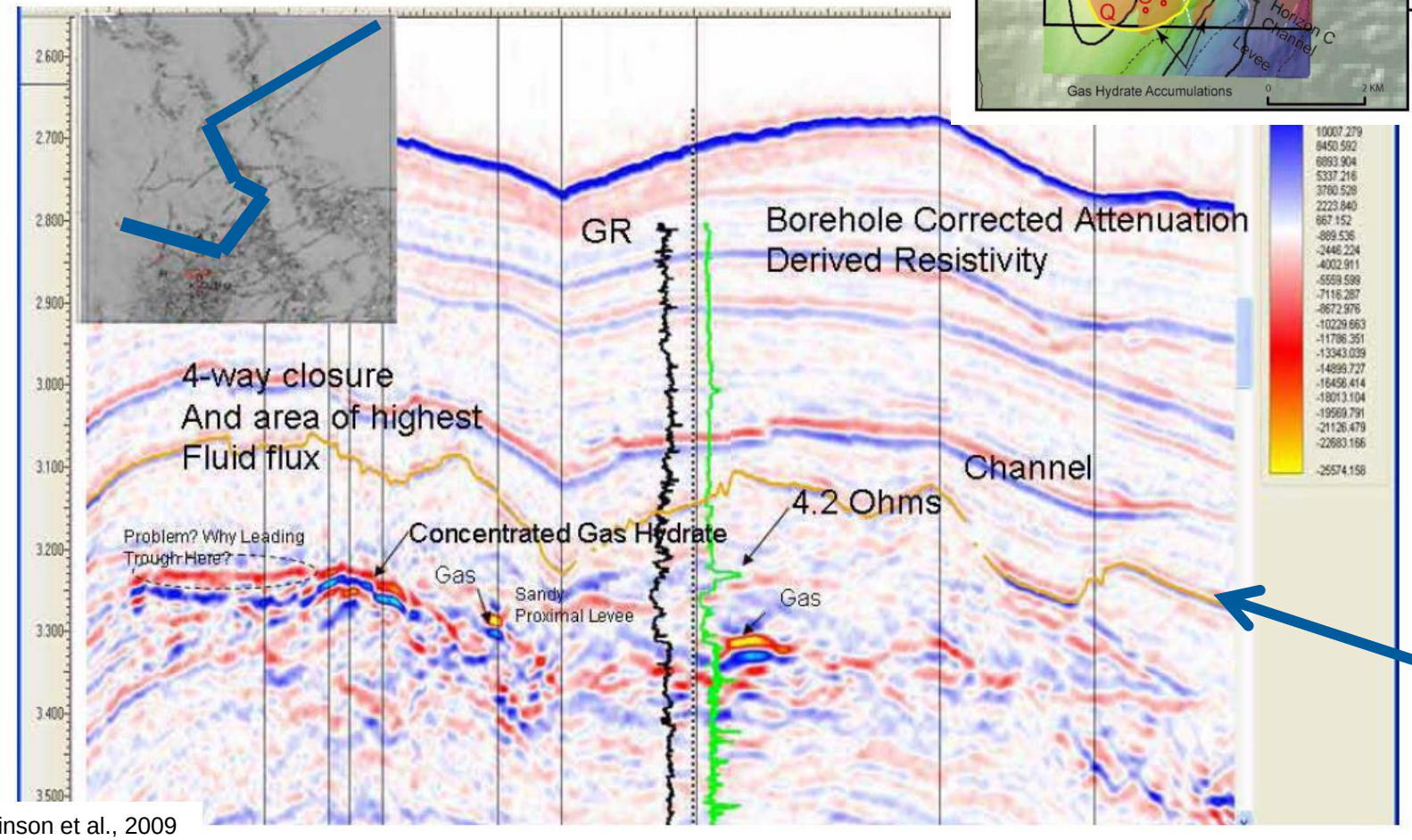


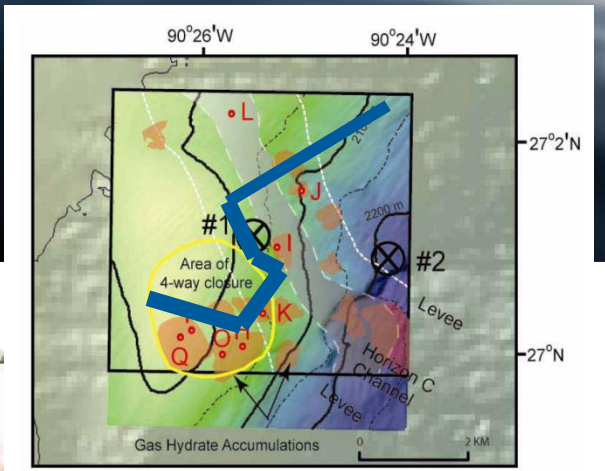
Hutchinson et al., 2009



Site was known to have gas hydrate in sands from previous industry drilling and seismic data

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?





Hutchinson et al., 2009

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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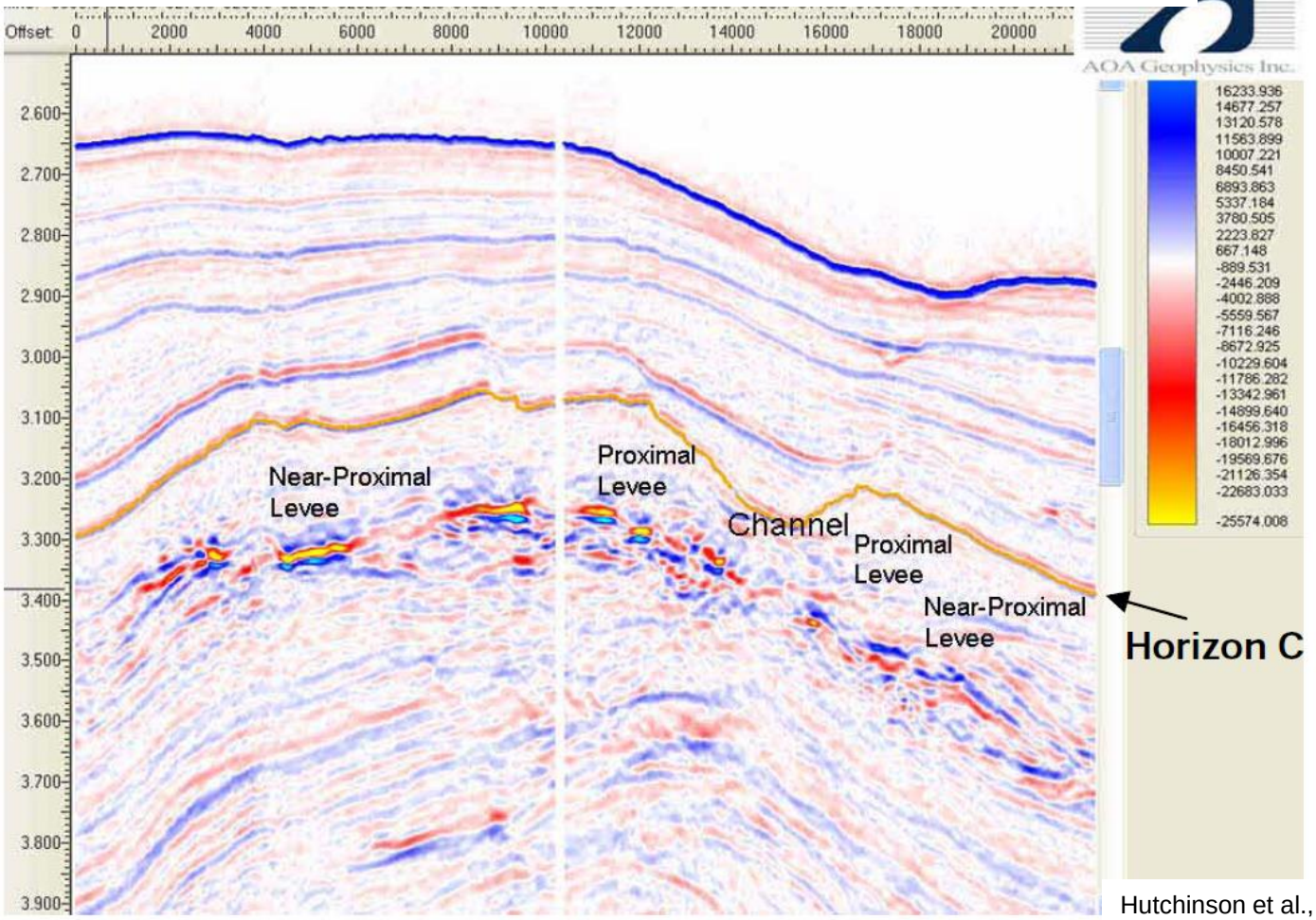
No clear BSR – old buried and subsequently faulted channel-levee system



Hutchinson et al., 2009

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

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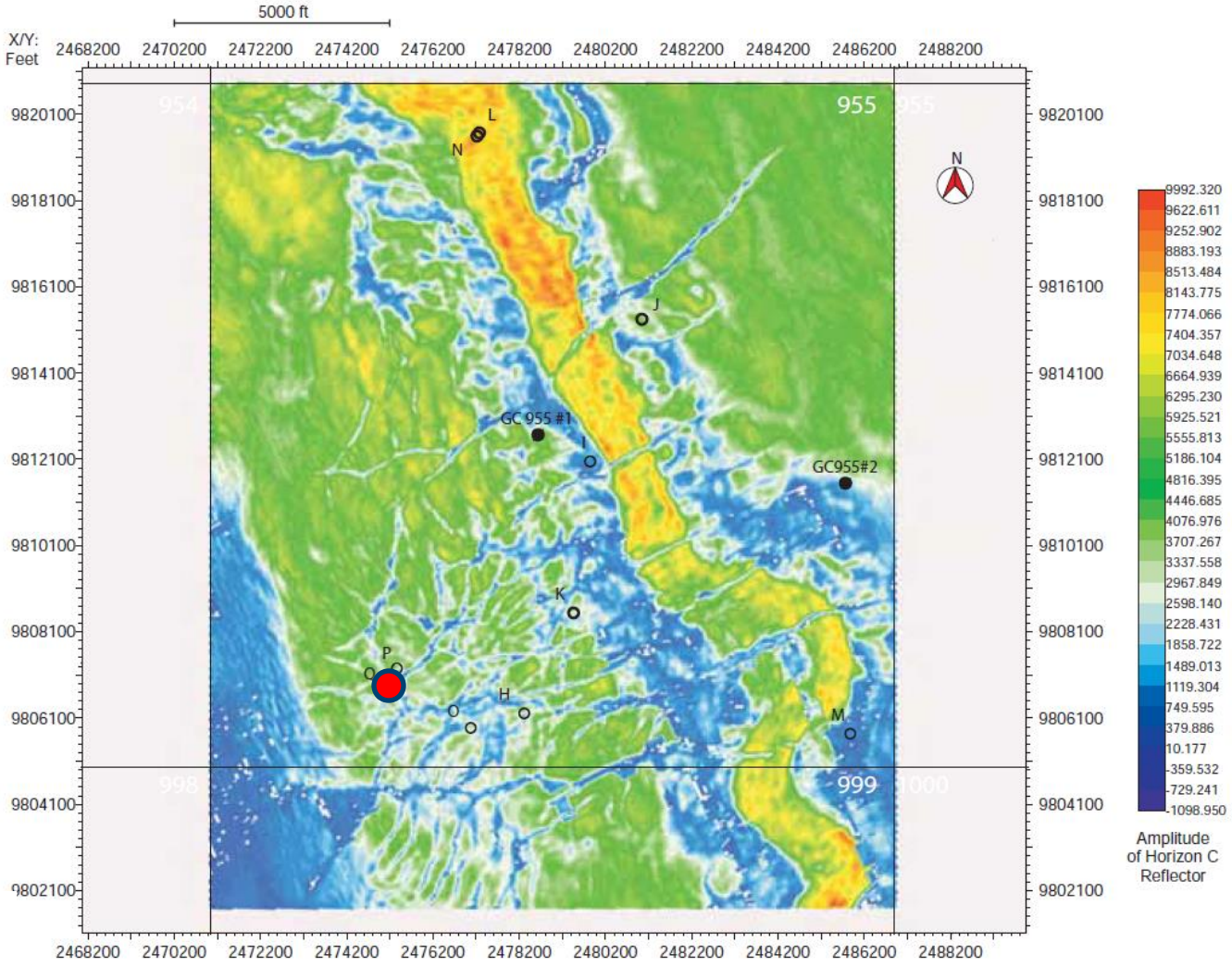
Amplitude of Horizon C



Hutchinson et al., 2009

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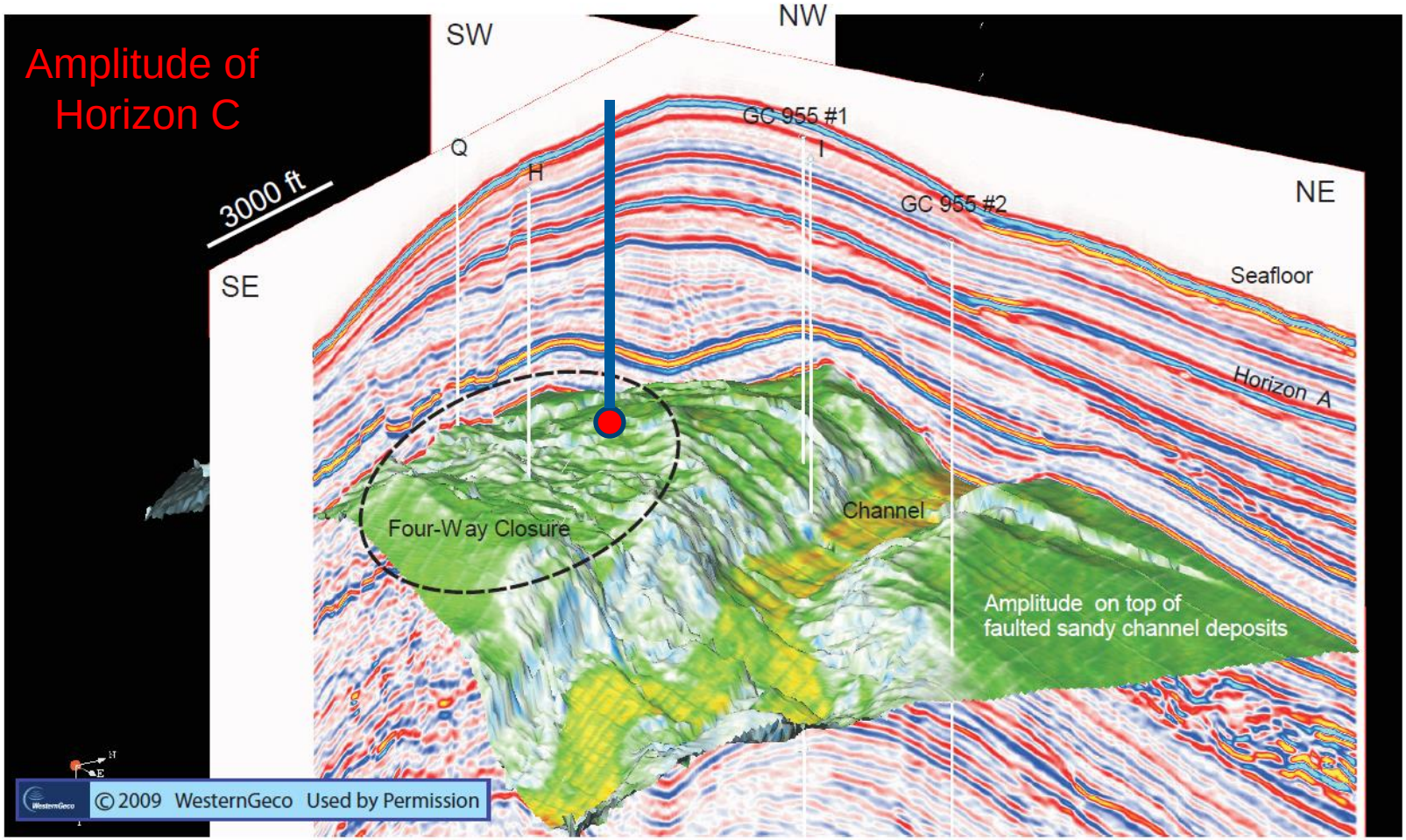
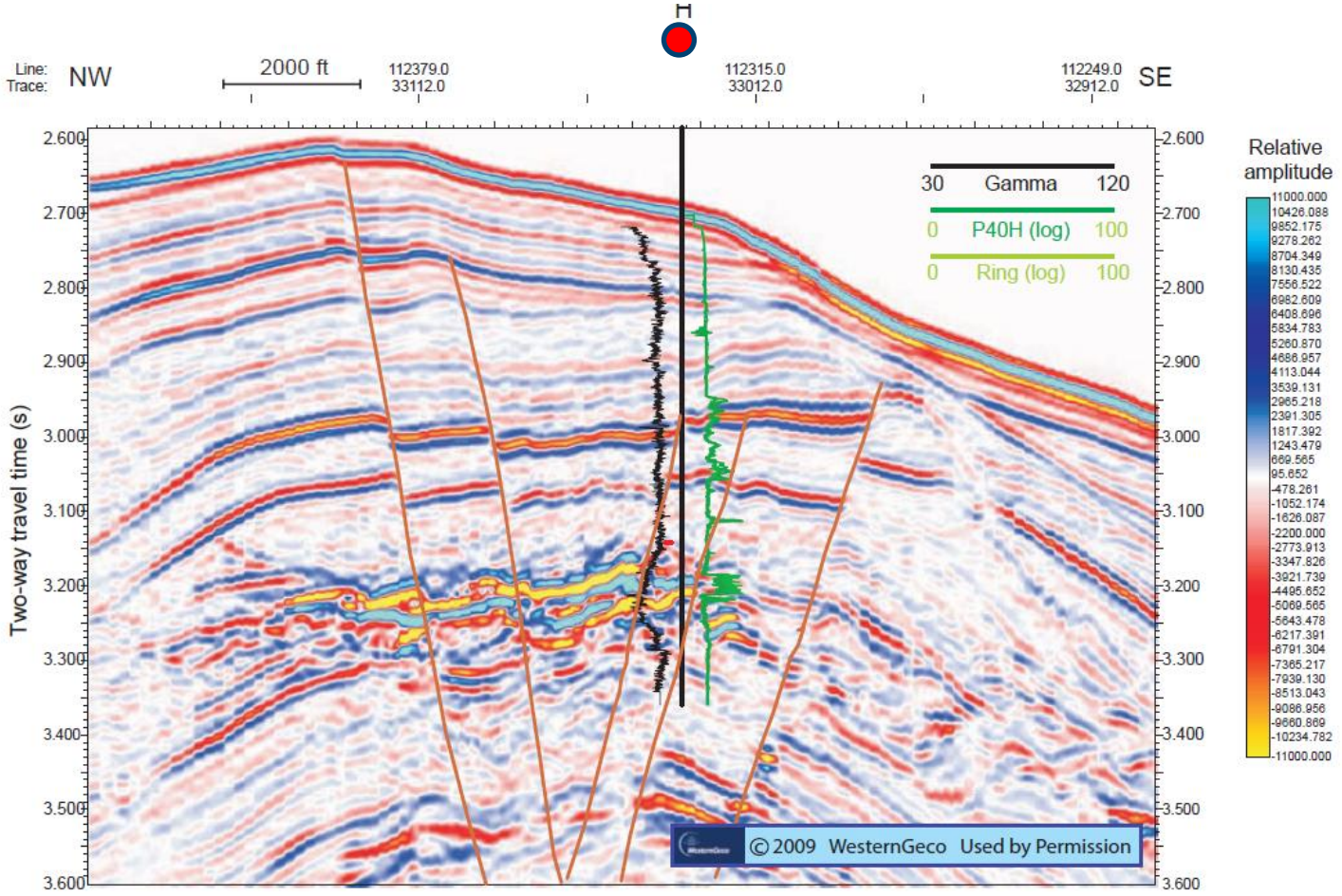


McConnell et al., 2009

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

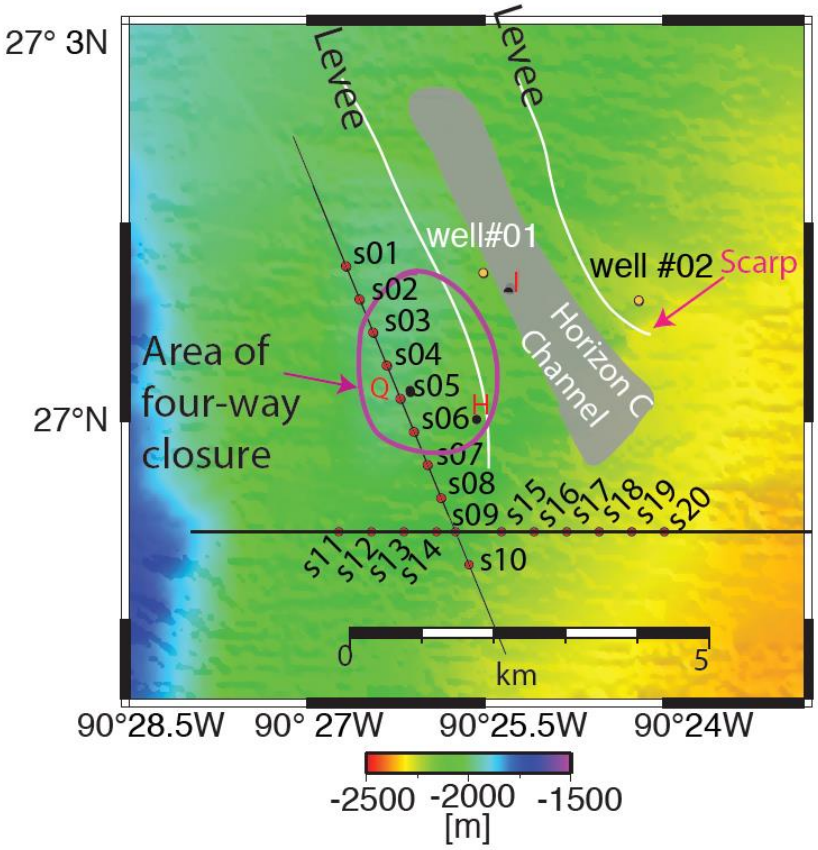


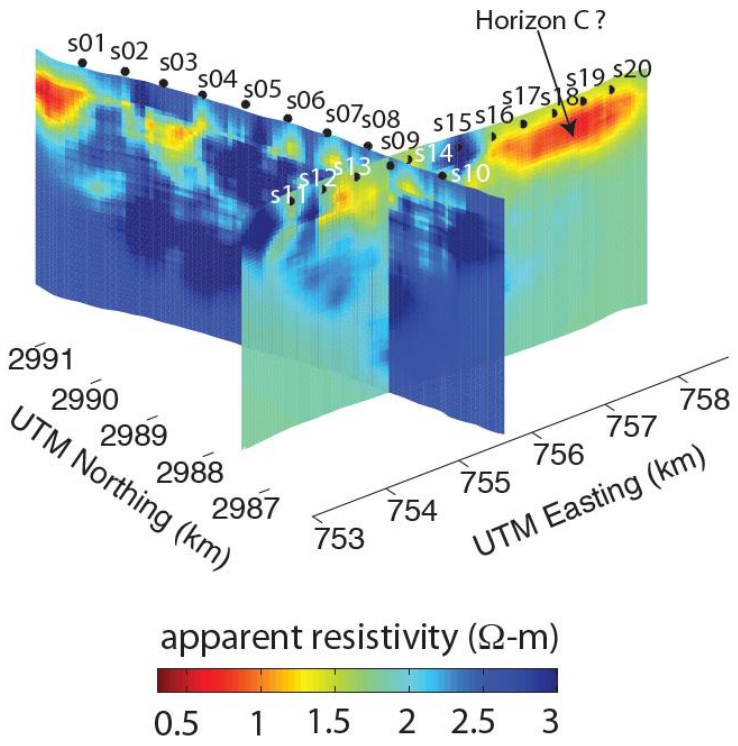
McConnell et al., 2009

Wie detektiert man Gas Hydrate mit geophysikalischen Methoden?

Gulf of Mexico
Green Canyon 955 with CSEM

From Constable, 2012 (Fig. 17)



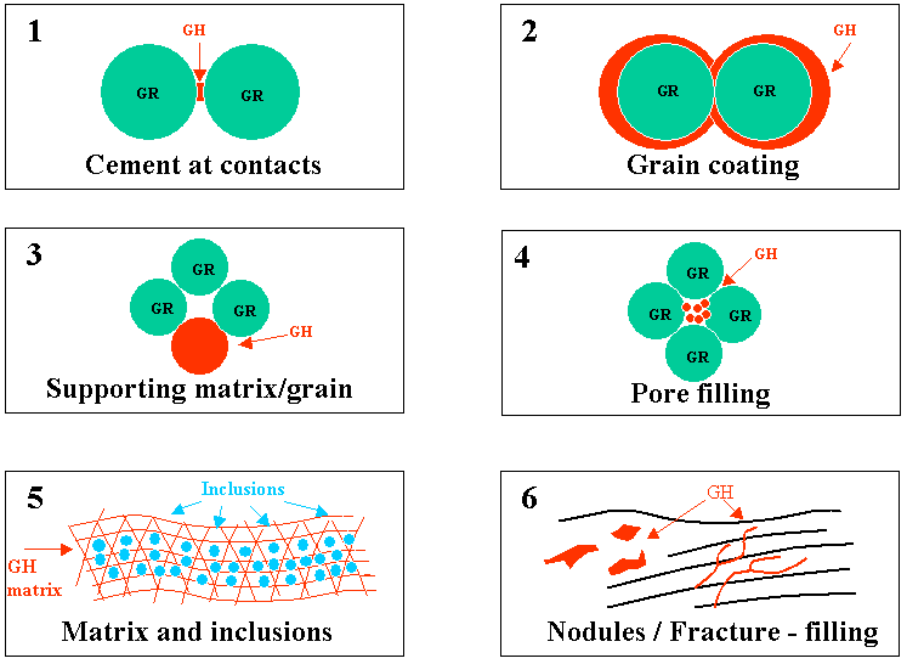


Wie quantifiziert man Gas Hydrate mit geophysikalischen Methoden?

For seismic data, several algorithms have been proposed and tested

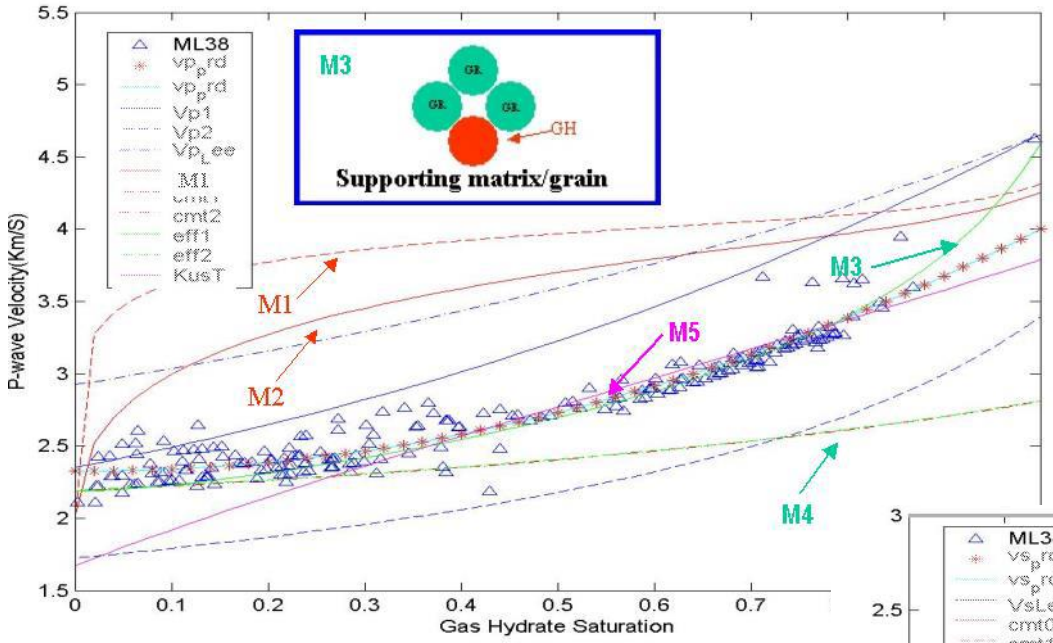
All these techniques exploit in principle the correlation between seismic velocity (impedance) and gas hydrate content using a specific rock-physics model

- Impedance inversion
  (P-velocity only)
- Elastic inversion
  (P- and S- velocity)
- Full-waveform inversion
  (P+S velocity + attenuation)



From Dai et al., 2004

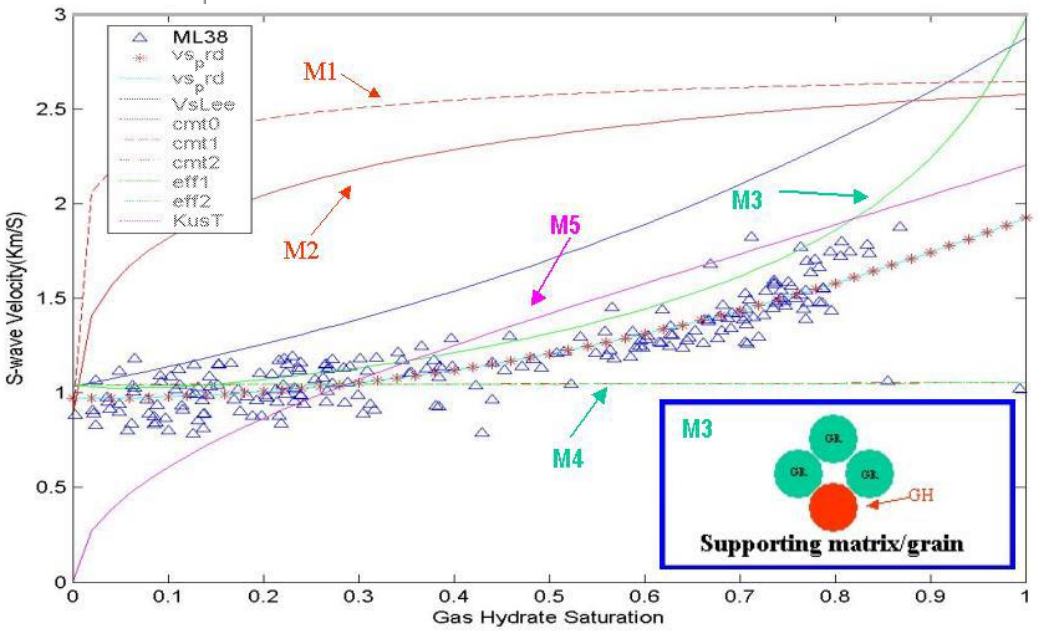
Wie quantifiziert man Gas Hydrate mit geophysikalischen Methoden?



Sediment velocity values and measured gas hydrate saturation from a clean sand environment of Arctic deposits (Mallik, NWT, Canada)

From Dai et al., 2004

All commercial algorithms now marketed by industry use this set of equations underlying the two images and work best in sandy regions.



Wie quantifiziert man Gas Hydrate mit geophysikalischen Methoden?

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Controlled source EM data can be used to assess gas hydrate saturation through the use of an *empirical relationship* between resistivity and porosity

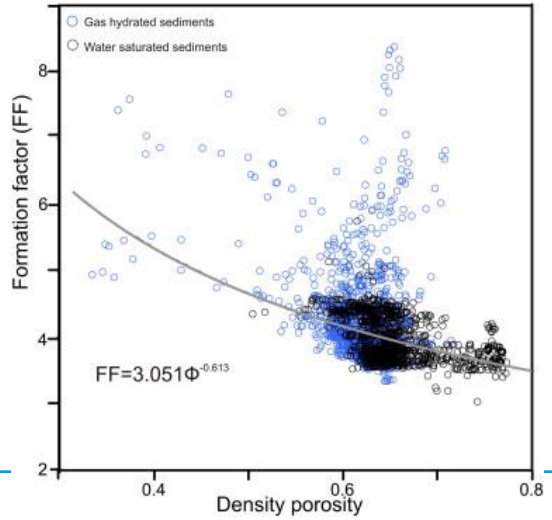
Archie's equation

$$F = \frac{R_0}{R_w} = a\phi^{-m}$$

$$S_h = 1 - \left[\frac{aR_w}{\phi^m R_t}\right]^{\frac{1}{n}}$$

Porosity ϕ , resistivity of seawater-saturated sediment (Ro) and resistivity of pore water (Rw); a, m and n are constants to be defined from cross-plotting

Shankar and Riedel, 2013



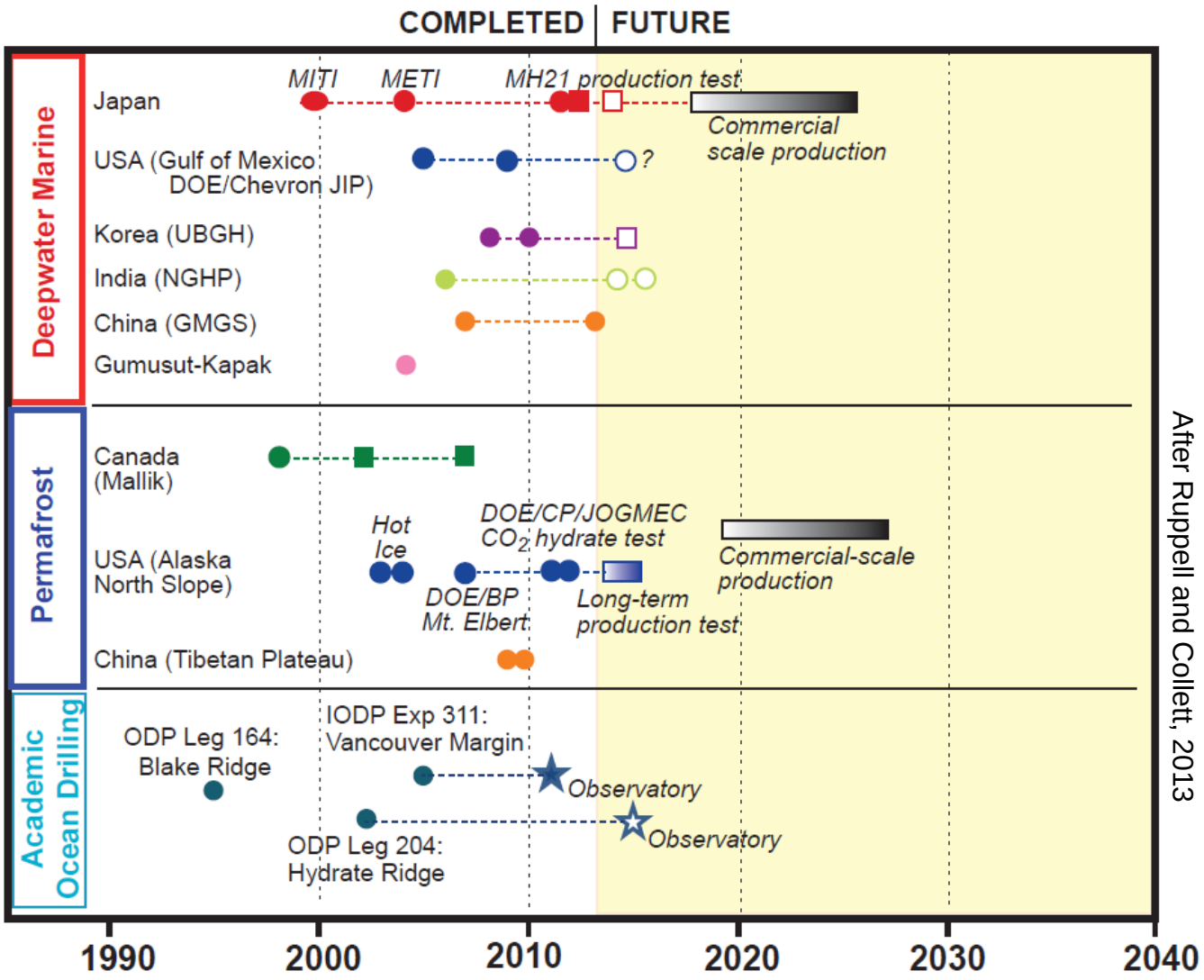
Parameter 'a' is formation factor @ full water content (ϕ = 1)

One school of scientists therefore sets a == 1

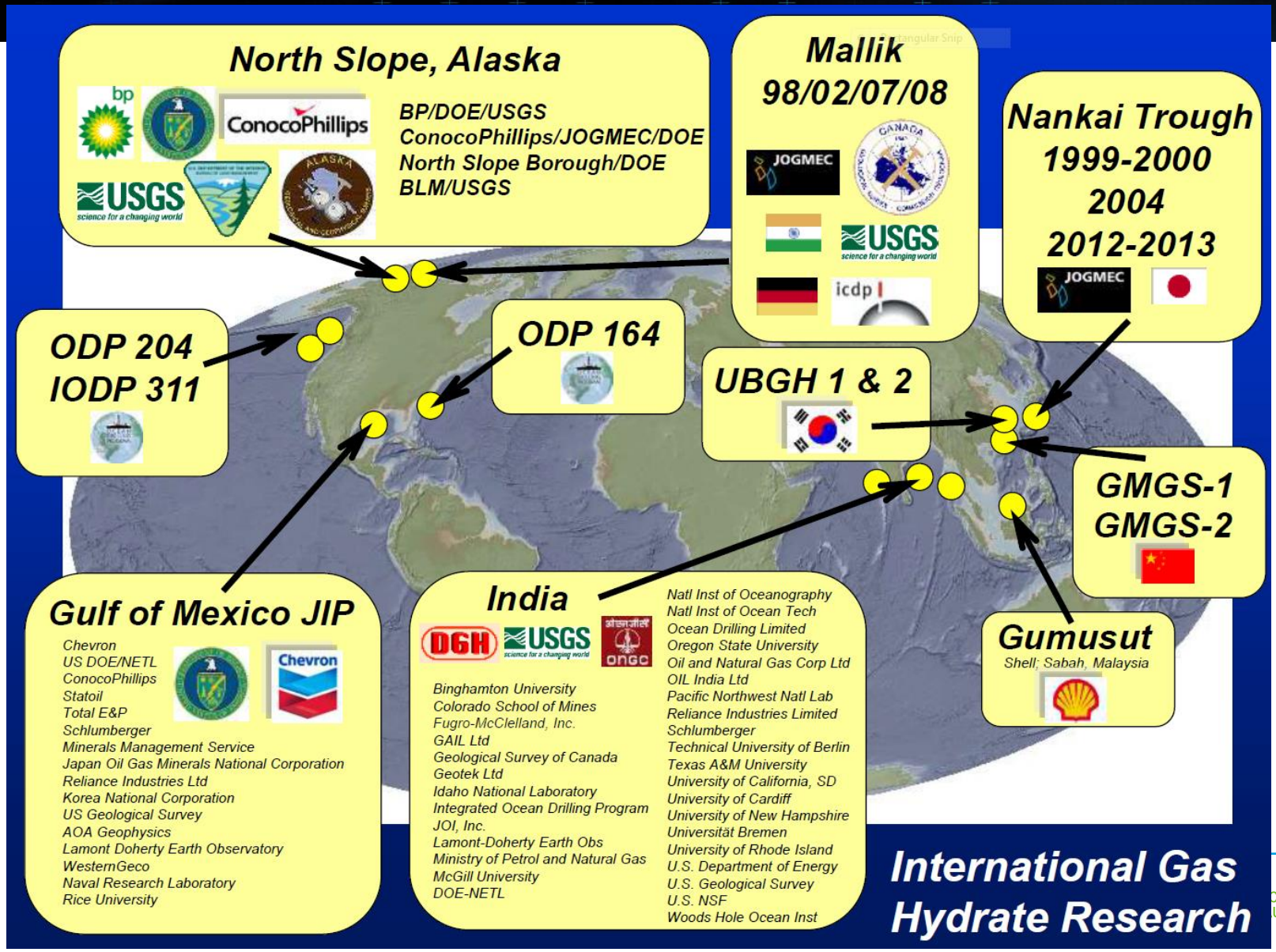
Meilensteine in der Gashydrat-Exploration

Timeline chart showing the deepwater marine, Arctic permafrost, and academic ocean drilling scientific drilling expeditions dedicated to the research on natural occurring methane hydrates

From:
Consortium for Ocean Leadership and the methane hydrate project science team, 2013



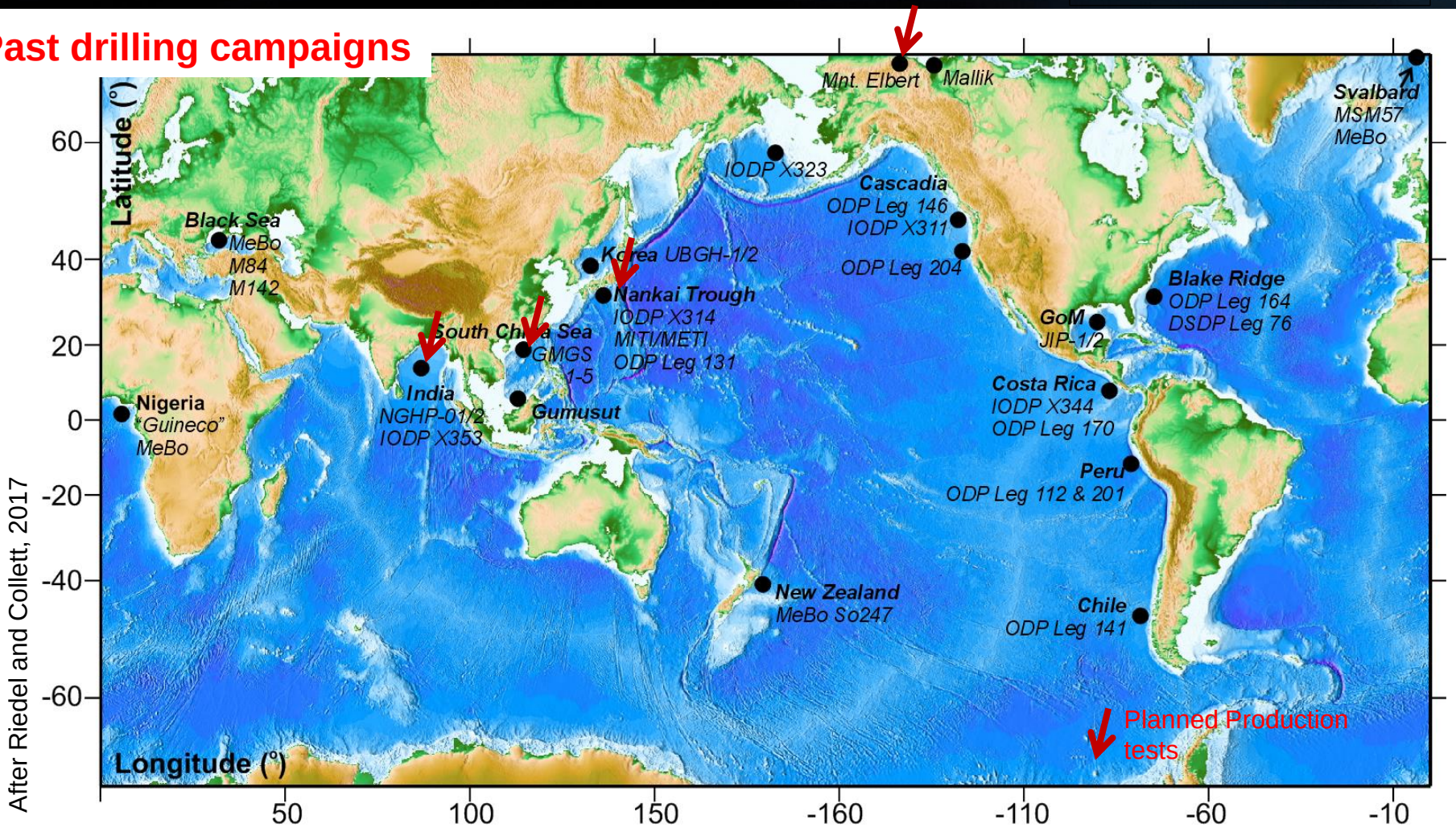
Meilensteine in der Gashydrat-Exploration



Slide courtesy T. Collett, USGS

Meilensteine in der Gashydrat-Exploration

Past drilling campaigns



After Riedel and Collett, 2017

Meilensteine in der Gashydrat-Exploration

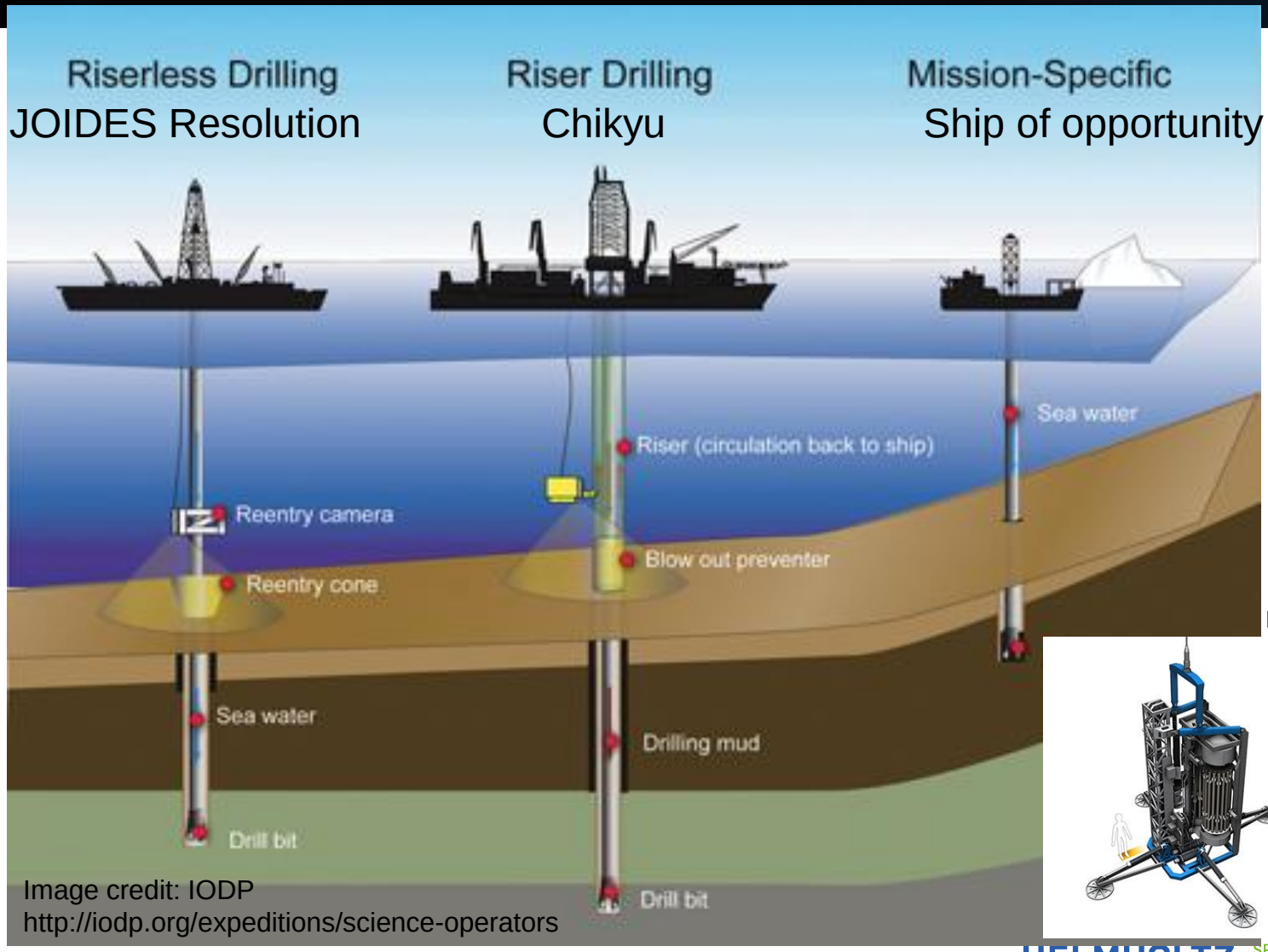
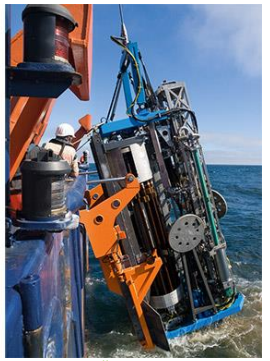


Image credit: IODP
http://iodp.org/expeditions/science-operators

Also seafloor rigs
MeBo
(Meeresboden Bohrgerät)

photo: V. Diekamp, MARUM



HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

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Konzeptionelles “Gas Hydrat Petroleum System”

(ähnlich zu anderen fossilen Brennstoffen)

Gas hydrate Stability conditions (phase boundary)

Gas Source (biogenic / thermogenic)
Gas Migration pathways

Availability of water

Reservoir - Sediment (depositional environment)

Timing (sedimentation rates / tectonics / faulting)

Konzept zum ersten mal beschrieben bei Collett et al., 2009 – AAPG book

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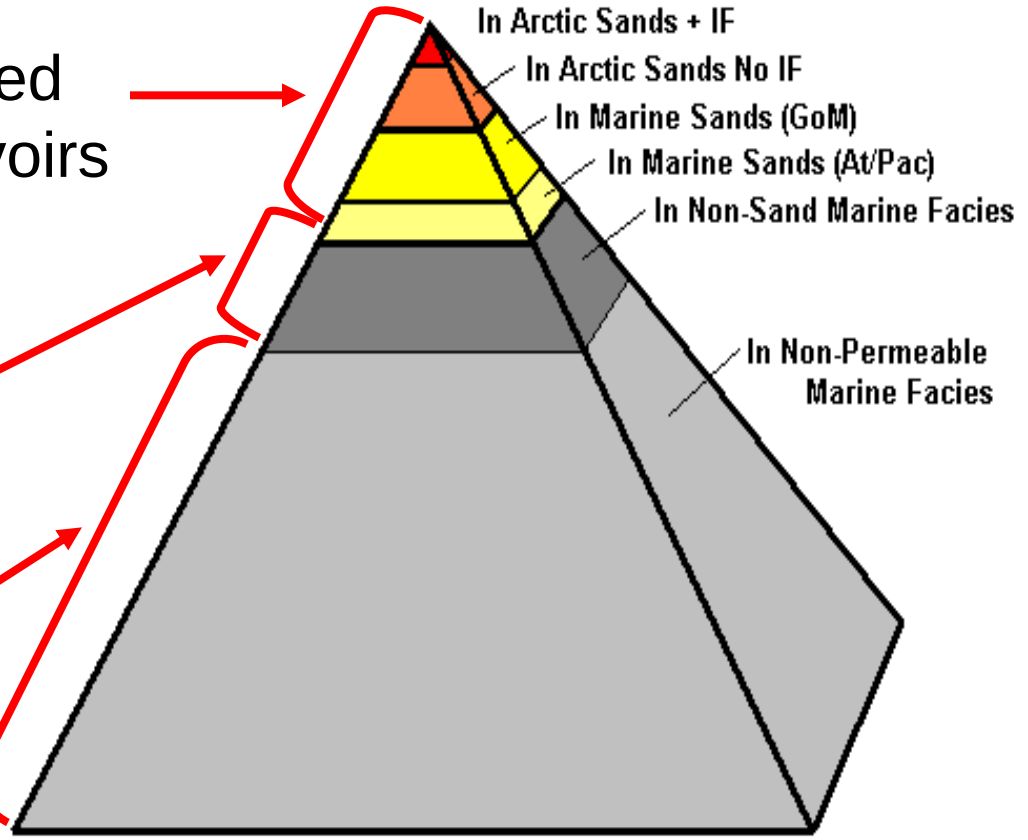
Gas Hydrate Resource Pyramid

Sand dominated hydrate reservoirs

Fractured hydrate reservoirs

Clay dominated hydrate reservoirs



After Boswell and Collett, 2006

(IF = infrastructure)

Kommerzielle Nutzung von Gas Hydraten

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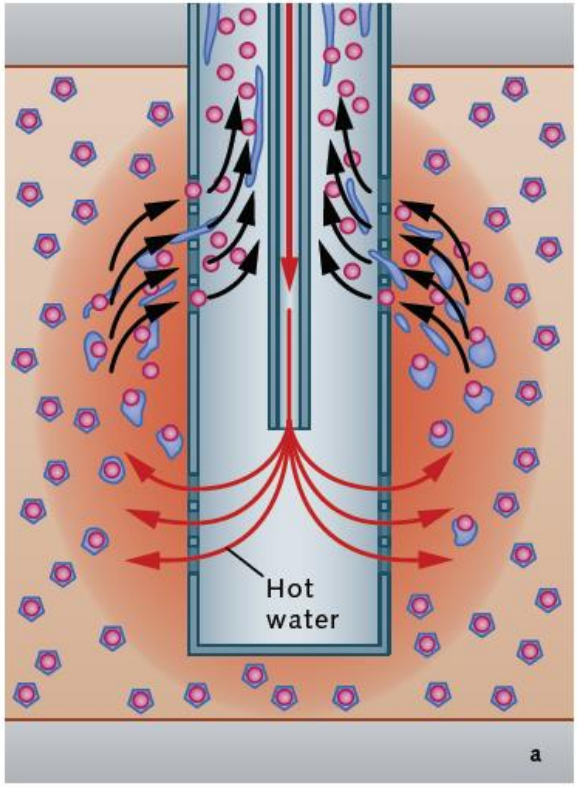
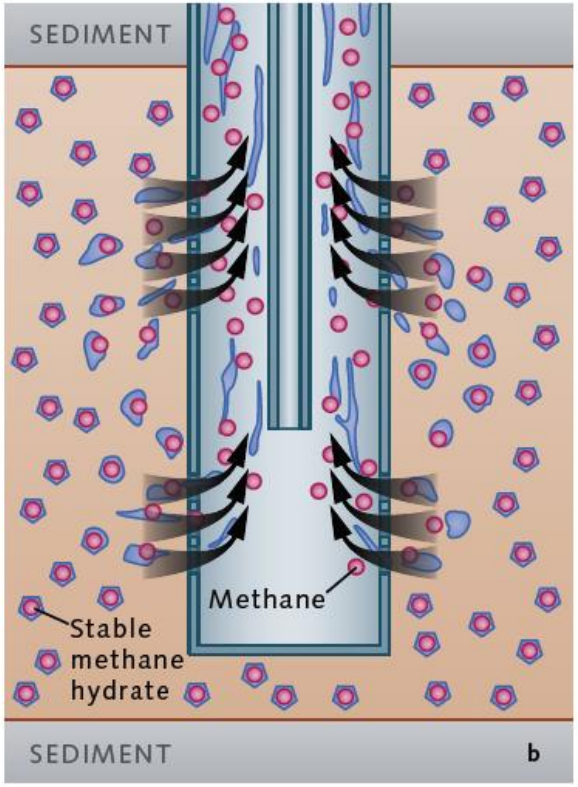
Die drei Grundkonzepte, um Gas Hydrat zu fördern

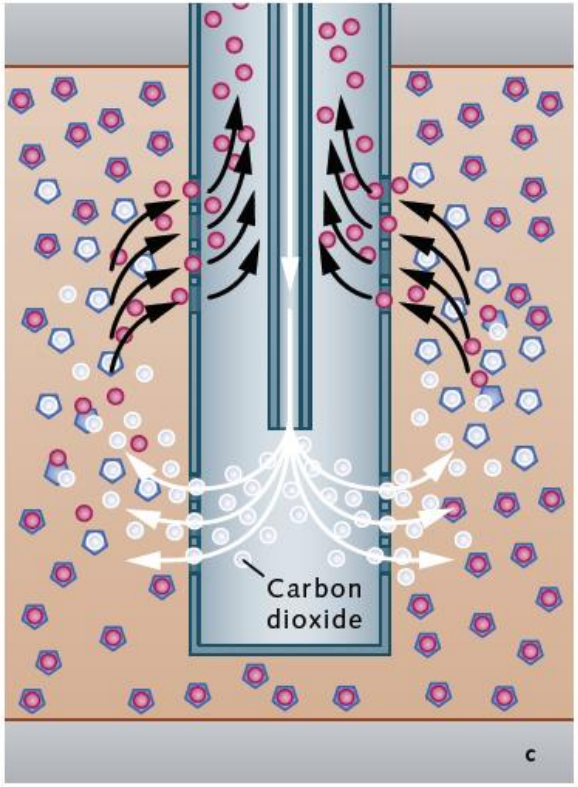
Thermische Stimulation



Druck-Minderung



Chemische Inhibitoren



Source: World Ocean Review-3, Abb. 3.8 - Seite 105, https://worldoceanreview.com/en/wor-3/methane-hydrate/extraction/

Kommerzielle Nutzung von Gas Hydraten

Mallik – Canada/Japan/US/Germany
2002 Thermal Stimulation
Borehole pressure drawn-down (MDT)

2007/2008
Pressure draw-down
~2,000 m^3 pro Tag
Größtes Problem: Sand!

https://en.wikipedia.org/wiki/Mallik_gas_hydrate_site

Japan - Nankai Trough
März 2013 (6 Tage) ~20,000 m^3 pro Tag

April 2017 (~3 Wochen)
200,000 m^3 in 24 Tagen → < 20,000 m^3 pro Tag

Kommerzielle Nutzung von Gas Hydraten

Mnt. Albert – Alaska

Februar 2007

Stratigraphic test (MDT)

CO_2-CH_4 swap

https://www.usgs.gov/media/images/gas-hydrate-drill-rig-mt-elbert-test-site-alaska

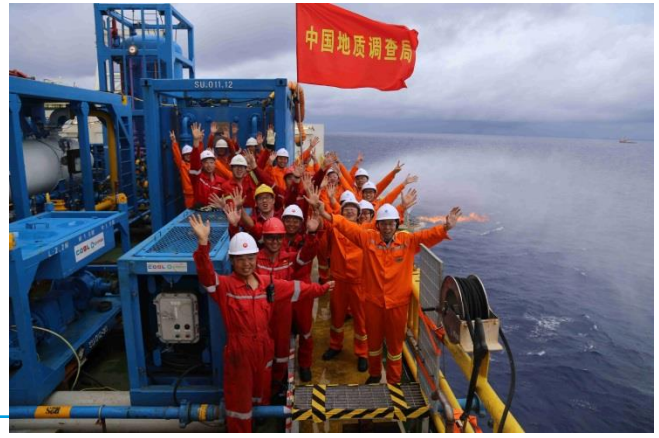
Special Issue in J. Marine Petrol. Geology:
https://www.sciencedirect.com/journal/marine-and-petroleum-geology/vol/28/issue/2

China

Mai 2017 (South China Sea)

Pressure draw-down (60 Tage)

~16,000 m^3 pro Tag



https://news.cgtn.com/news/3d67544f786b7a4d/share_p.html

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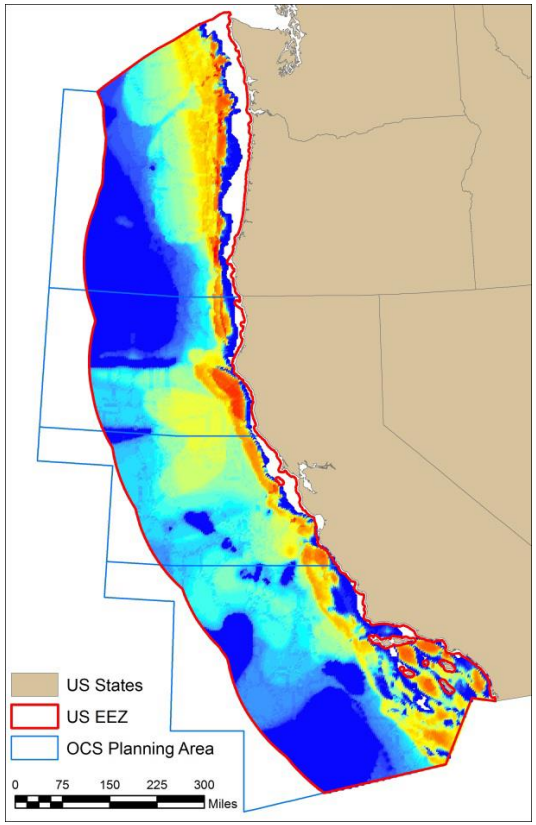
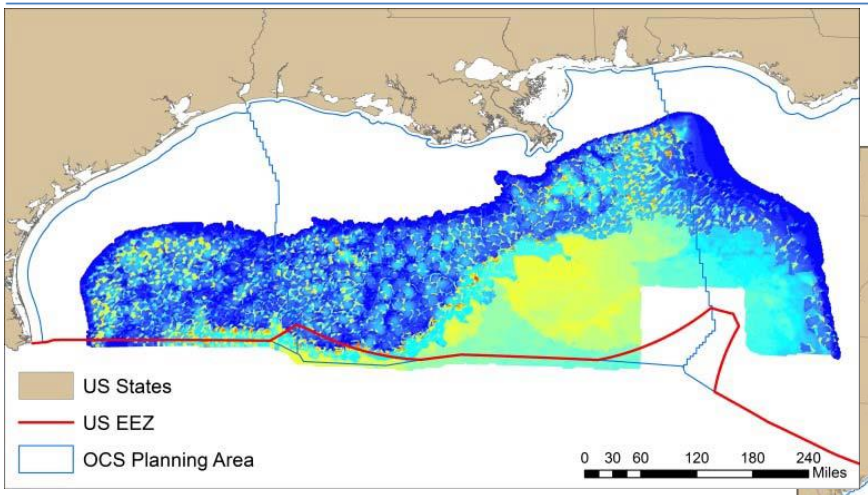
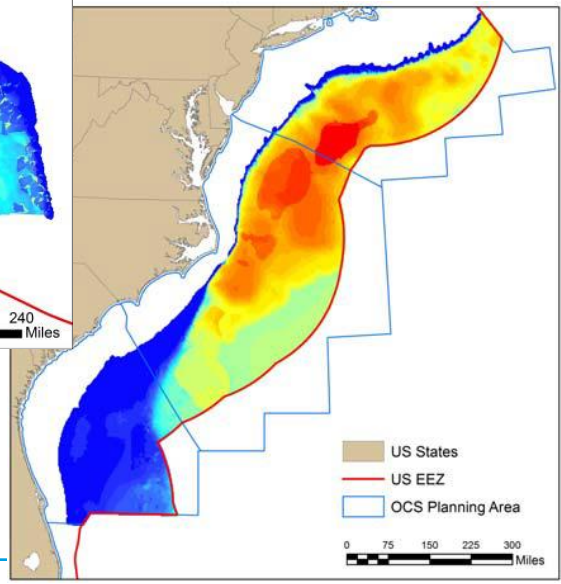
The next step - Regional assessments of resource potential



BOEM
Bureau of Ocean Energy Management

Assessment of In-Place Gas Hydrate Resources of the Lower 48 United States Outer Continental Shelf





https://www.boem.gov/Gas-Hydrates-Resource-Assessment/

HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

Kommerzielle Nutzung von Gas Hydraten
Die Vision von CO_2-neutraler Nutzung

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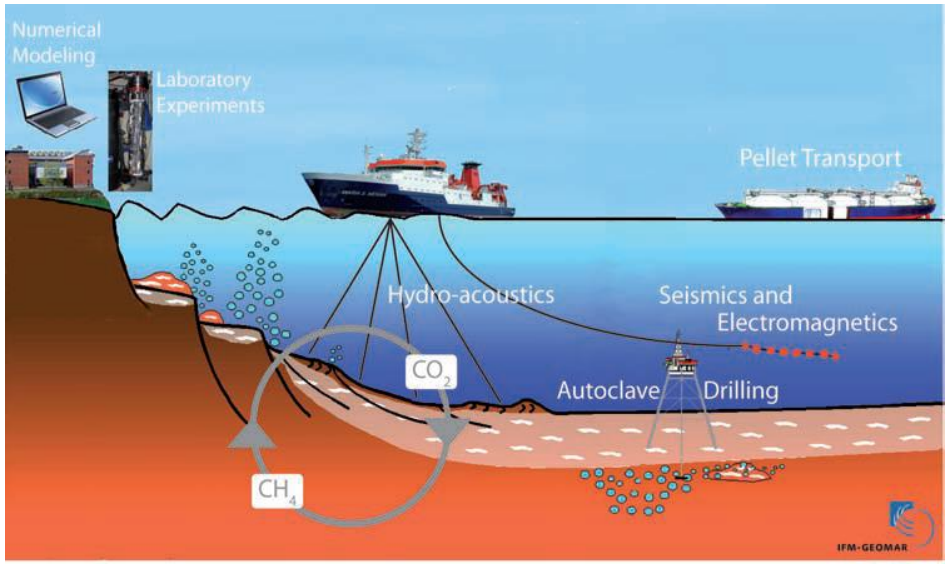
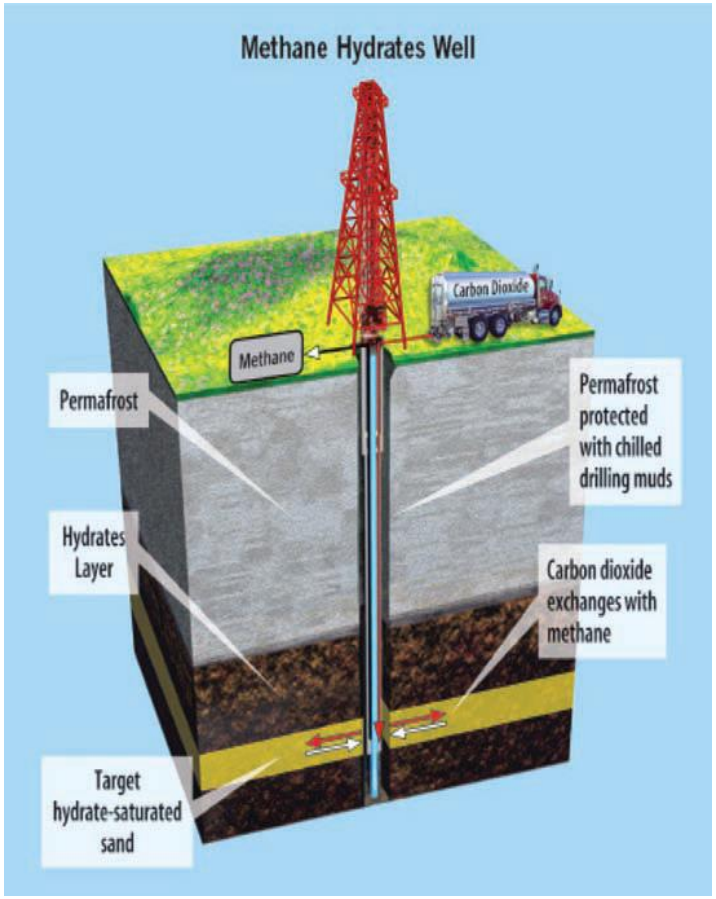
CO_2-CH_4 Exchange in Natural Gas Hydrate Reservoirs



SUGAR-Projekt
Wallmann and Bialas, 2010



Alaska, Ignk-Sikumi well
Farrell et al., 2010

Kommerzielle Nutzung von Gas Hydraten
Die Vision von CO_2-neutraler Nutzung

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Viele Studien, meist theoretischer oder Labor-technischer Natur sind zum Thema vorhanden …

Aber bisher nicht in der Größenordnung umsetzbar, das es kommerziell gewinnbringend ist

Eine kleine Auswahl:

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Zusammenfassung

- Weltweit sind natürliche Vorkommen an Gas Hdraten dokumentiert
- Geophysikalische Methoden zur Reservoir Charakterisierung sind etabliert (vor allem Seismische und Bohrloch-Geophysikalische Methoden)
- Erfahrungen durch akademische (ODP/IODP) und kommerzielle Projekte, in Japan, Indien, China, USA (Alaska, GoM), Kanada, und Korea
- Mehrere Produktionstests erfolgreich, aber Produktion noch nicht ökonomisch (zu geringe Fördermengen bei hohem finanziellen Aufwand und Umwelt-Risiko, sowie weltweitem Angebot an LNG)
- CO2-neutrale Umsetzung der Gas Hydrat Produktion als Zukunftsvision

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Constable, S., 2012. Gas hydrate characterization in the GoM using Marine EM methods, Final report, DOE Award No.: DE-NT0005668, Oil & Natural Gas Technology, available at: https://www.netl.doe.gov/research/oil-and-gas/project-summaries/methane-hydrate/de-nt0005668

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Zusätzliche nützliche links:

World-Ocean Review
https://worldoceanreview.com/en/wor-3/methane-hydrate/
UNEP-Program Reports:

Volume 1: https://www.netl.doe.gov/File%20Library/Research/Oil-Gas/methane%20hydrates/gas-hydrate-global-assessment-volume-1.pdf
Volume 2: https://www.netl.doe.gov/File%20Library/Research/Oil-Gas/methane%20hydrates/gas-hydrate-global-assessment-volume-2.pdf
Summary: https://www.netl.doe.gov/File%20Library/Research/Oil-Gas/methane%20hydrates/gas-hydrate-global-assessment-executive-summary.pdf

https://www.boem.gov/Gas-Hydrates-Resource-Assessment/
https://www.netl.doe.gov/research/oil-and-gas/methane-hydrates

Referenzen und Quellenangaben -5

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World-Ocean Review
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UNEP-Program Reports:
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Canadian Assessment
http://www.scienceadvice.ca/en/feature/gas-hydrates.aspx
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