Gas Hydrates - The World's Largest Energy Resource
"But Should I Care"*

By
Timothy S. Collett[1]

Search and Discovery Article #80026 (2008)
Posted October 1, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, Texas, April 20-23, 2008

[1]Energy Resources Program, U.S. Geological Survey, Denver, CO (tcollett@usgs.gov)

Some Presentation Highlights

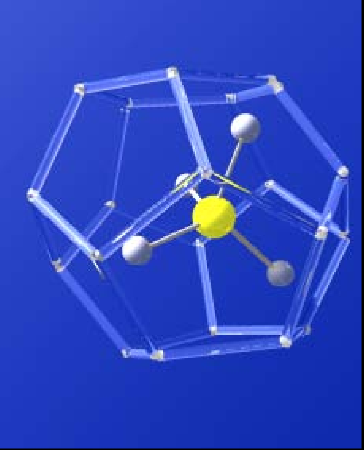
What is a Gas Hydrate? Crystalline solid consisting of gas molecules, usually methane, each surrounded by a cage of water molecules. One volume hydrate typically equivalent to about 160 volumes methane gas. Occurs abundantly in nature--Arctic regions and in marine sediments.

Methane Hydrate Stability--temperatures above and below 0°C; stable in Arctic, associated with permafrost and marine sediments (> 500m deep); requires gas source—biogenic and/or thermogenic.

Controls on the occurrence of gas hydrate include:

- Formation temperature
- Formation pressure
- Pore water salinity
- Gas chemistry
- Availability of gas and water
- Gas and water migration
- Presence of reservoir rocks and seals

Actions needed include:1. conduct exploratory drilling and production testing by first identifying viable test sites through an improved seismic and geologic understanding of gas hydrates; 2. work with industry, government, and the international research community to develop the production technology for safe and economic gas hydrate development; 3. development and calibrate gas hydrate production models through field testing projects – Pilot ; long term production rate calculations are critical to evaluating field economics.





GAS HYDRATES - THE WORLDS LARGEST ENERGY RESOURCE
“BUT SHOULD I CARE”

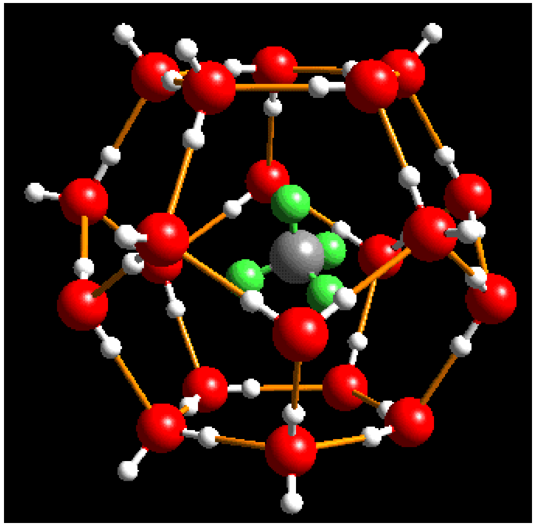
Timothy S. Collett
Energy Resources Program
U.S. Geological Survey

Presentation Outline

1. Geologic Controls on Gas Hydrate
   The Gas Hydrate Petroleum System
2. Gas Hydrate Energy Assessments
3. Gas Hydrate Production
4. Motivations – Economics and Political
5. NEXT STEPS………….

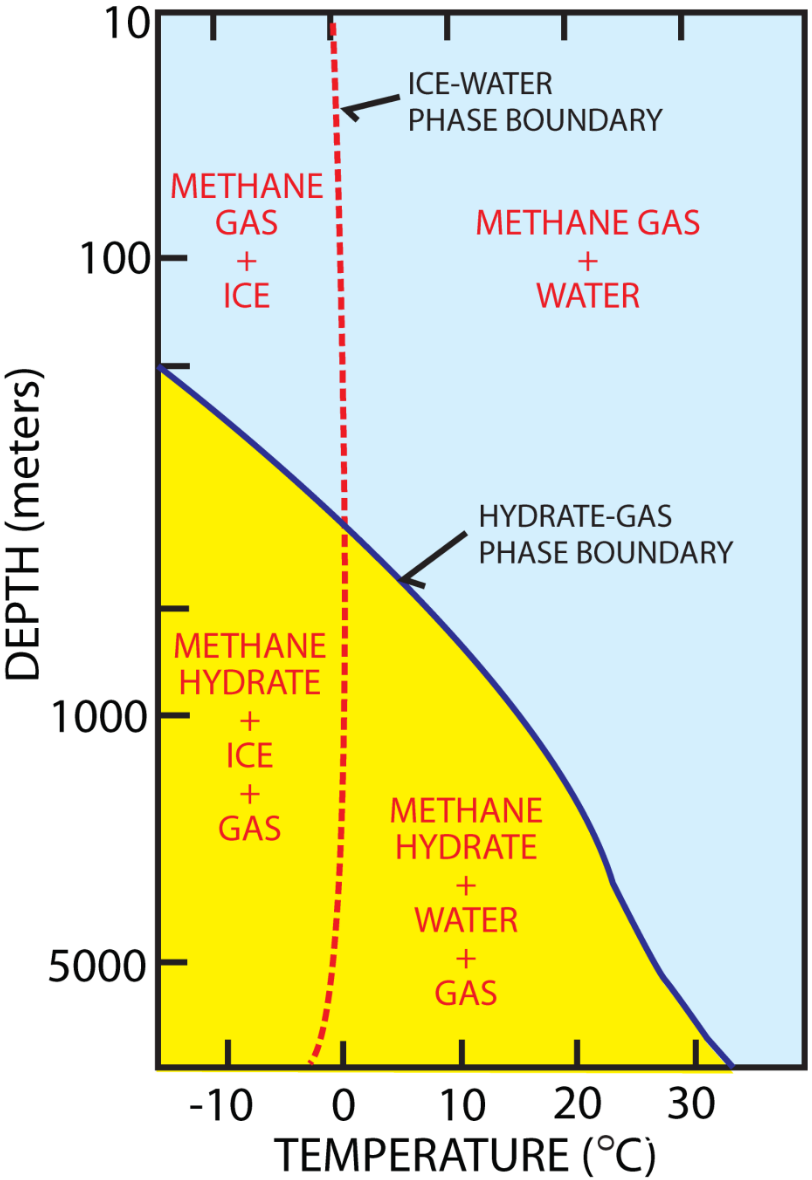
What is a Gas Hydrate?

- Crystalline solid consisting of gas molecules, usually methane, each surrounded by a cage of water molecules
  - One volume hydrate typically equivalent to about 160 volumes methane gas



- Occur abundantly in nature
  - Arctic regions and in marine sediments

Methane Hydrate Stability



Temperatures and Moderate Pressures

- Temperatures above & below 0°C

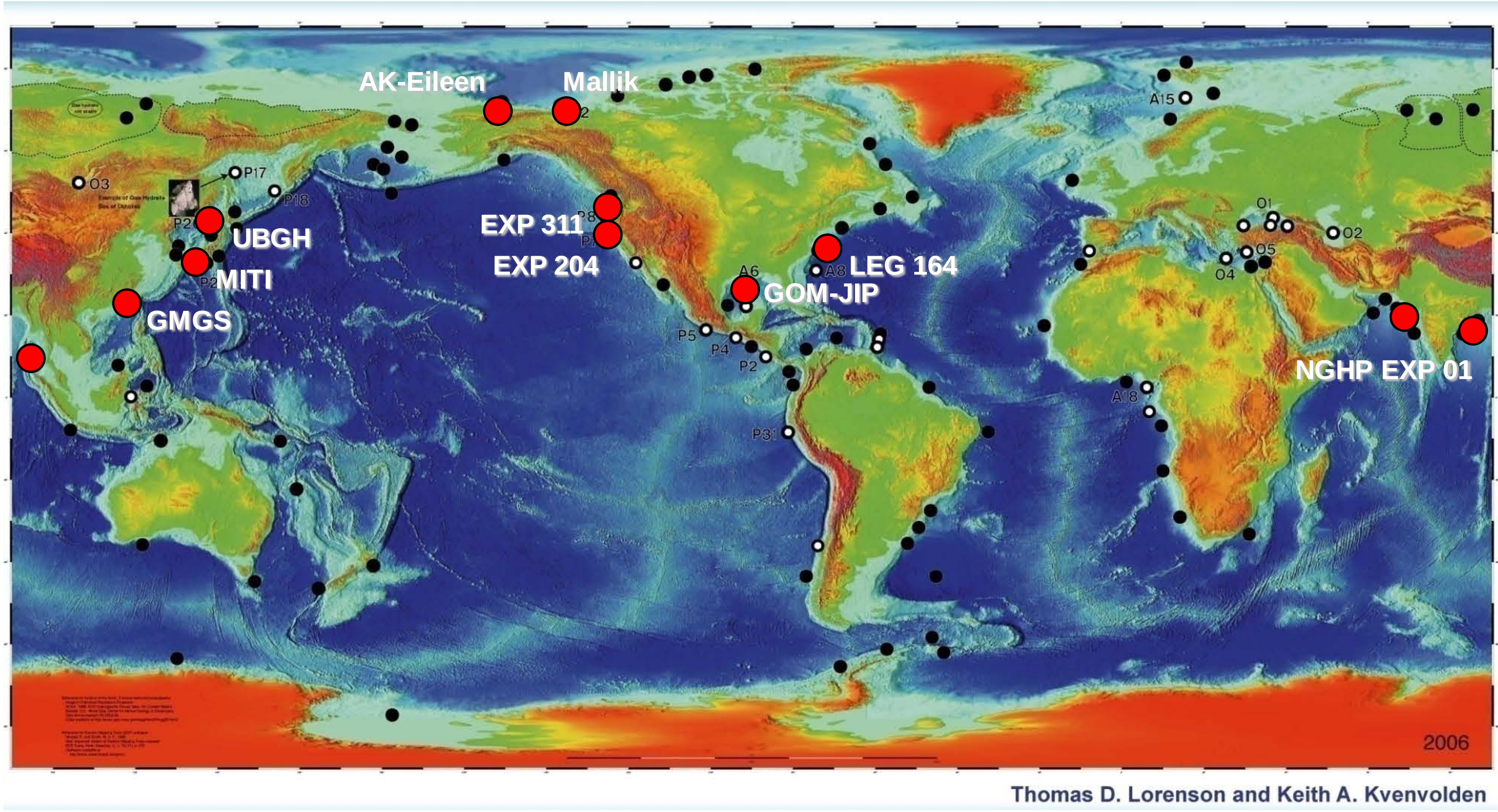
Stable

- Arctic associated with permafrost
- Marine sediments (> 500m deep)

Requires Gas Source

- Biogenic
- Thermogenic

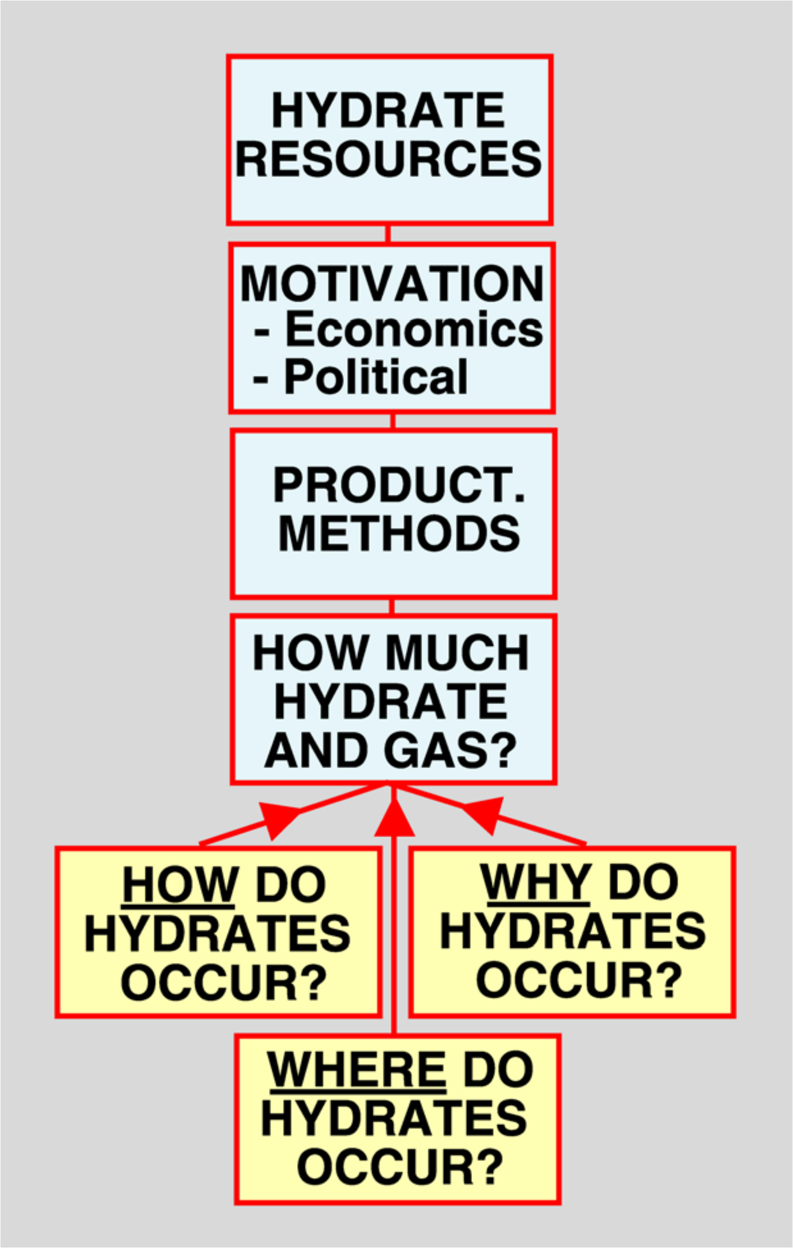
Gas Hydrate Occurrences



Open symbol, gas hydrate recovered
Closed symbol, gas hydrate inferred from other data

Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource

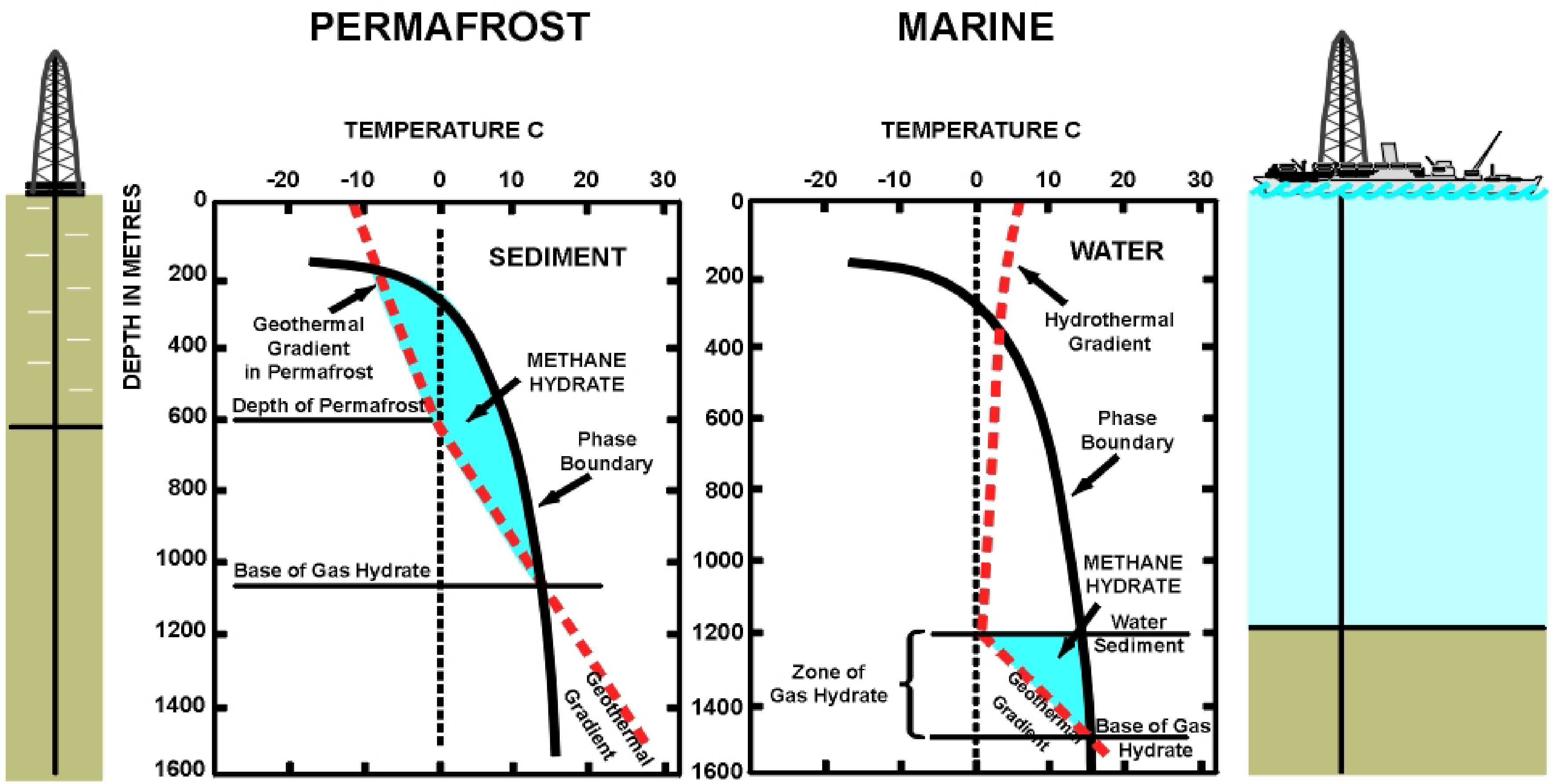


Controls on the Occurrence of Gas Hydrate

-Gas Hydrate Petroleum System-

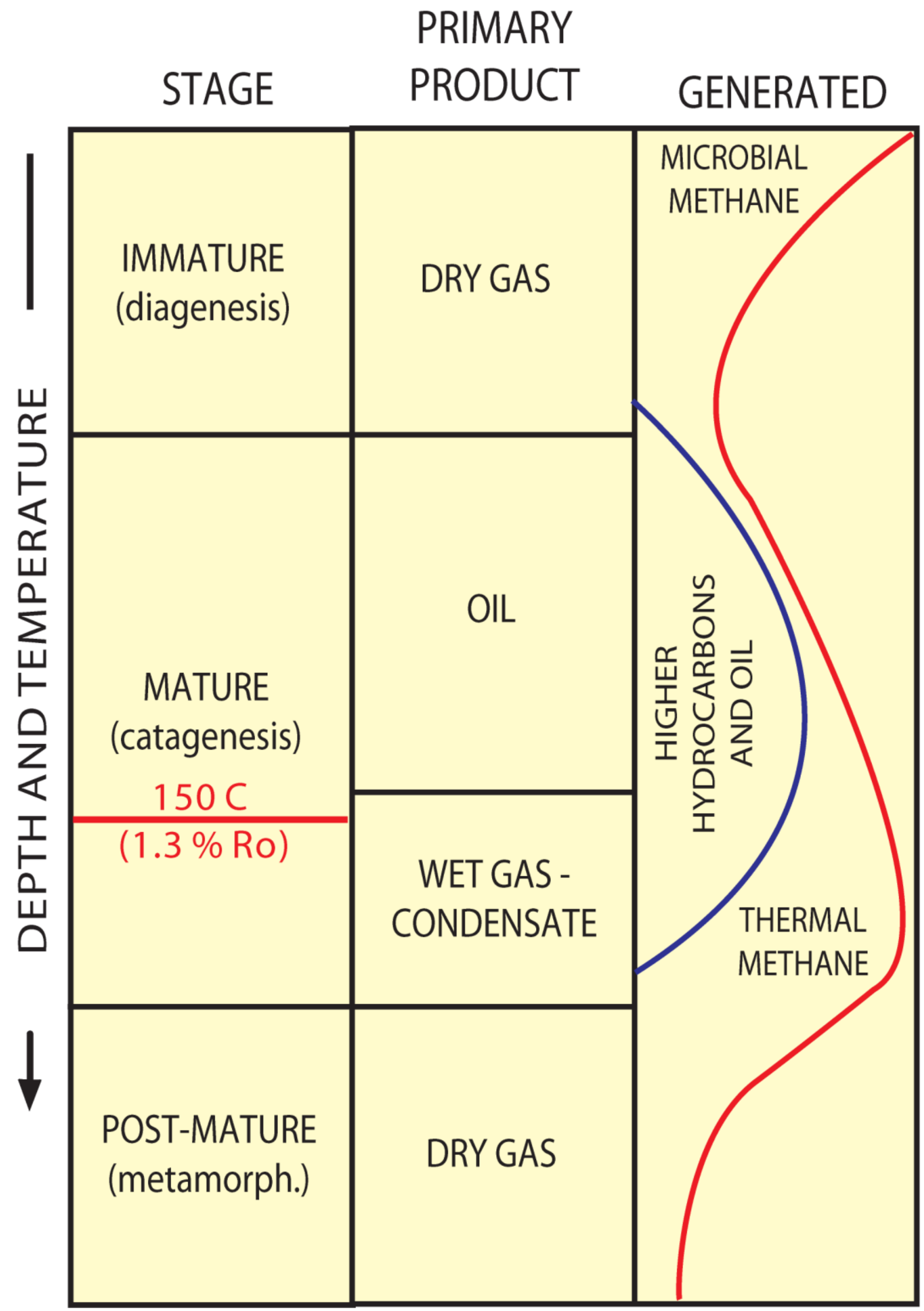
- Formation temperature
- Formation pressure
- Pore water salinity
- Gas chemistry
- Availability of gas and water
- Gas and water migration
- Presence of reservoir rocks and seals

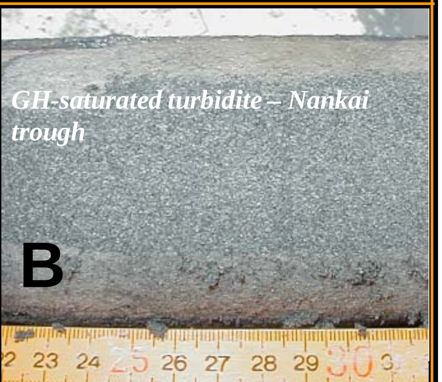
Gas Hydrate Stability



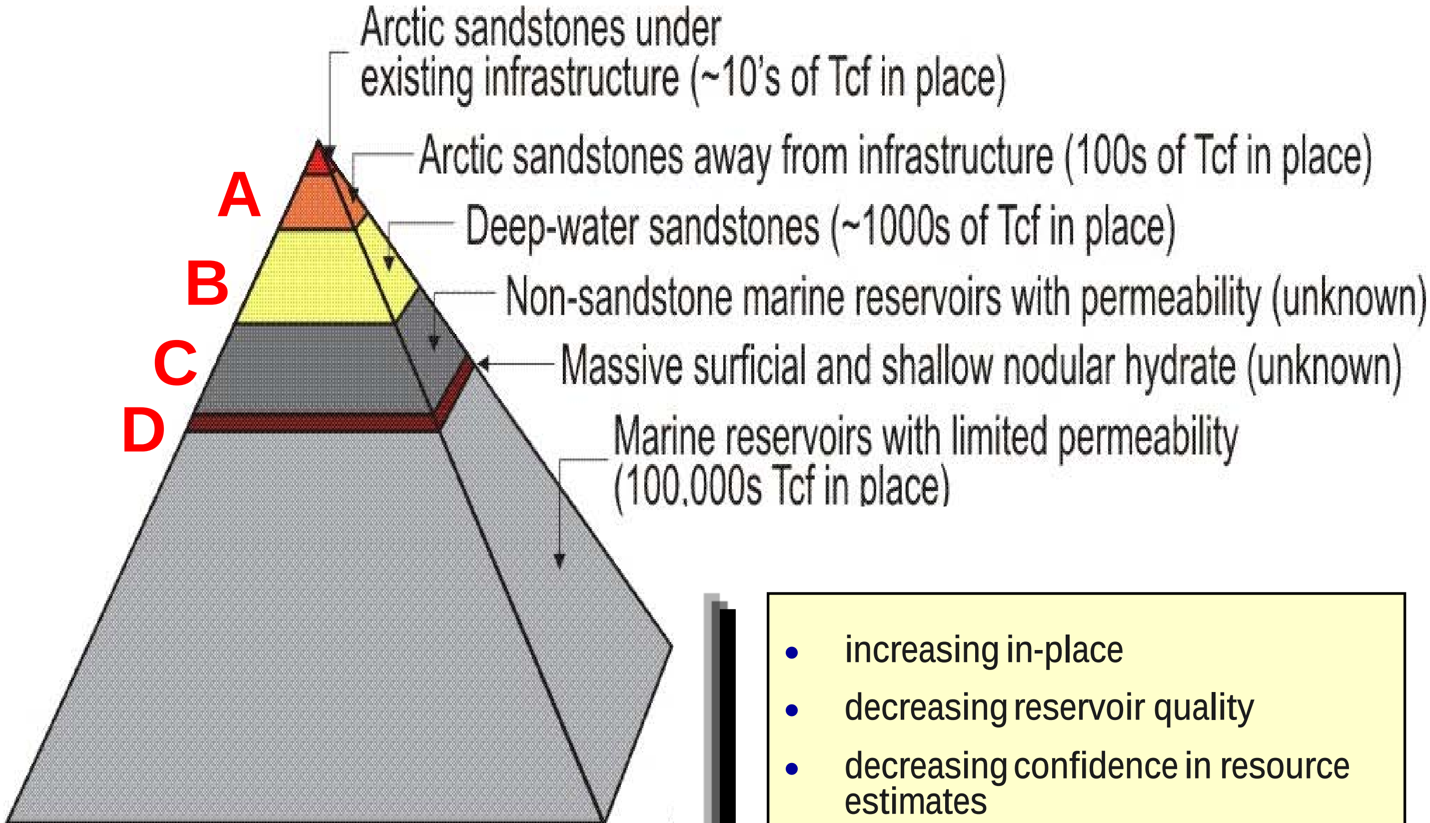
Gas generation

- Microbial
- Thermogenic

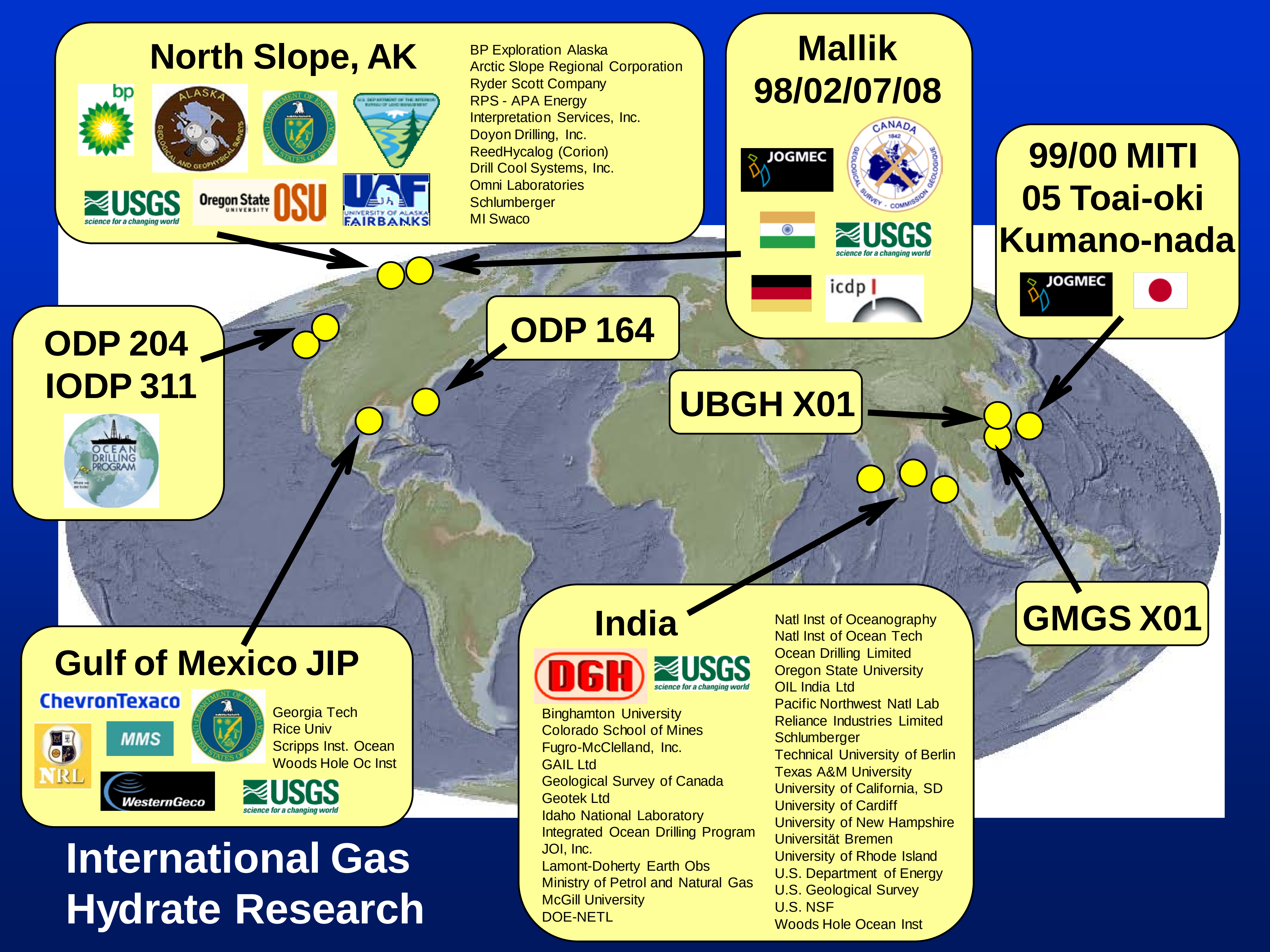




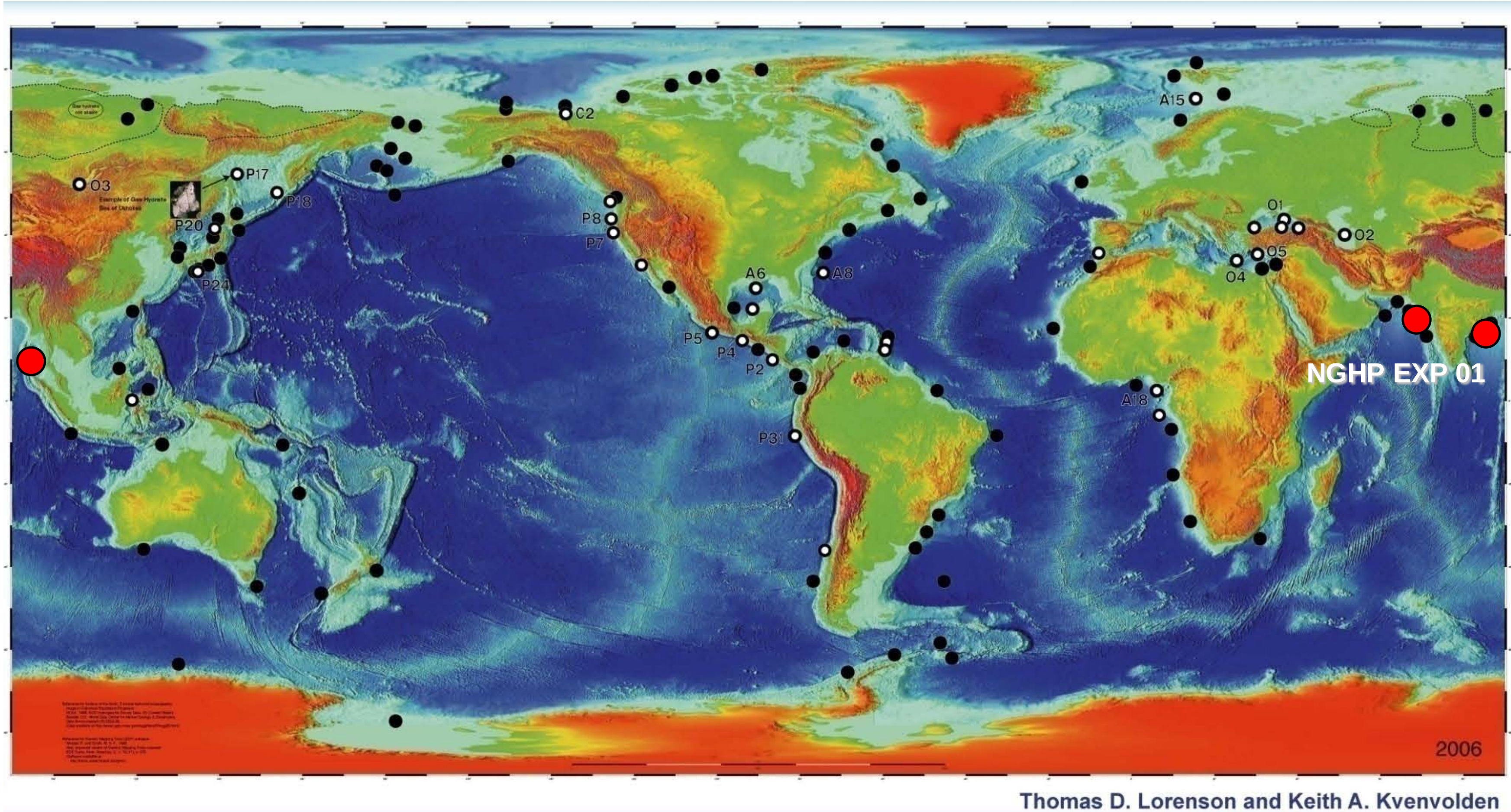
The Gas Hydrate Resource Pyramid



- increasing in-place
- decreasing reservoir quality
- decreasing confidence in resource estimates
- increasing technical challenges and likely decreasing % recoverable


North Slope, AK
BP Exploration Alaska
Arctic Slope Regional Corporation
Ryder Scott Company
RPS - APA Energy
Interpretation Services, Inc.
Doyon Drilling, Inc.
ReedHycalog (Corion)
Drill Cool Systems, Inc.
Omni Laboratories
Schlumberger
MI Swaco
bp
ALASKA GEOLOGICAL AND GEOPHYSICAL SURVEYS
USGS science for a changing world
Oregon State University OSU
UAF UNIVERSITY OF ALASKA FAIRBANKS
Mallik
98/02/07/08
JOGMEC
CANADA GEOLOGICAL SURVEY - COMMISSION GÉOLOGIQUE
USGS science for a changing world
icdp
99/00 MITI
05 Toai-oki
Kumano-nada
JOGMEC
ODP 204
IODP 311
OCEAN DRILLING PROGRAM
ODP 164
UBGH X01
GMGS X01
India
DGH
USGS science for a changing world
Binghamton University
Colorado School of Mines
Fugro-McClelland, Inc.
GAIL Ltd
Geological Survey of Canada
Geotek Ltd
Idaho National Laboratory
Integrated Ocean Drilling Program
JOI, Inc.
Lamont-Doherty Earth Obs
Ministry of Petrol and Natural Gas
McGill University
DOE-NETL
Natl Inst of Oceanography
Natl Inst of Ocean Tech
Ocean Drilling Limited
Oregon State University
OIL India Ltd
Pacific Northwest Natl Lab
Reliance Industries Limited
Schlumberger
Technical University of Berlin
Texas A&M University
University of California, SD
University of Cardiff
University of New Hampshire
Universität Bremen
University of Rhode Island
U.S. Department of Energy
U.S. Geological Survey
U.S. NSF
Woods Hole Ocean Inst
Gulf of Mexico JIP
ChevronTexaco
NRL
MMS
WesternGeco
Georgia Tech
Rice Univ
Scripps Inst. Ocean
Woods Hole Oc Inst
USGS science for a changing world
International Gas
Hydrate Research

Gas Hydrate Occurrences



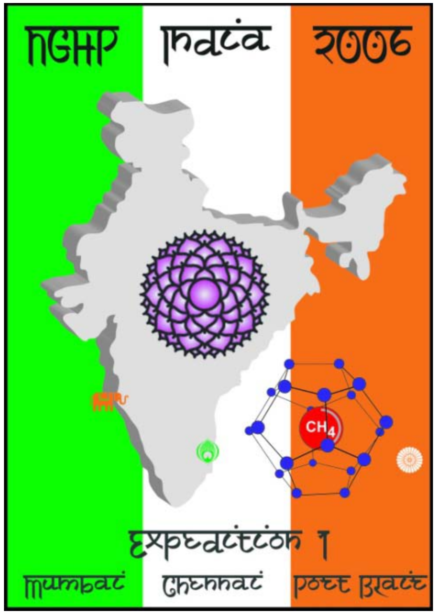
Open symbol, gas hydrate recovered
Closed symbol, gas hydrate inferred from other data

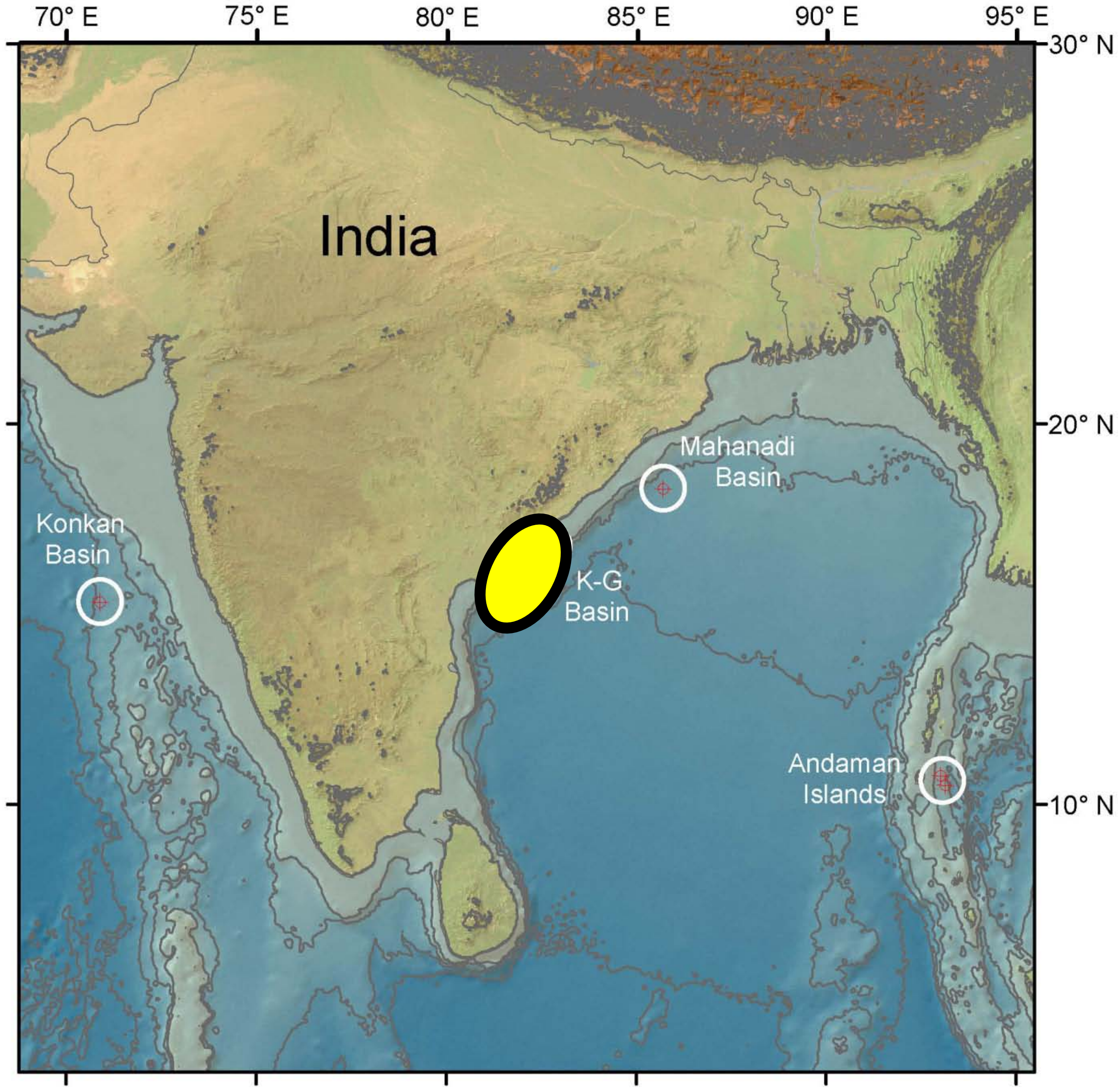
Sand dominated gas hydrate reservoirs

NGHP Expedition 01

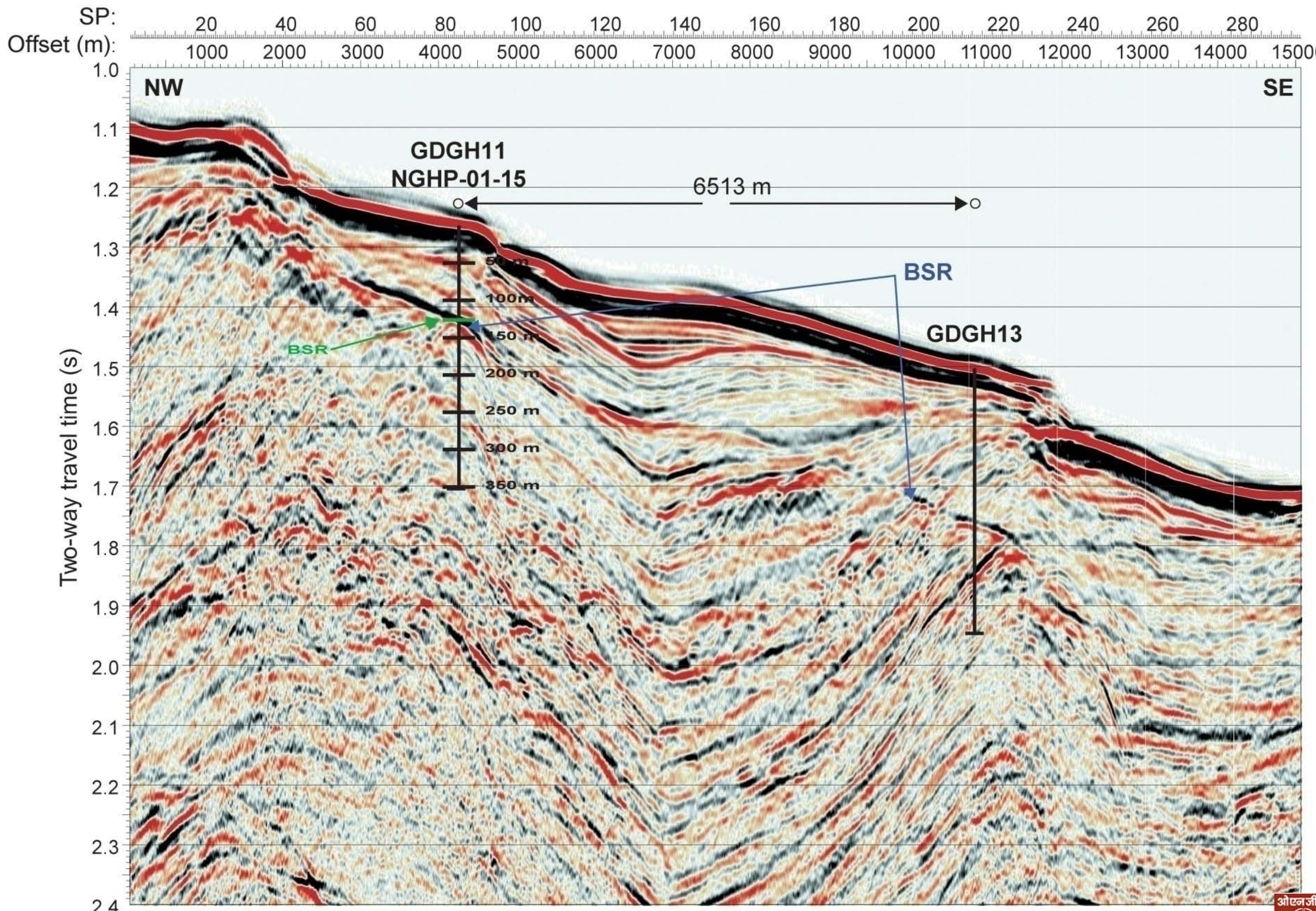
Scientific Coring-Logging

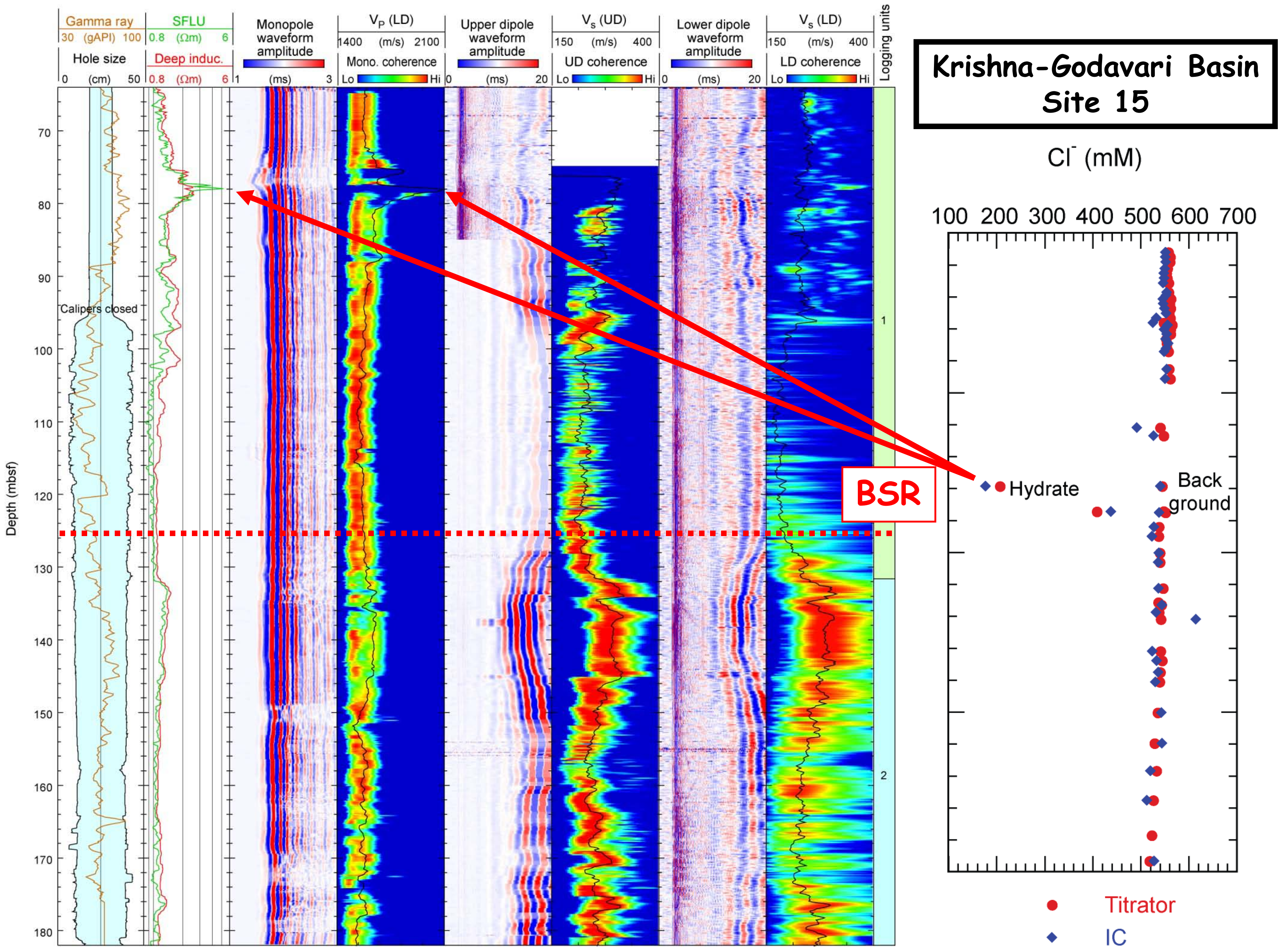
- Kerala-Konkan Basin
- Krishna-Godavari Basin
- Mahanadi Basin
- Andaman Islands



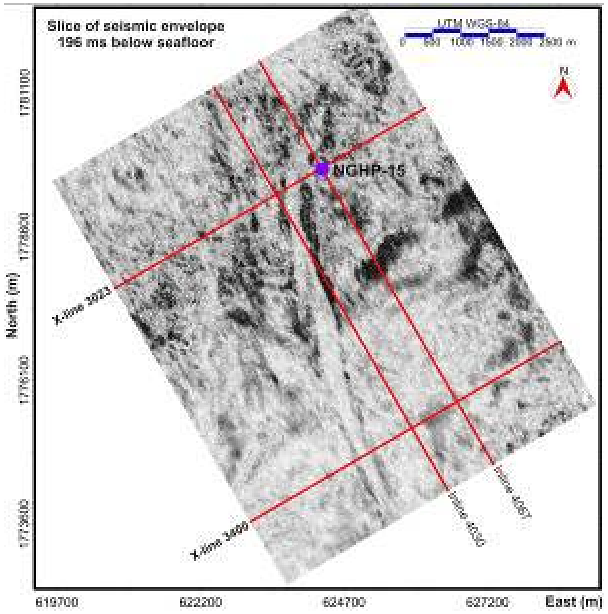


Krishna-Godavari Basin – Site 15

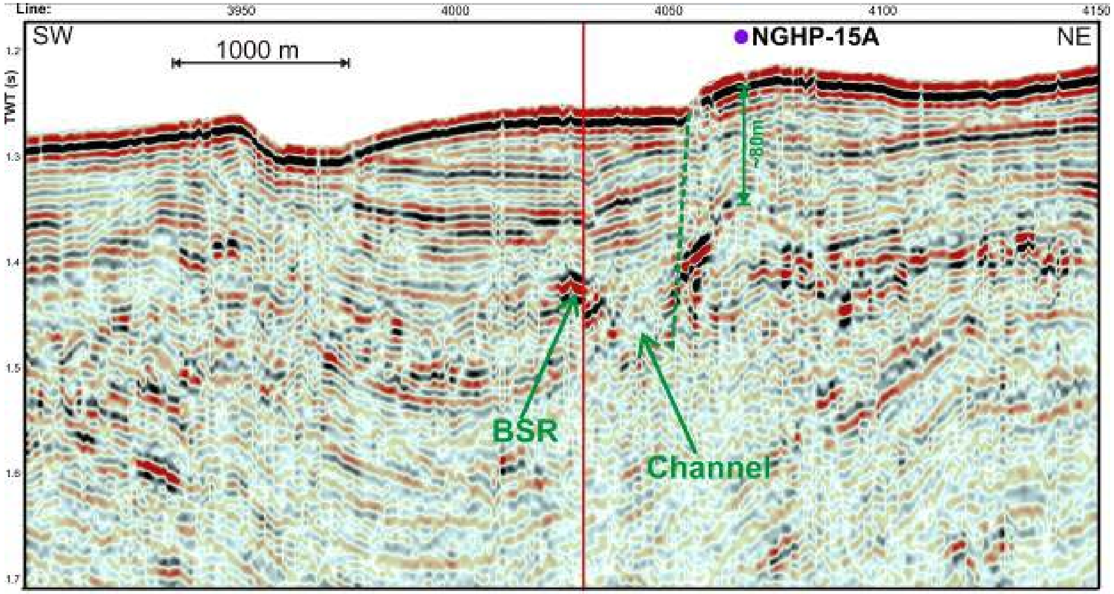



Krishna-Godavari Basin
Site 15
Gamma ray
30 (gAPI) 100
Hole size
0 (cm) 50
SFLU
0.8 (Ωm) 6
Deep induc.
0.8 (Ωm) 6
Monopole waveform amplitude
1 (ms) 3
VP (LD)
1400 (m/s) 2100
Mono. coherence
Lo Hi
Upper dipole waveform amplitude
0 (ms) 20
Vs (UD)
150 (m/s) 400
UD coherence
Lo Hi
Lower dipole waveform amplitude
0 (ms) 20
Vs (LD)
150 (m/s) 400
LD coherence
Lo Hi
Logging units
1
2
Depth (mbsf)
Calipers closed
BSR
Cl- (mM)
100 200 300 400 500 600 700
Hydrate
Back ground
Titrator
IC

Site 15 – Sand Reservoir
-Gas Hydrate Distribution-



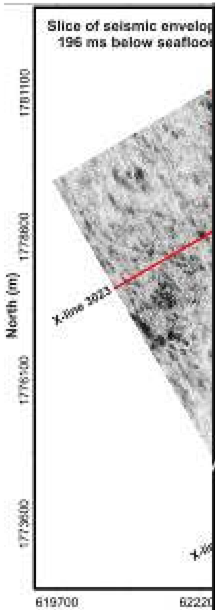
Time slice (196 ms below seafloor) of instantaneous amplitude showing a channel cutting through the study area of Site NGHP-15.

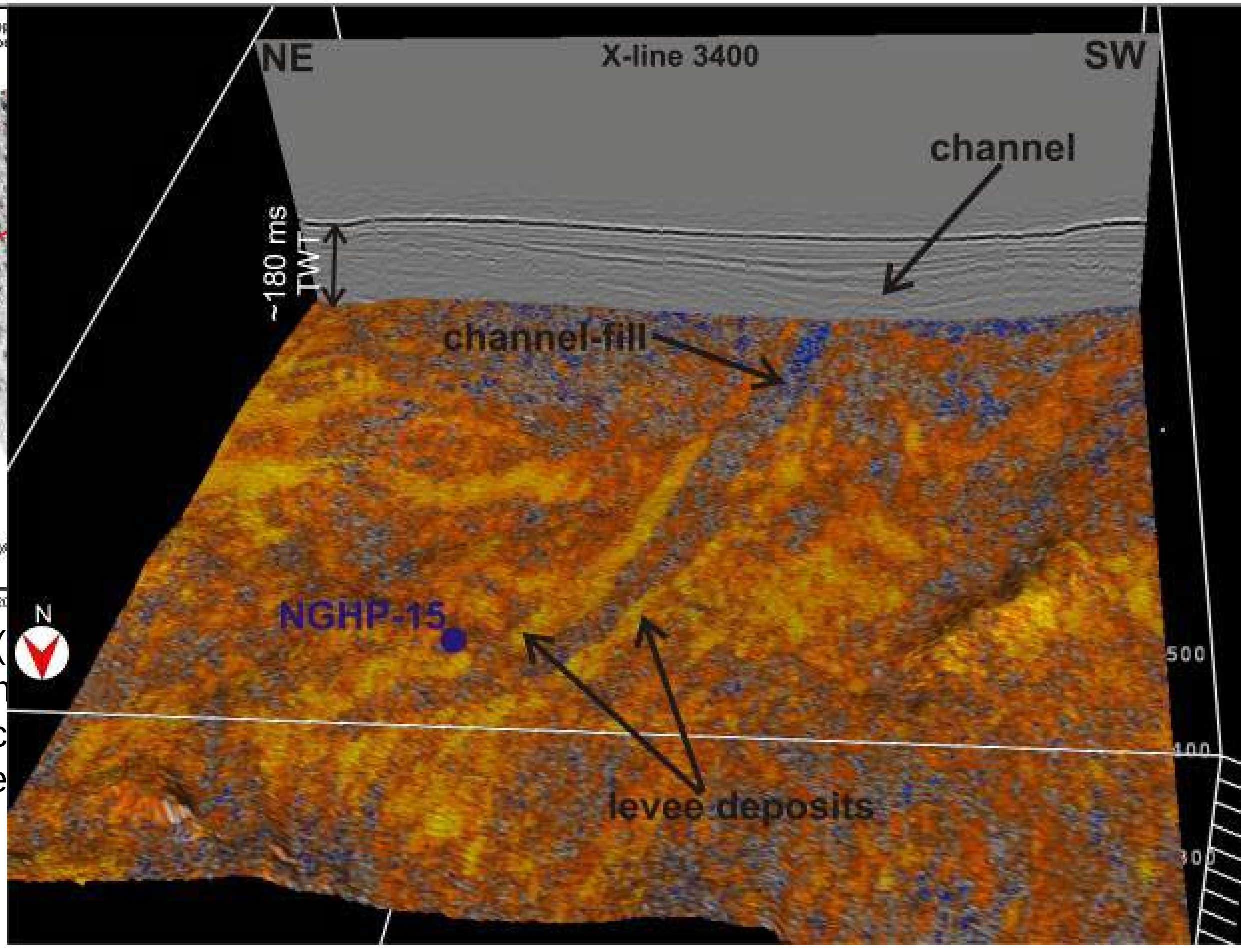


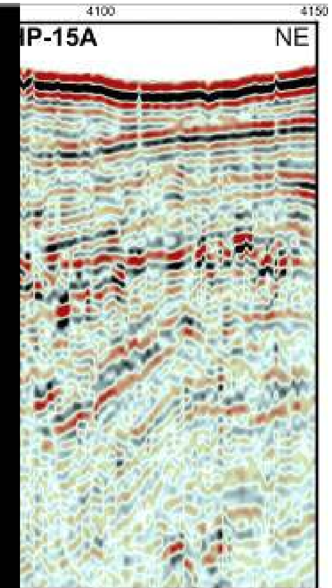
Seismic X-line 3023, showing the channel with edges enhanced in reflection amplitude at the BSR level.

Michael Riedel, 2008

Site 15 – Sand Reservoir
-Gas Hydrate Distribution-







Time slice (
of instantan
a channel c
area of Site

edges enhanced

Michael Riedel, 2008

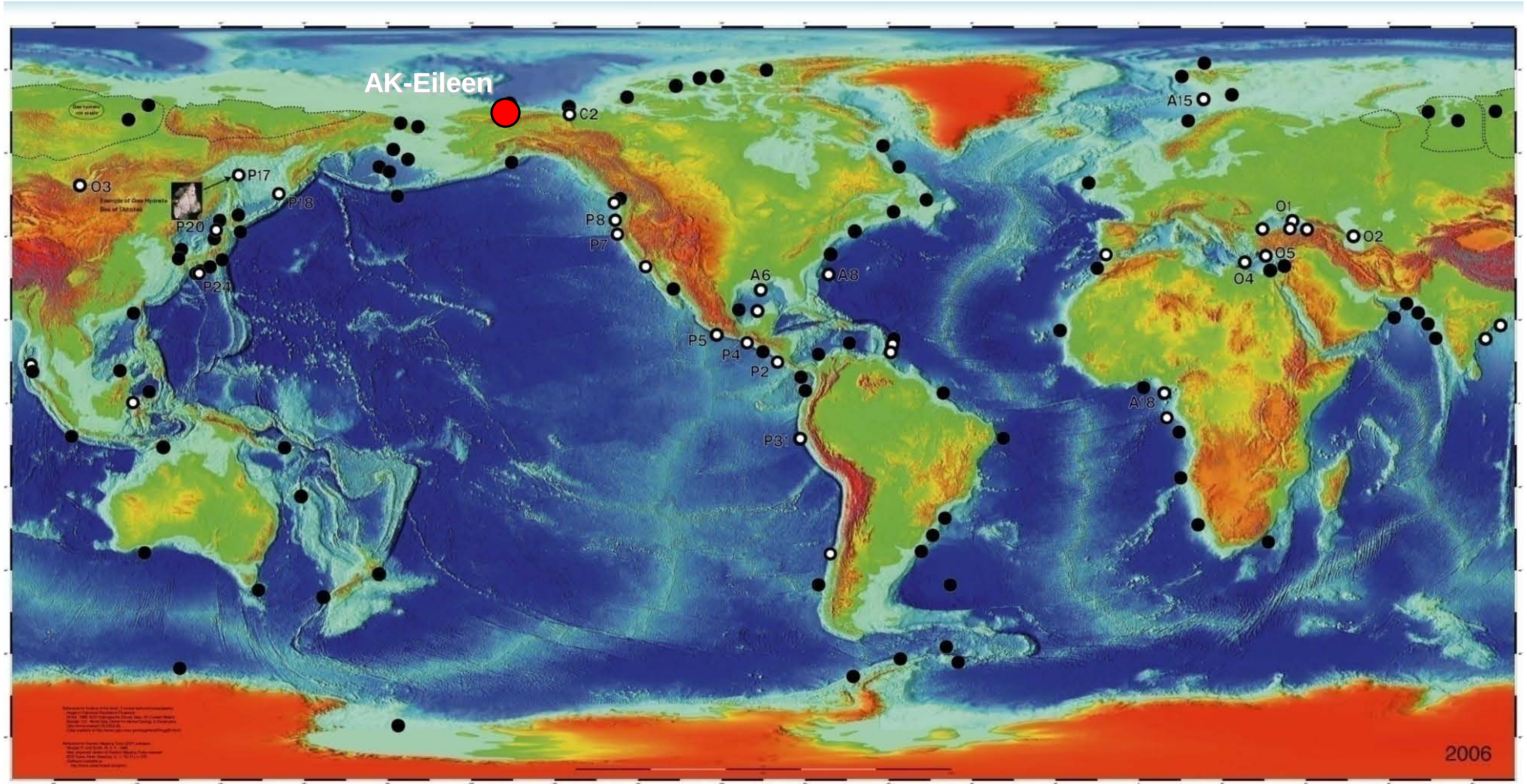
NGHP Expedition 01
Gas Geochemistry Summary

NGHP EXP 01 Gas Hydrate Composition

- Microbial origin of methane
- 99.9 - 100% methane, Structure-I hydrate
- Up to 0.1 % CO_2
- Up to 0.02% ethane

- Sediment Gas Composition
  - Microbial origin, mainly methane, traces of thermogenic gas (C_3+) in Mahanadi and Andaman.

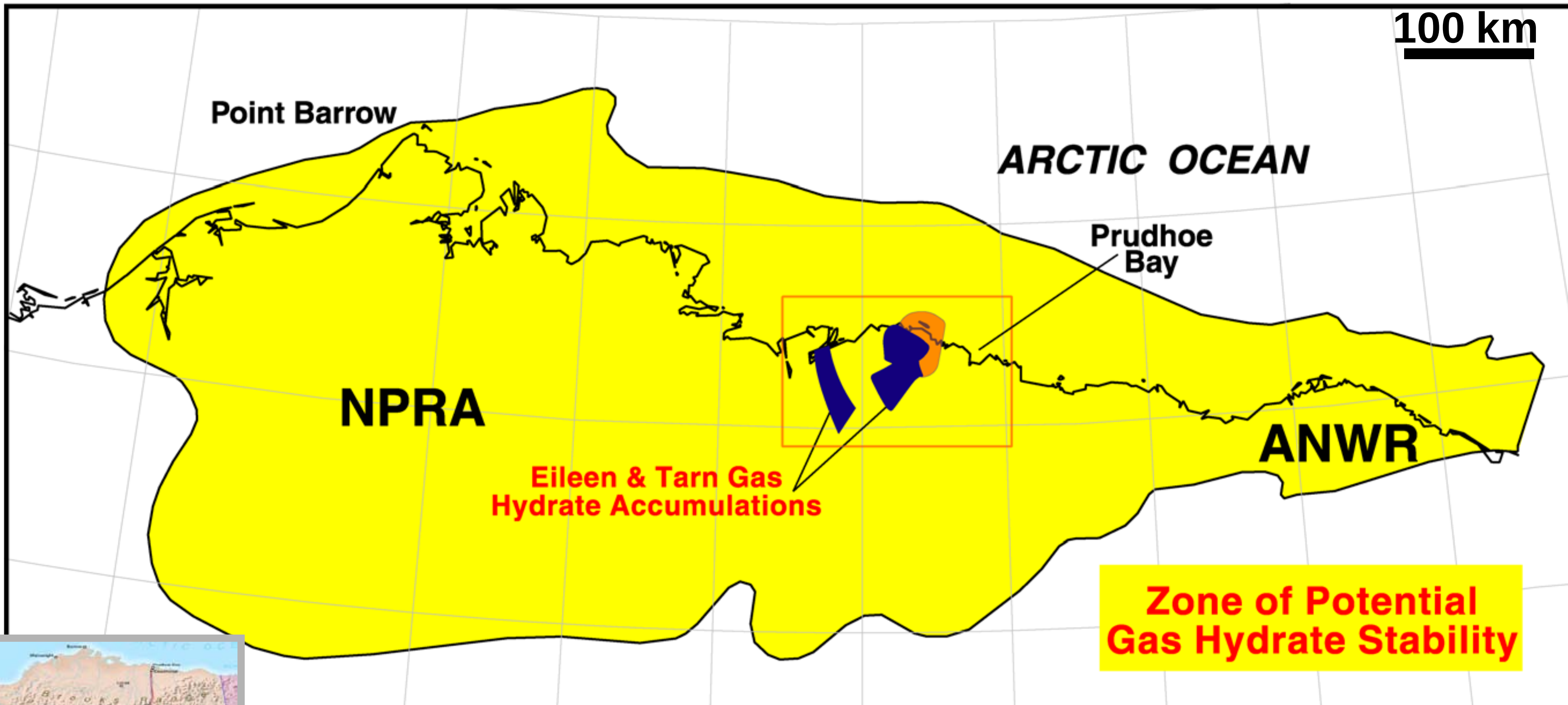
Gas Hydrate Occurrences



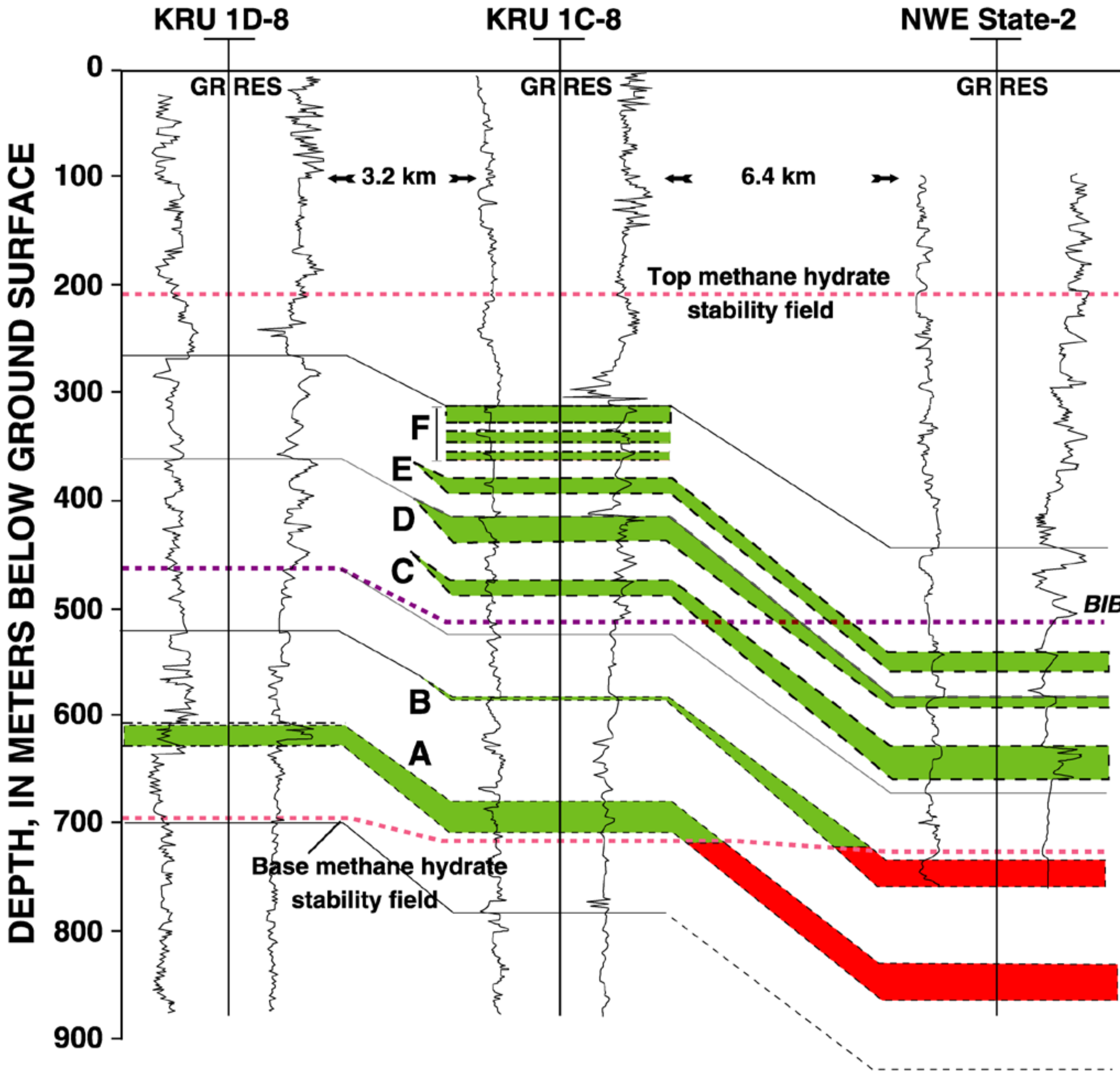
Thomas D. Lorenson and Keith A. Kvenvolden

Open symbol, gas hydrate recovered
Closed symbol, gas hydrate inferred from other data

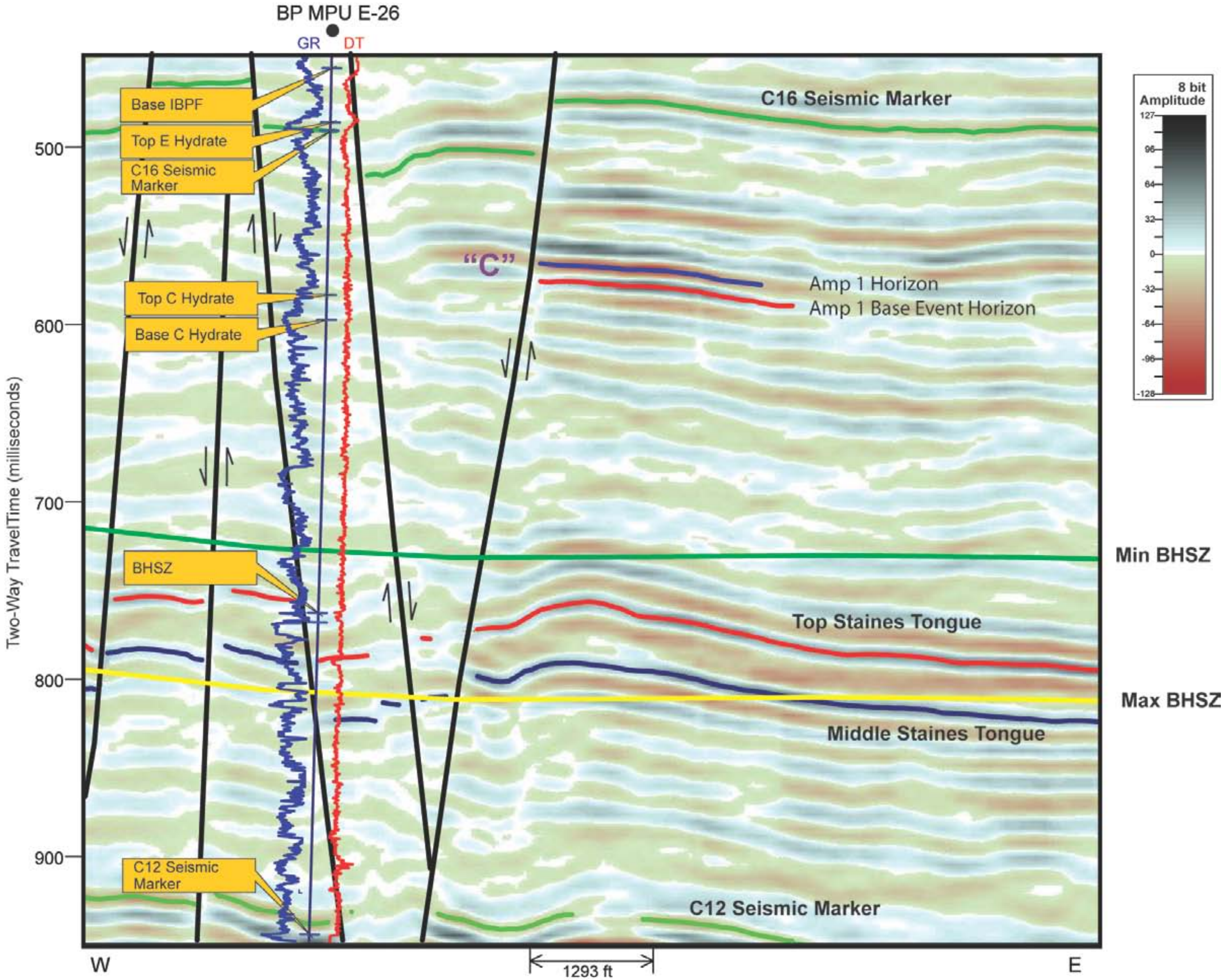
Alaska NS Gas Hydrates

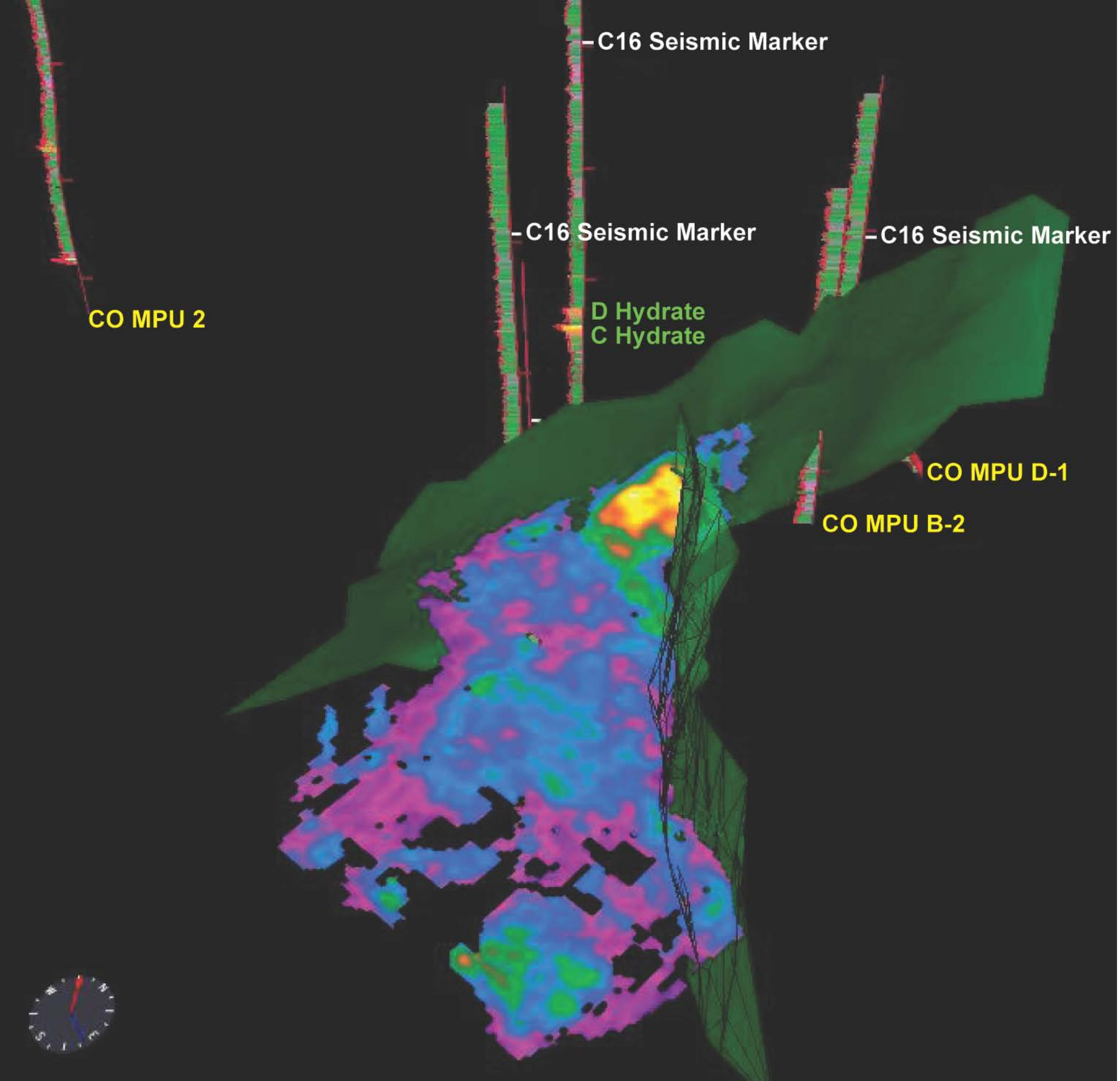


Eileen Gas Hydrate Accumulation



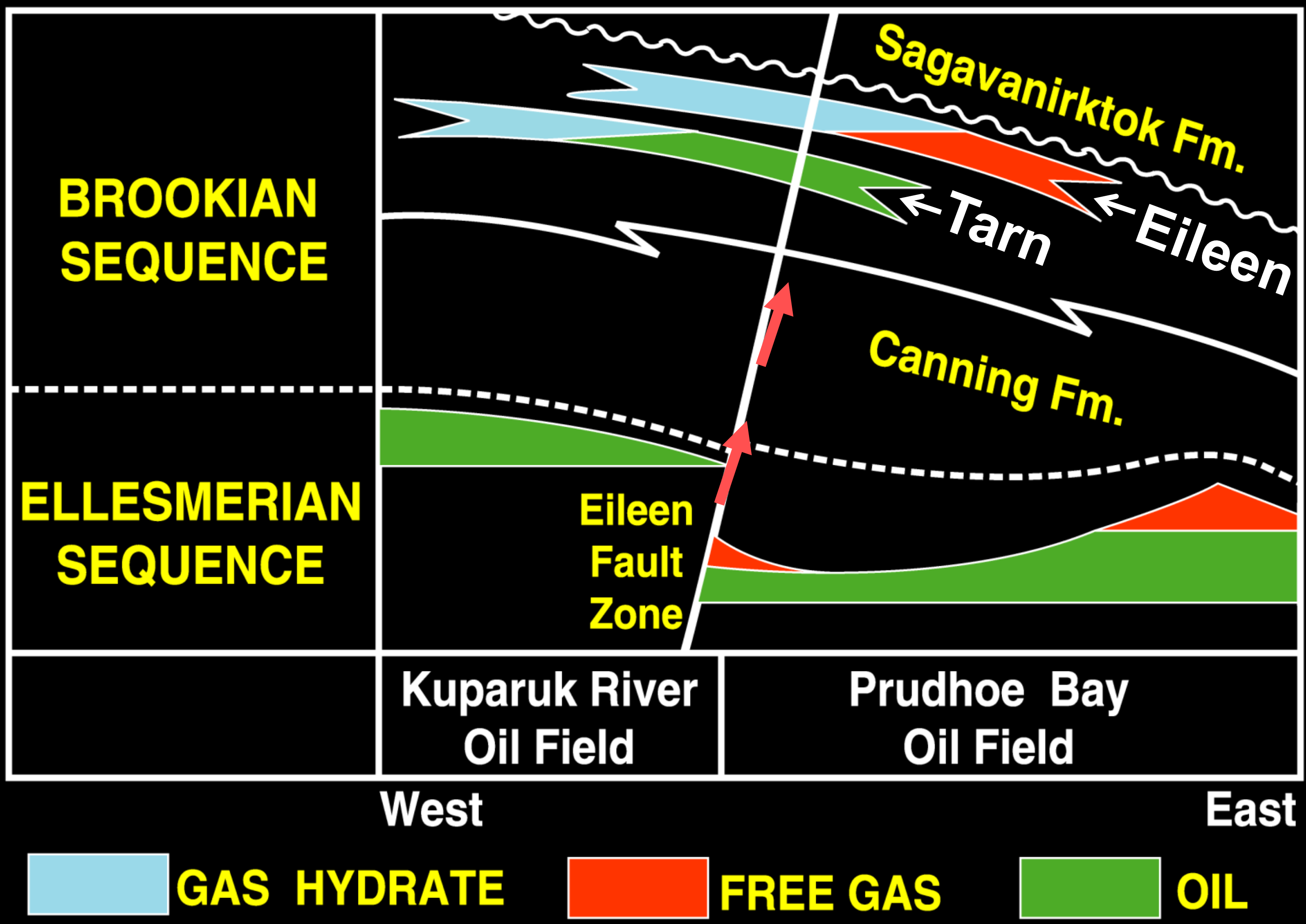
Mt Elbert Prospect





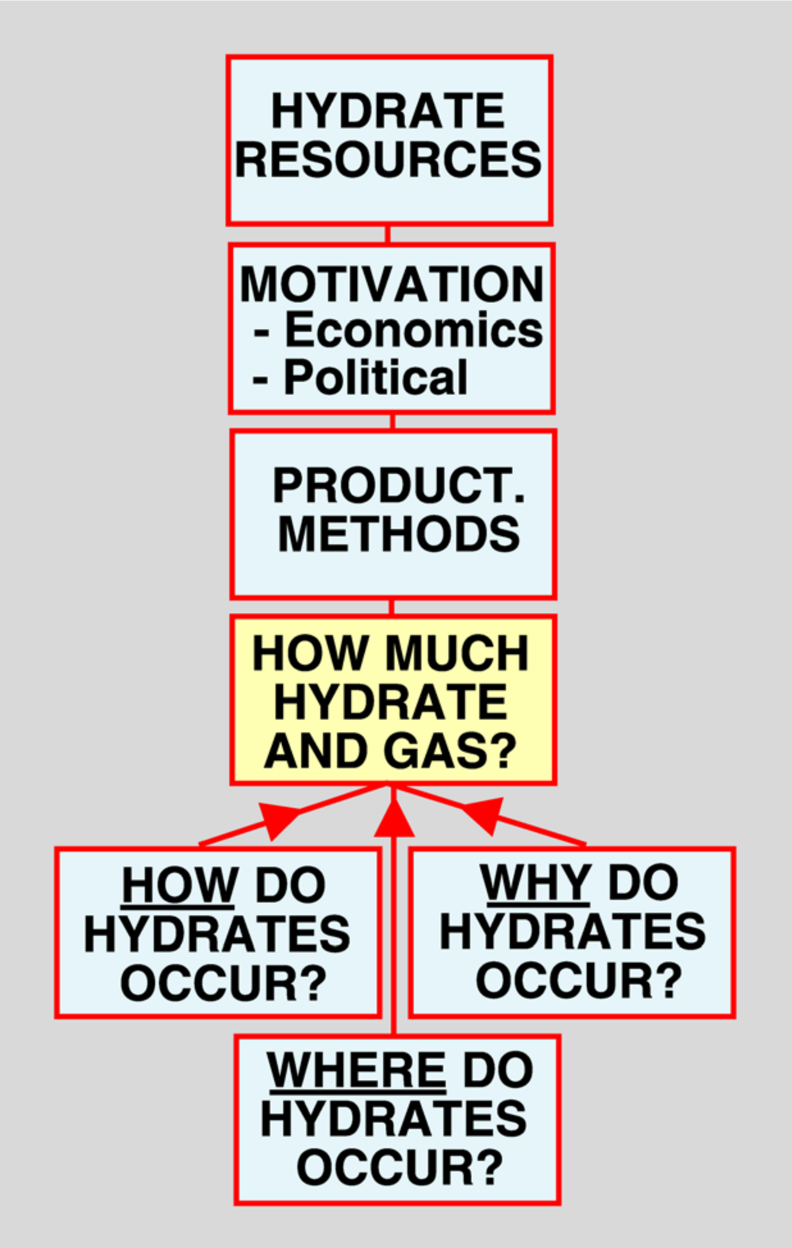
Mt Elbert Prospect

Eileen and Tarn Gas Hydrate Petroleum System



Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource



NATIONAL-REGIONAL-LOCAL ESTIMATES OF THE AMOUNT OF GAS WITHIN GAS HYDRATES (cubic feet of gas)

UNITED STATES

$317,700 \times 10^{12}$ Collett, 1995

INDIA

$4,307 \times 10^{12}$ ONGC, 1997

BLAKE RIDGE

635×10^{12} Dillon et al., 1993
$2,471 \times 10^{12}$ Dickens et al., 1997*
$2,827 \times 10^{12}$ Holbrook et al., 1996*
$2,012 \times 10^{12}$ Collett et al., 2000*
$1,331 \times 10^{12}$ Collett et al., 2000
*Includes associated free-gas

NANKAI TROUGH, JAPAN

$1,765 \times 10^{12}$ MITI/JNOC, 1998

NORTH SLOPE, ALASKA, USA

590×10^{12} Collett, 1997

MACKENZIE DELTA, CANADA

$35\text{-}353 \times 10^{12}$ Osadetz et al., 2005

GULF OF MEXICO, USA

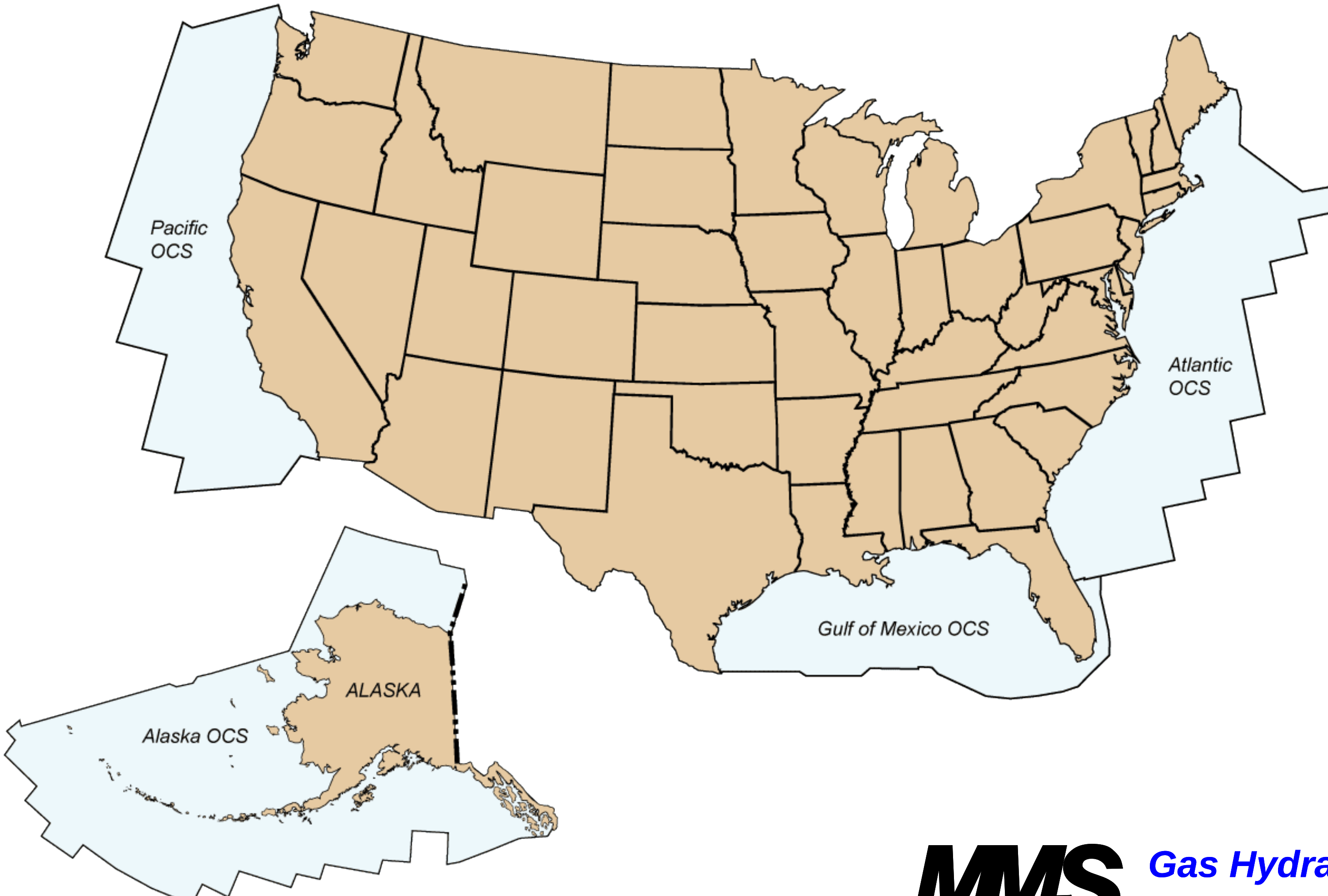
$21,444 \times 10^{12}$ Frye (MMS), 2008
(with $6,717 \times 10^{12}$ in sand reservoirs)

EILEEN FIELD, ALASKA , USA

42×10^{12} Collett, 1993

AT STP

Goal: Assess In-Place, Technically Recoverable, and Economically Recoverable Gas Hydrate resources on the U.S. Outer Continental Shelf (OCS)

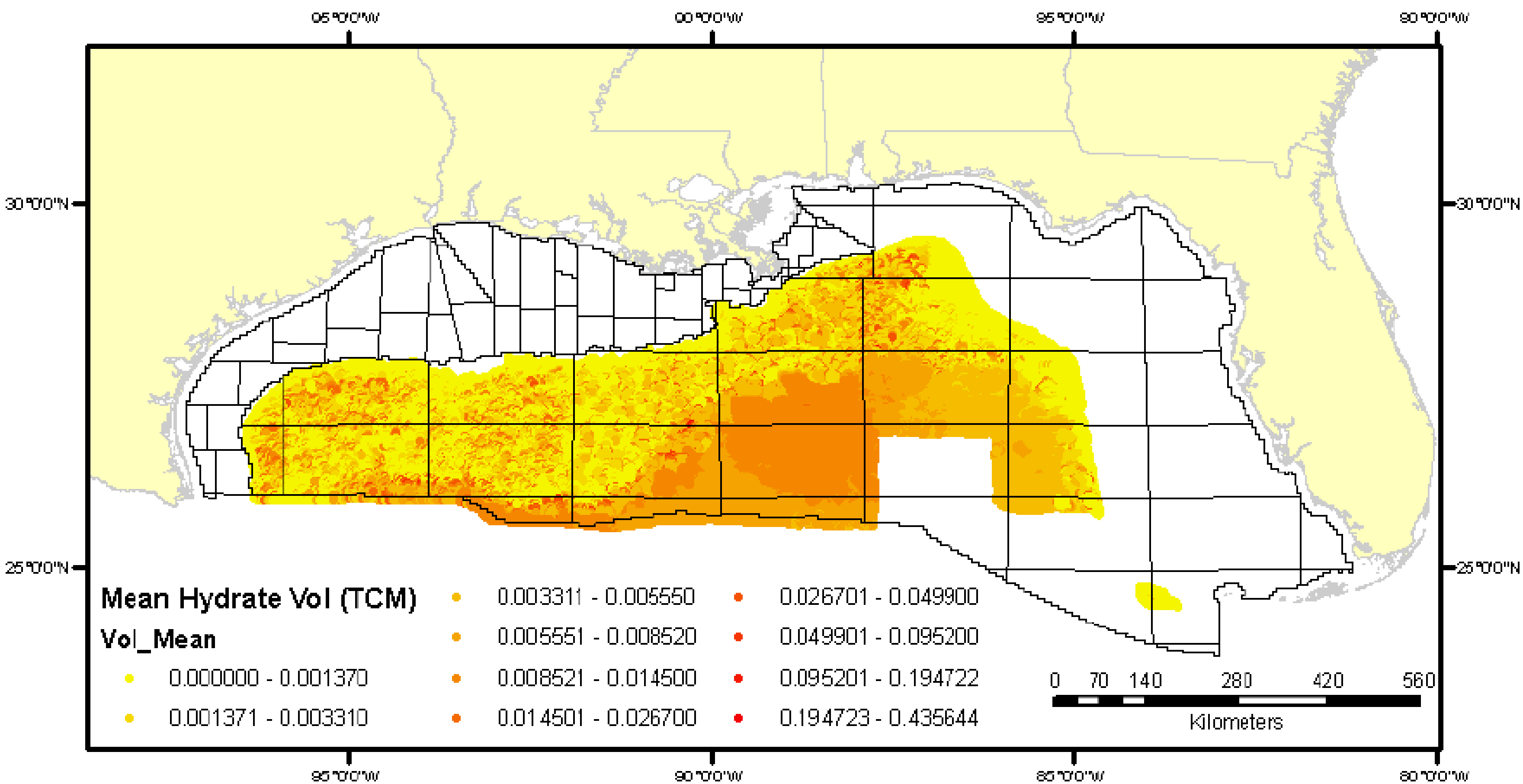


MMS Gas Hydrate Resource Evaluation

Gas Hydrate Assessment: All Sediments

In-place Gas Hydrate Resources for the Gulf of Mexico

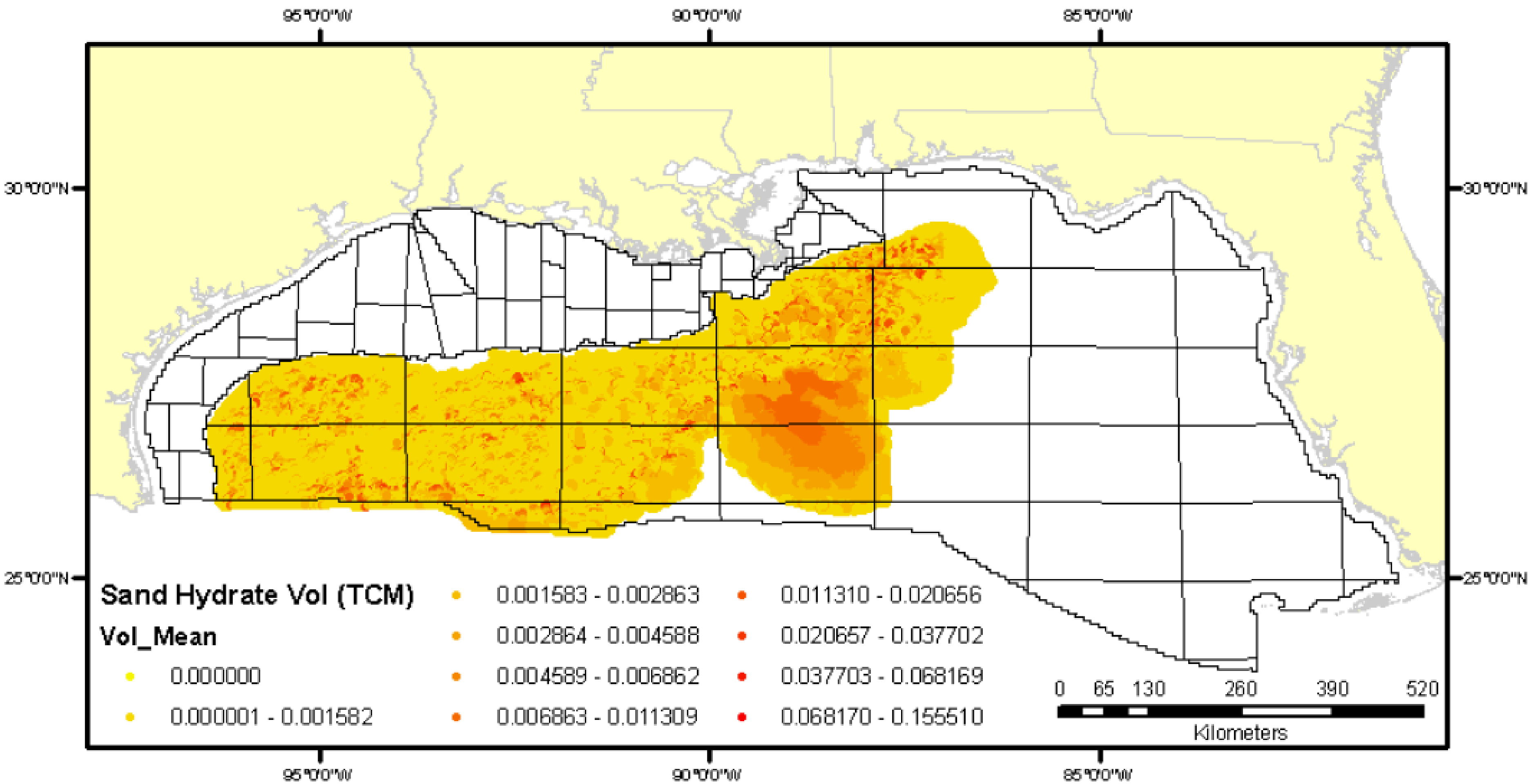
Region	95%	mean	5%
Gulf of Mexico	11,112 TCF	21,444 TCF	34,423 TCF



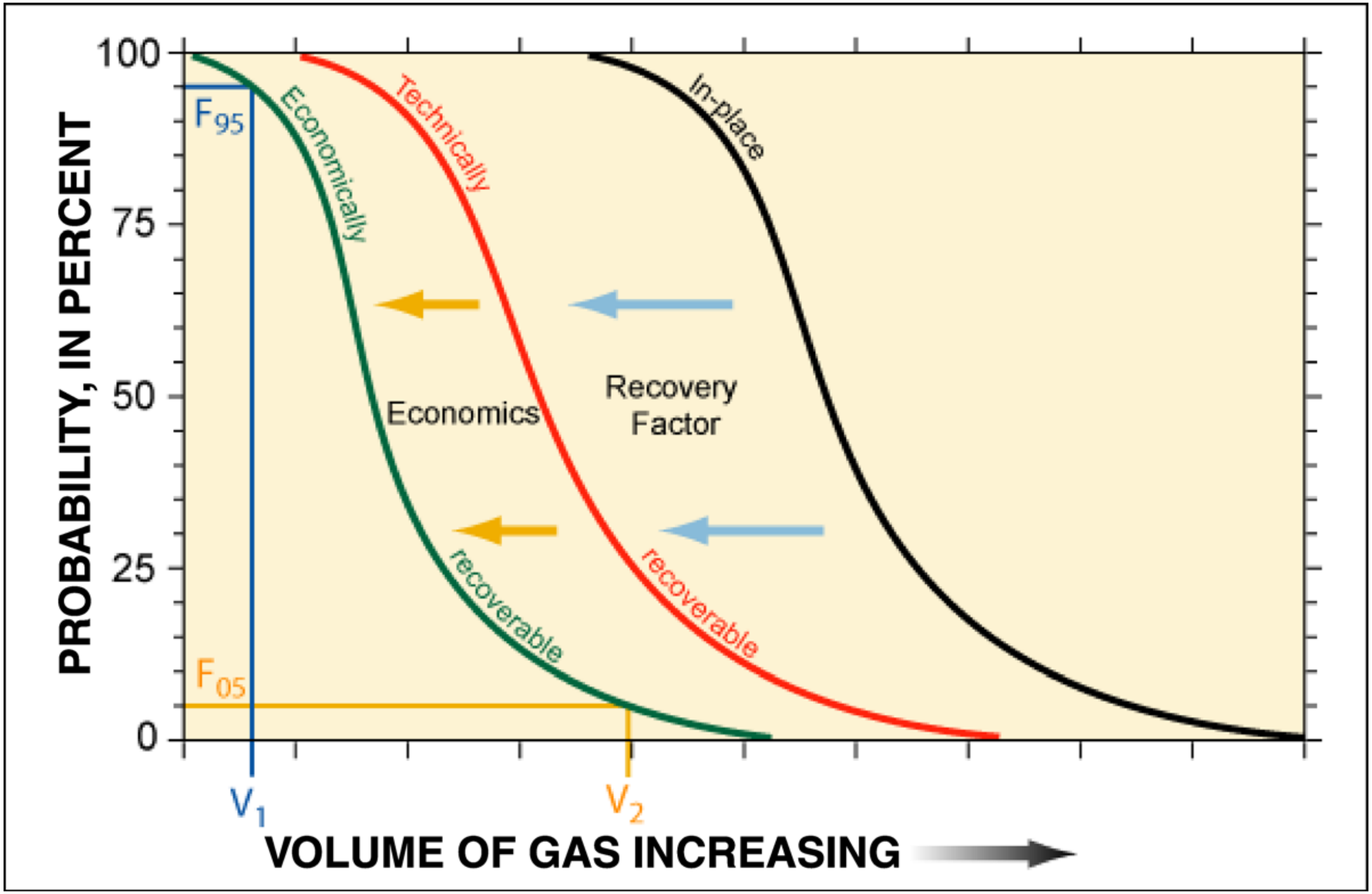
Gas Hydrate Assessment: Sand Reservoirs

Sand-only Gas Hydrate Resources for the Gulf of Mexico (trillion cubic feet).

Region	95%	mean	5%
Gulf of Mexico	n/a	6,717 TCF	n/a

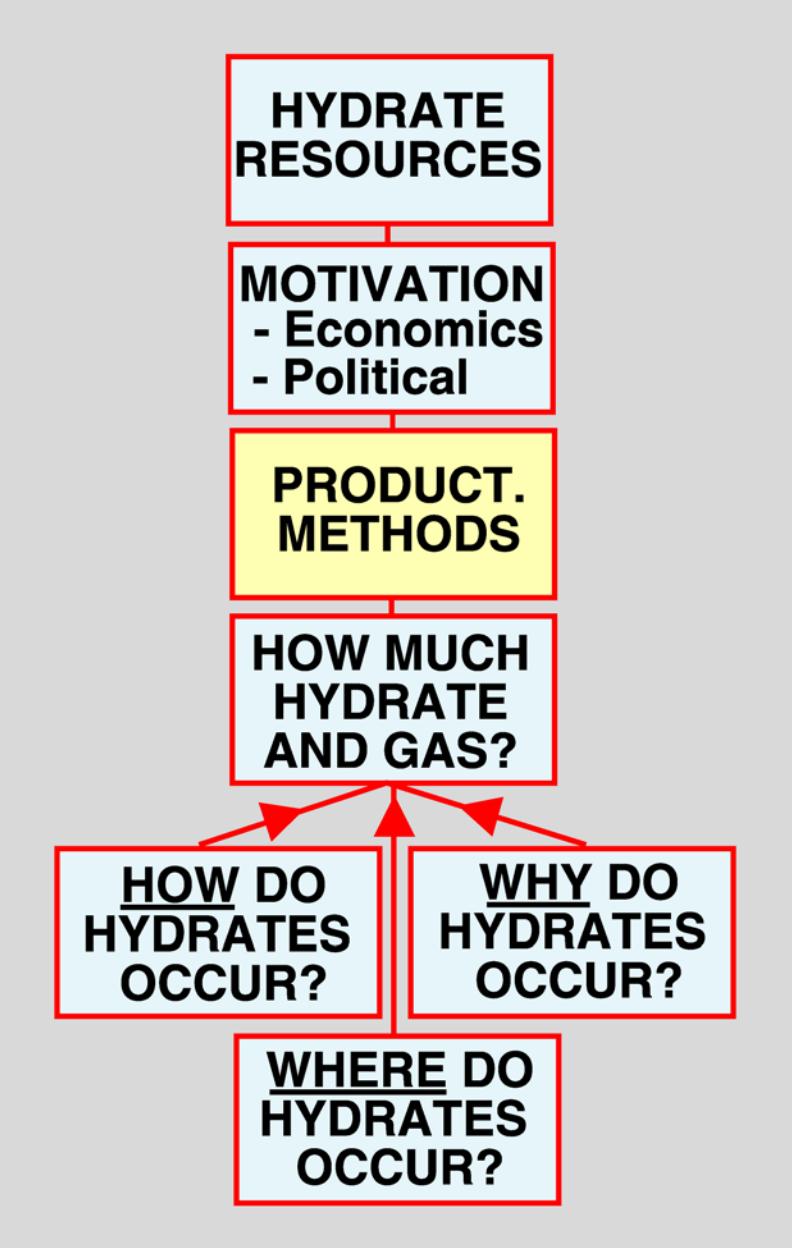


Hydrate Resource Assessment
"Economically Recoverable Assessment"

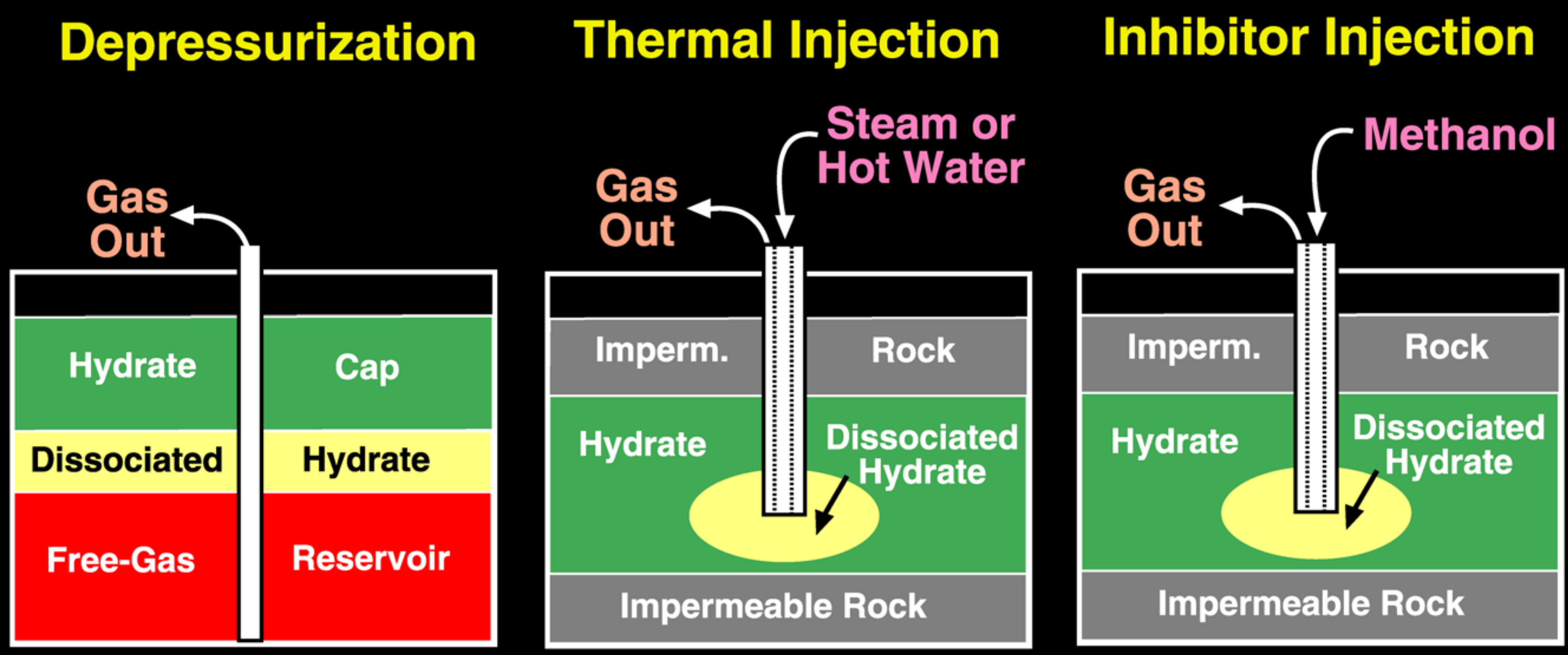


Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource



Gas Hydrate Production Methods



Mallik 2002 Gas Hydrate Production Test Well

- Japan
  - JNOC/JOGMEC (METI)
  - JNOC collaborators
- Canada
  - GSC
  - BP/Chevron/Burlington
  - (Japex Canada, Imperial Oil)
- USA
  - USGS
  - USDOE
- Germany
  - GeoForschungsZentrum Potsdam
- India
  - National Gas Hydrate Program (NGHP), with DGH, MOP&NG, ONGC, and GAIL
- International Continental Scientific Drilling Program
  - Universities and research institutes in Japan, Canada, USA, Germany and China

Mount Elbert Gas Hydrate Stratigraphic Test Well, Alaska

INDUSTRY

- BP Exploration Alaska
- Arctic Slope Regional Corporation
- Ryder Scott Company
- RPS - APA Energy
- Interpretation Services, Inc.
- Doyon Drilling, Inc.
- ReedHycalog (Corion)
- Drill Cool Systems, Inc.
- Omni Laboratories
- Schlumberger
- MI Swaco

GOVERNMENT

- US Geological Survey
- Department of Energy

ACADEMIA

- U. Alaska-Fairbanks
- U. Arizona
- Oregon State University

Gas Hydrate Production Modeling

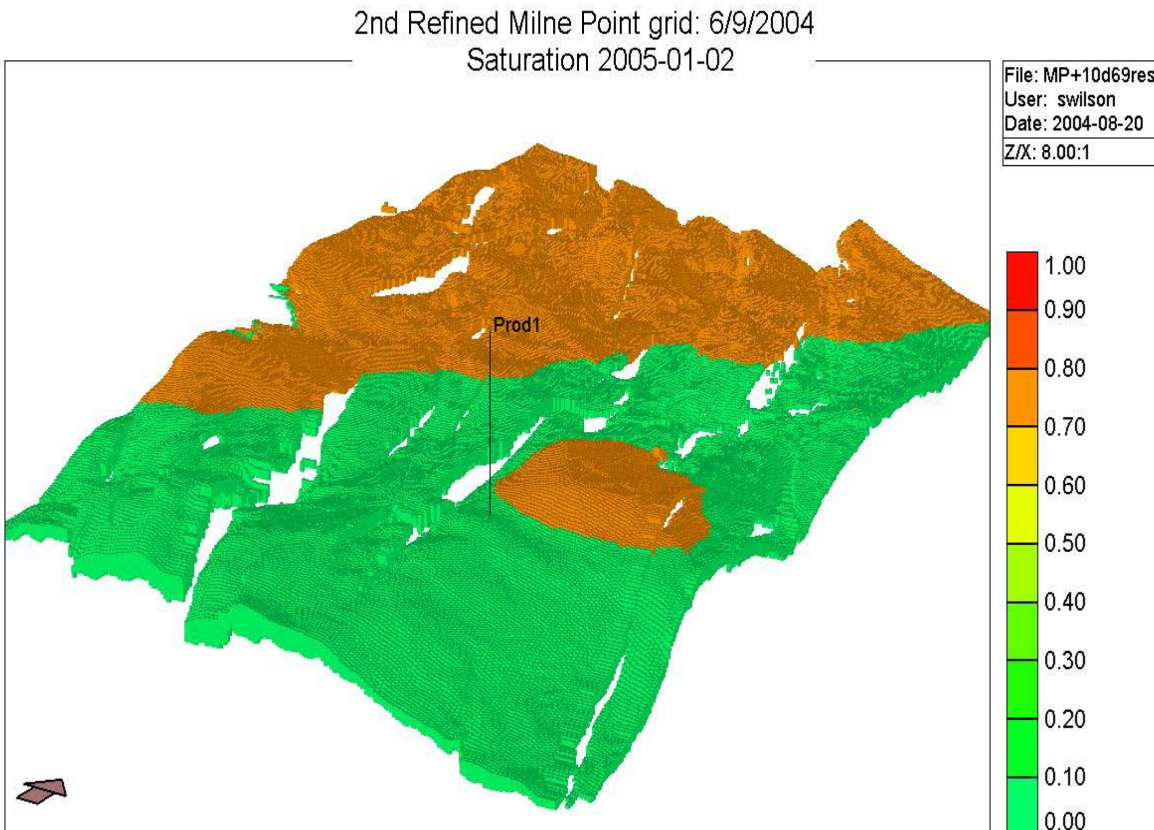
- TOUGH2/EOSHYDR
  - Developed by LBNL (DOE)
  - Research Code
  - Multi-component simulator

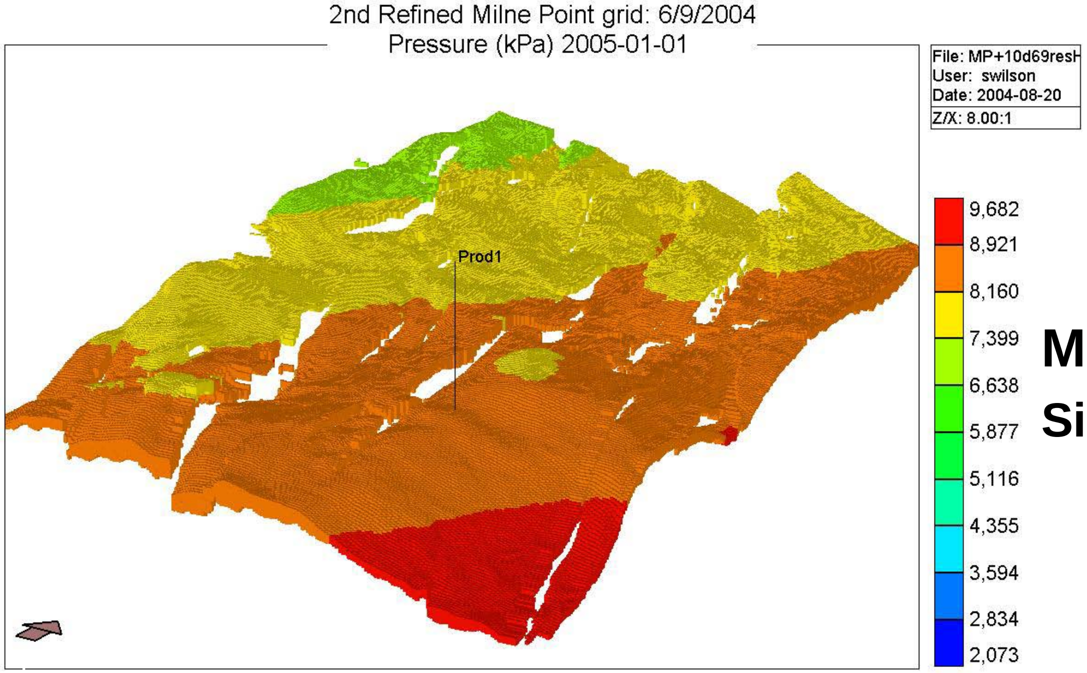
- CMG STARS
  - Industry simulator
  - Commercial quality i/o

- Methane Hydrate 21
  - Developed by JOGMEC
  - Research Code
  - Multi-component simulator

General Milne Point Model, Alaska

- 201 x 340 x 2 cells = 136,680 total cells
- 82.5 foot grid spacing
  3 miles x 5 miles
- Horizontal well;
  175 meters long
  in Small Gas
  Accumulation

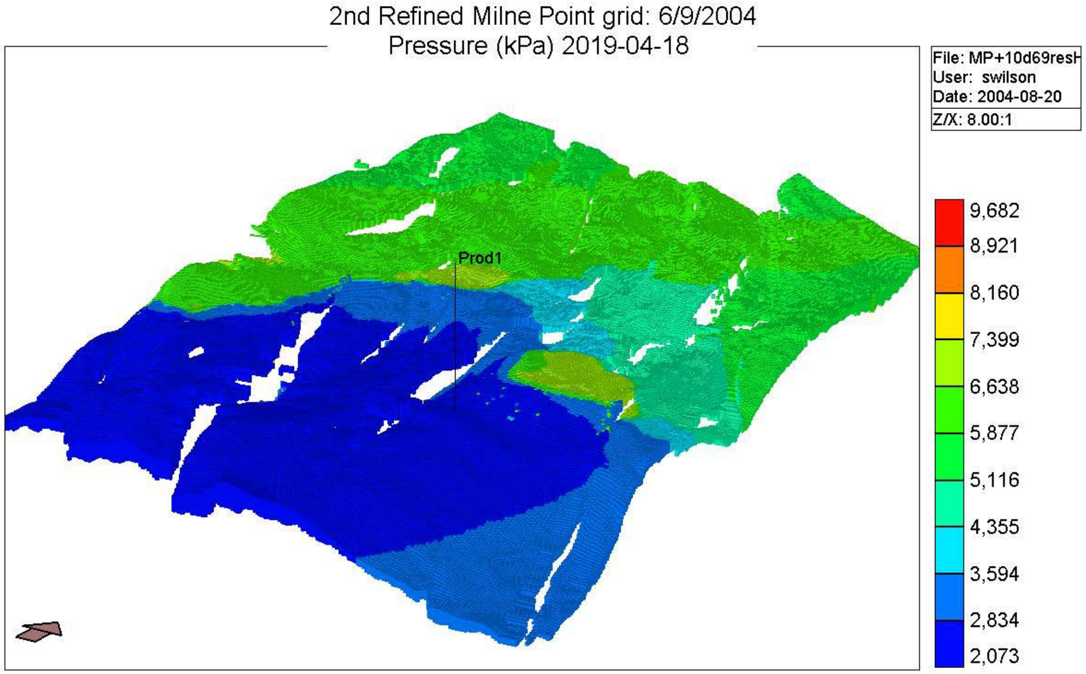


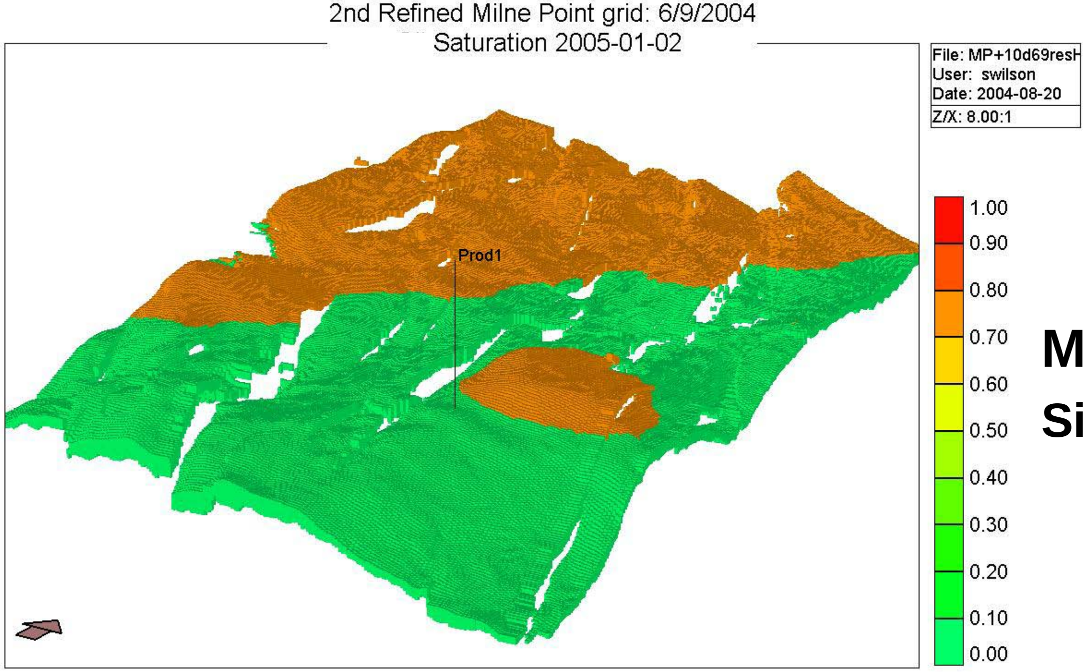


Milne Point, AK - STARS MODEL

Single well down-dip below gas hydrate in free-gas

Pressure Response

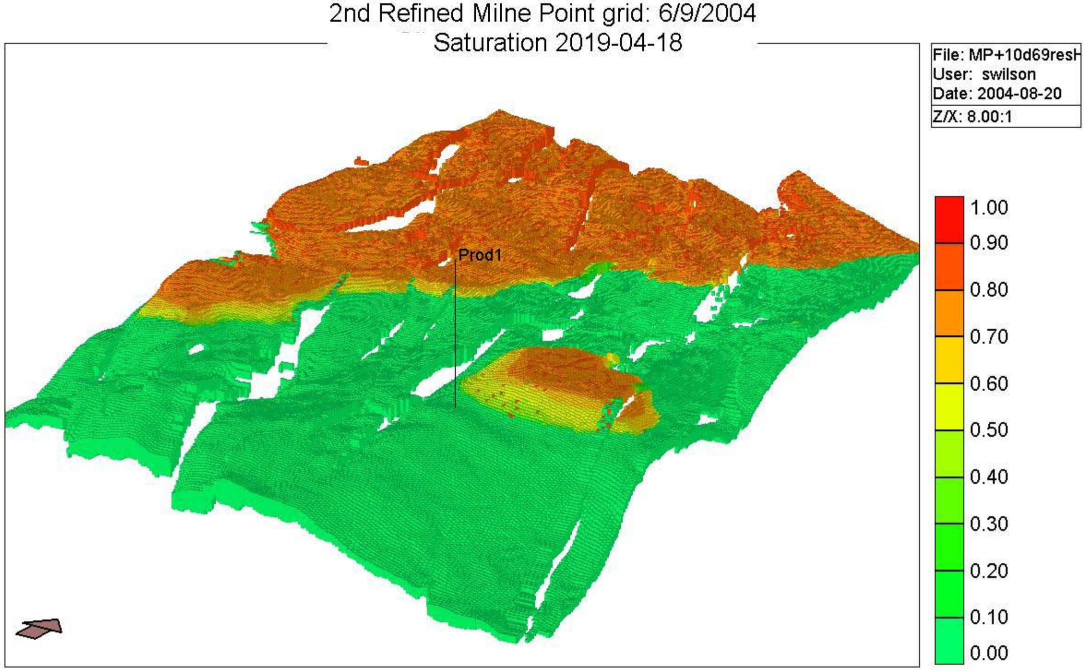




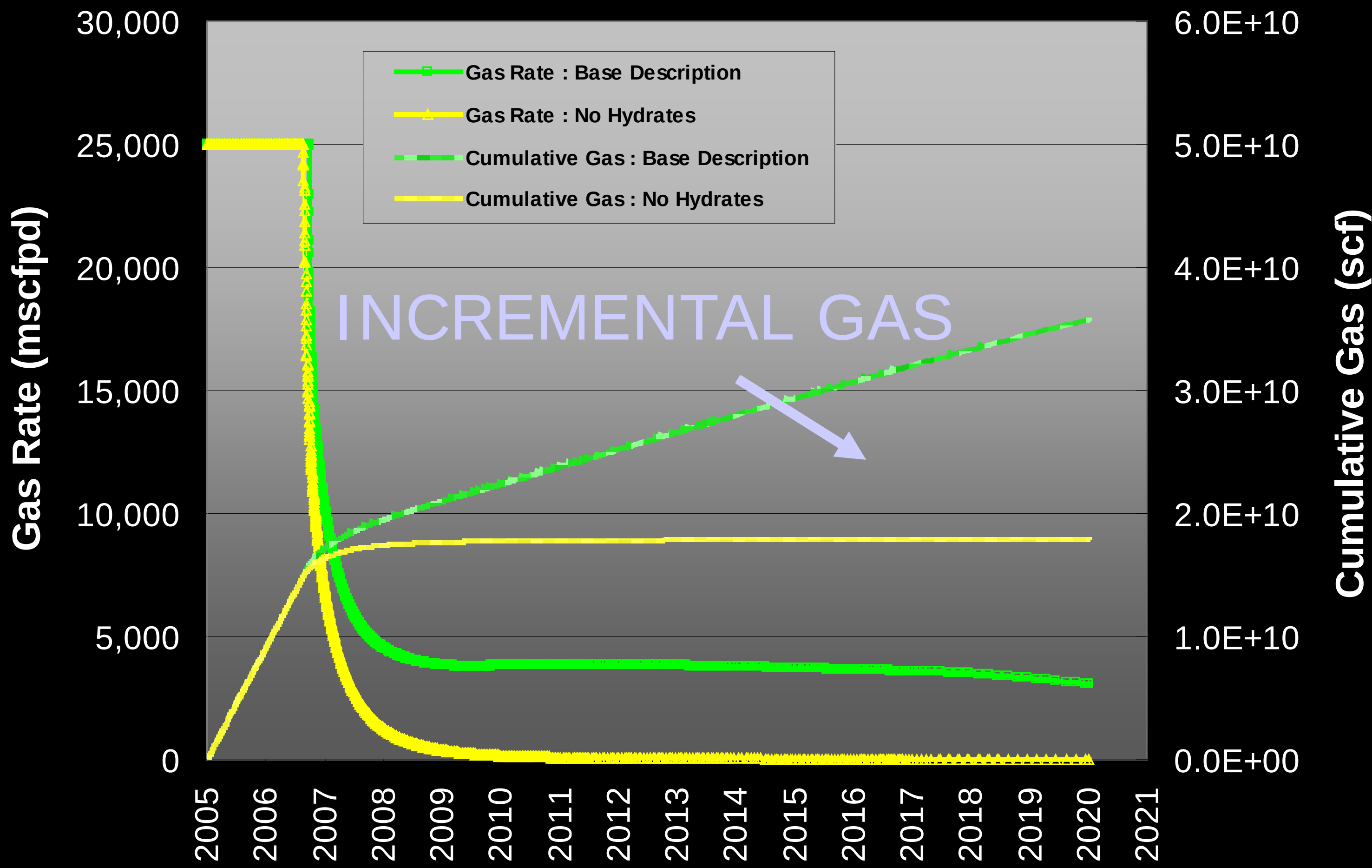
Milne Point, AK - STARS MODEL

Single well down-dip below gas hydrate in free-gas

Hydrate Saturation

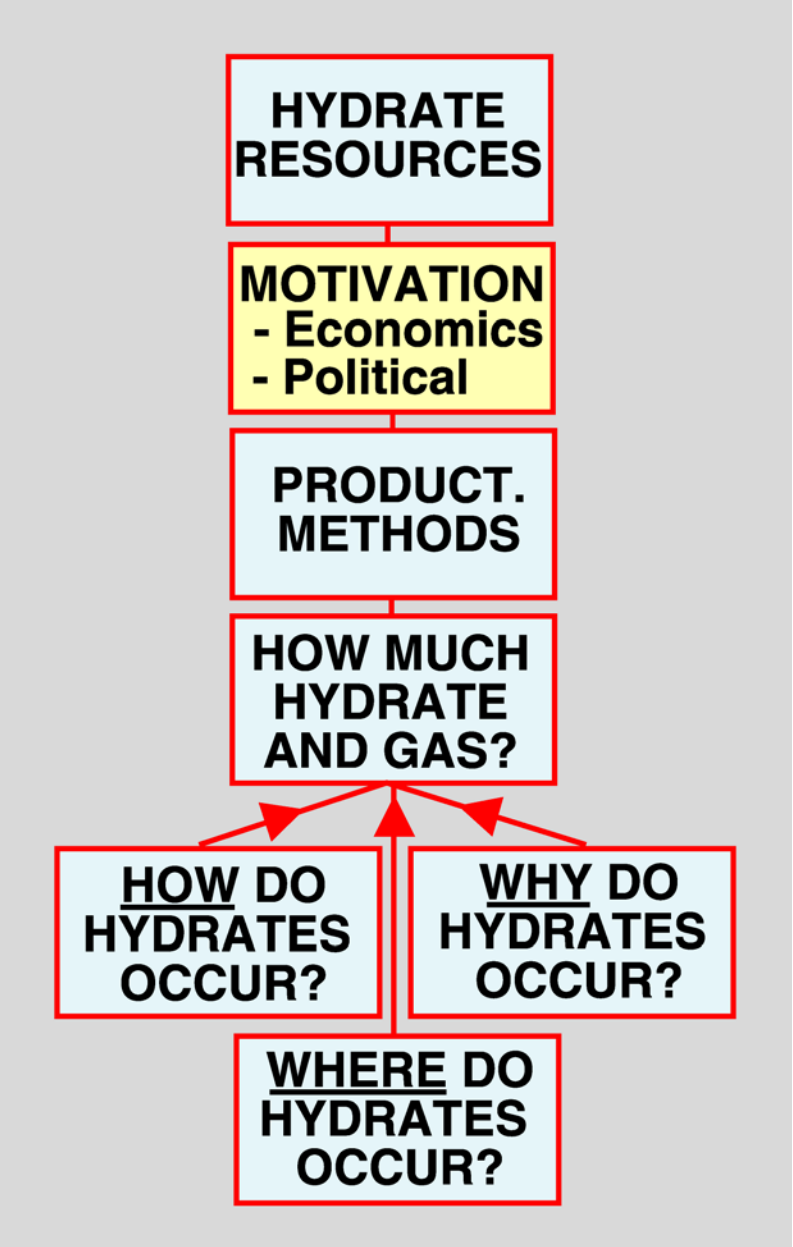


Reservoir Model - Depressurization
Production Profile Comparison



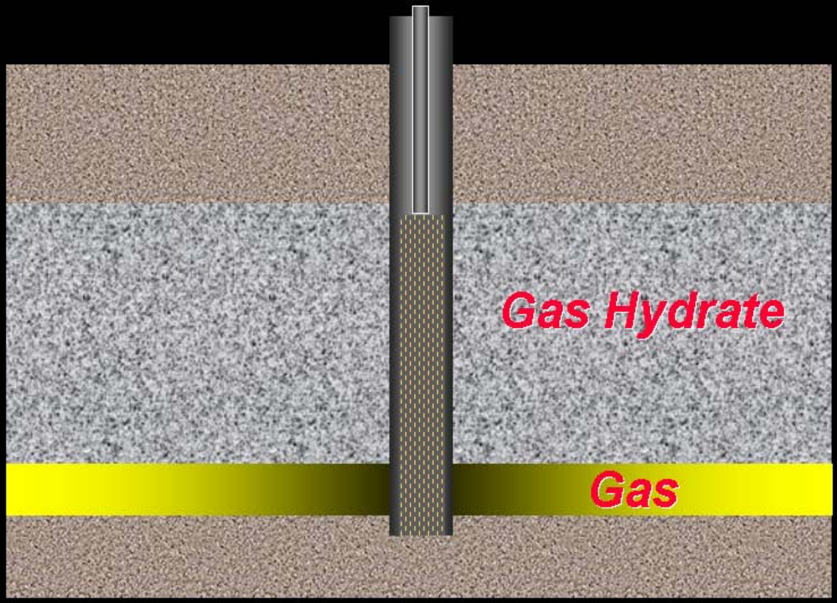
Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource

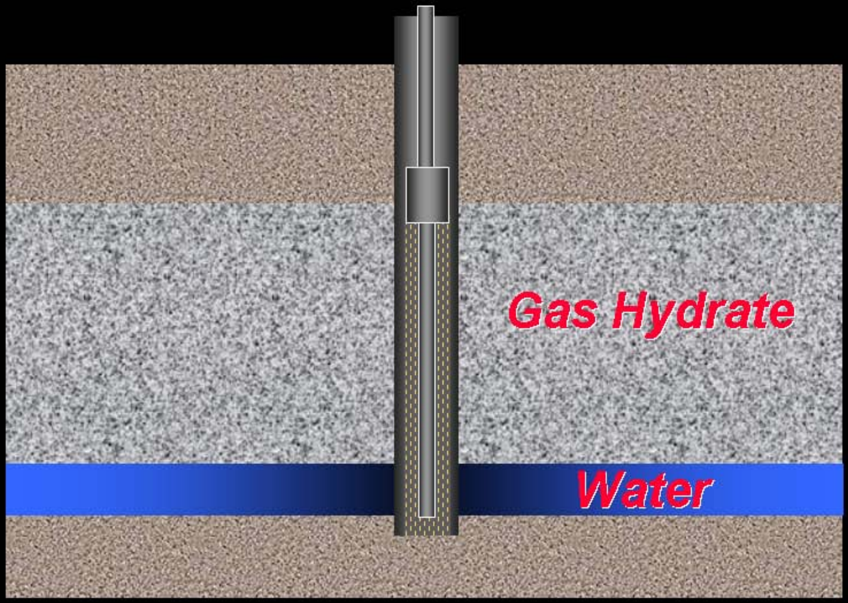


Gas Hydrate Field Evaluation
- Five Wells-

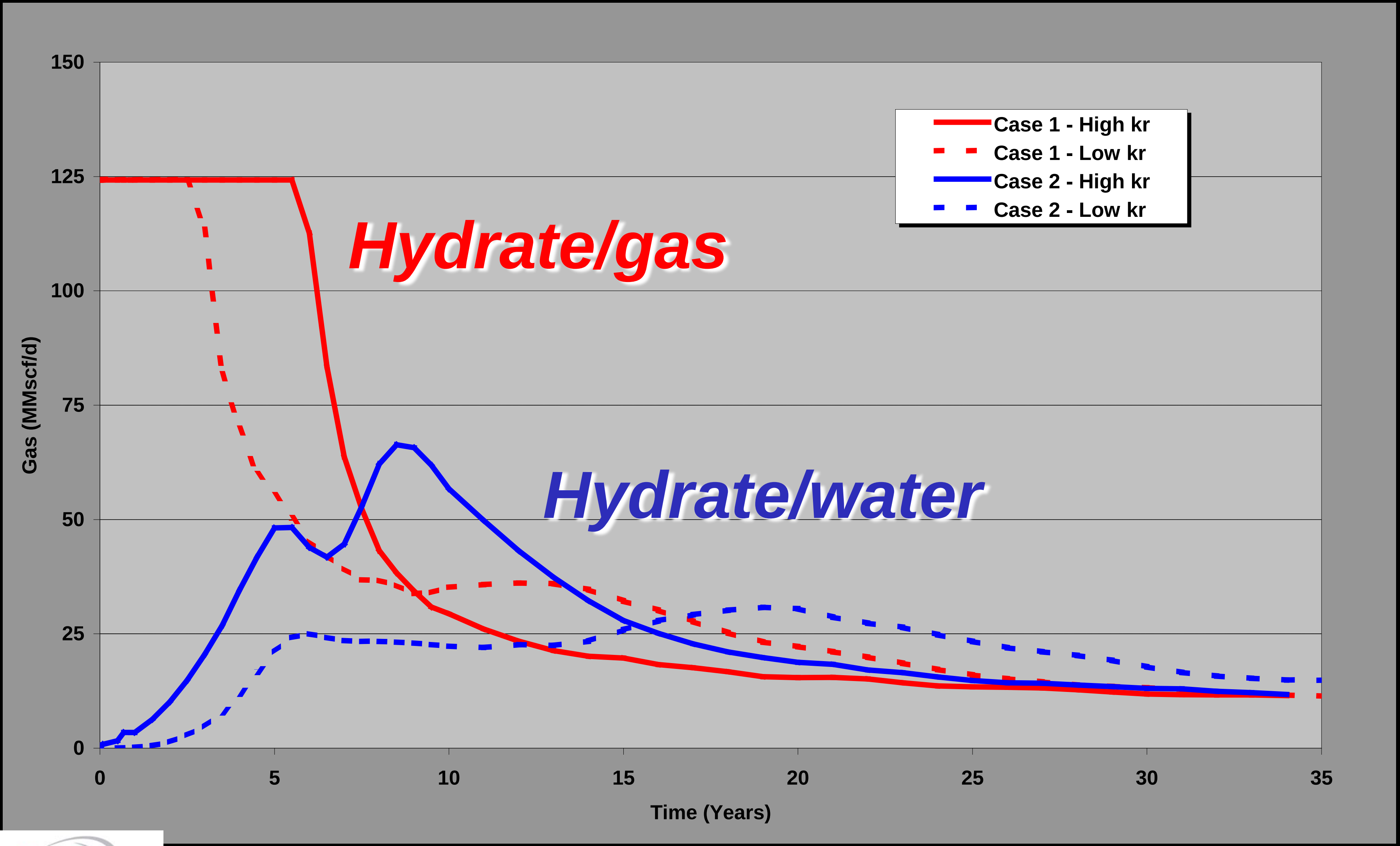
Case 1 – Gas Hydrate Over Free Gas
50 m gas hydrate, over 10 m free gas



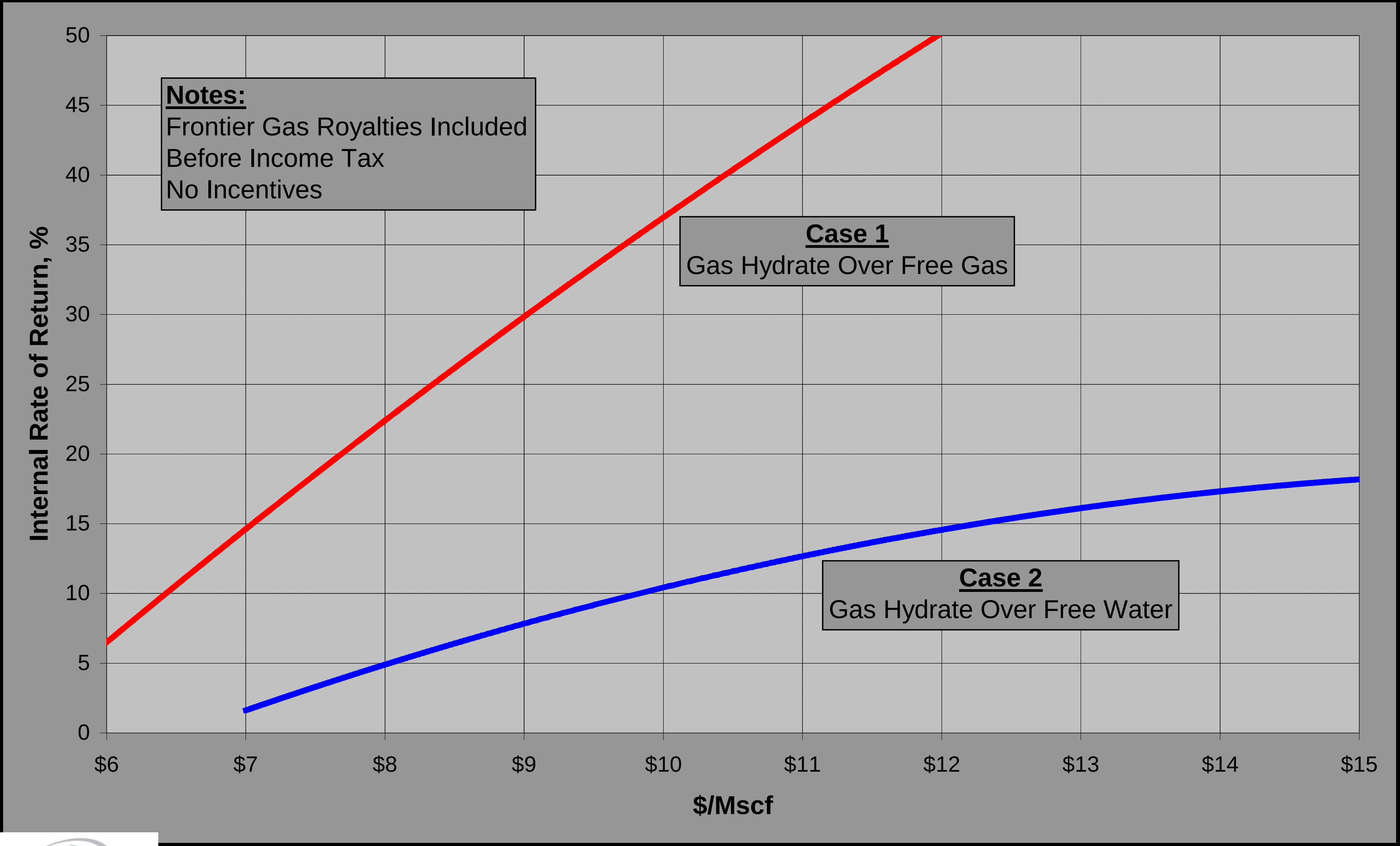
Case 2 – Gas Hydrate Over Water
50 m gas hydrate, over 10 m water



STARS Gas Production



Internal Rate of Return



ALASKA GAS EXPORT

Unique ANS Motivations to Encourage Production of Gas from Gas Hydrate

- Industry uses of natural gas in northern Alaska:

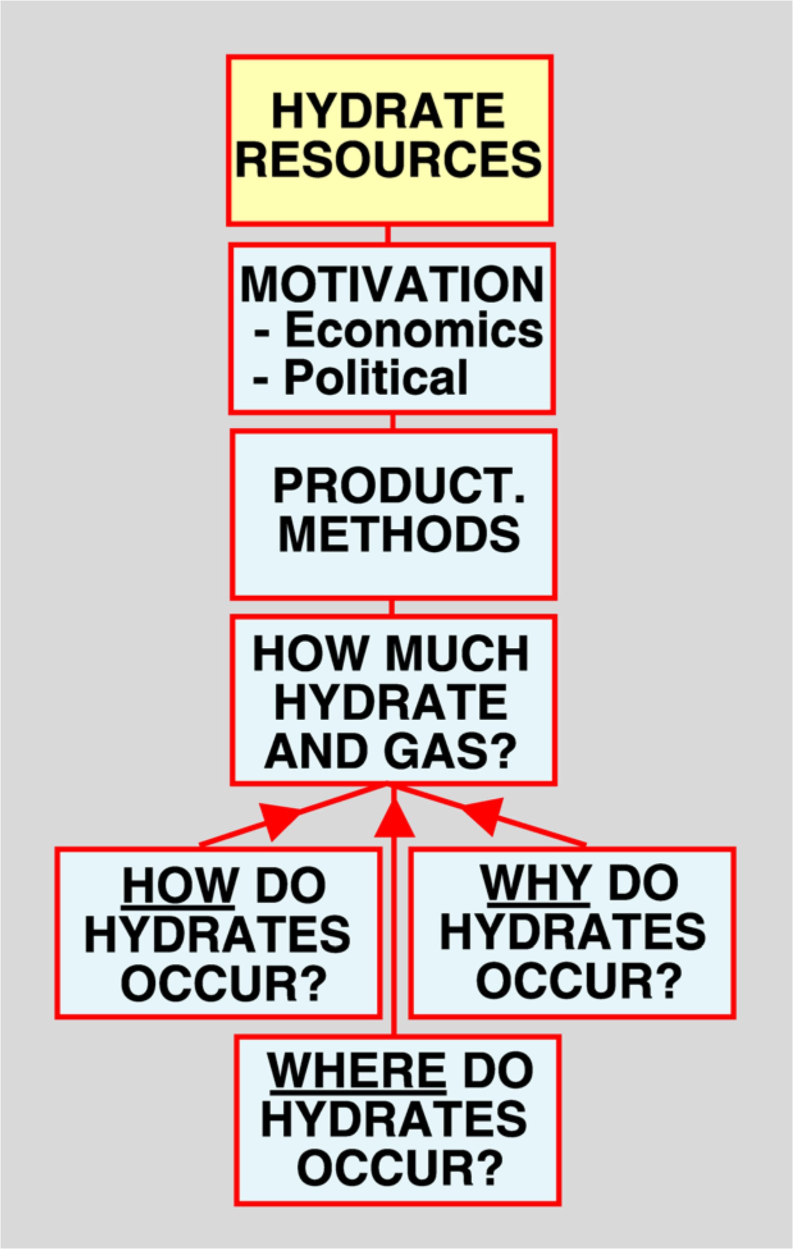
- Generate electricity for field operations
- Miscible gas floods
- Gas lift in producing oil wells
- Reinjection to maintain reservoir pressures
- Steam generation: EOR and viscous oil projects

POLITICAL MOTIVATIONS LEADING TO GAS HYDRATE PRODUCTION

- Government Regulatory and Taxation Policy: Carbon dioxide emissions - tax, Unconventional energy tax credits
- National Security: Concerns over the reliance on imported energy, Trade balance

Gas hydrate energy resource flow chart

- Evolution from a nonproducible unconventional gas resource to a producible energy resource



Next Steps

Actions Needed

1. Conduct exploratory drilling and production testing by first identifying viable test sites through an improved seismic and geologic understanding of gas hydrates.

2. Work with industry, government, and the international research community to develop the production technology for safe and economic gas hydrate development.

Next Steps (cont'd)

Actions Needed

3. Development and calibrate gas hydrate production models through field testing projects – PILOT TEST

   Long term production rate calculations are critical to evaluating field economics

GAS HYDRATES - THE WORLD'S LARGEST ENERGY RESOURCE

BUT SHOULD I CARE?

- ***You know Best…..***
- ***Do I export gas to Japan, Korea, India ?***
- ***Do I have hydrates within my existing operations ?***

Reference

Collett, T., M. Riedel, J. Cochran, R. Boswell, J. Presley, P. Kumar, A. Sathe, A. Sethi, M. Lall, V. Siball, and Natural Gas Hydrate Program (NGHP) Expedition-01 Scientific Party, 2008, *in* Indian National Gas Hydrate Program Expedition 01 Initial Report*:* U.S. Geological Survey and Directorate General of Hydrocarbons, Ministry of Petroleum and Natural Gas India, 1 DVD.