Energy Resource Potential of Gas Hydrates

Historical Review Through Current Programs
-Assessment and Prospecting-

-USGS Project Team-

T.Collett, M. Lee, D. Taylor, T. Lorenson, W. Agena, J. Miller

What is going on?

-Mallik 2002 production testing program showed for the first time that gas hydrate can be produced with conventional technology

-Industry gas hydrate studies in Alaska and the Gulf of Mexico are proceeding, with BPXA drilling a gas hydrate test well in Alaska

-Renewal of the Methane Hydrate Research and Development Act

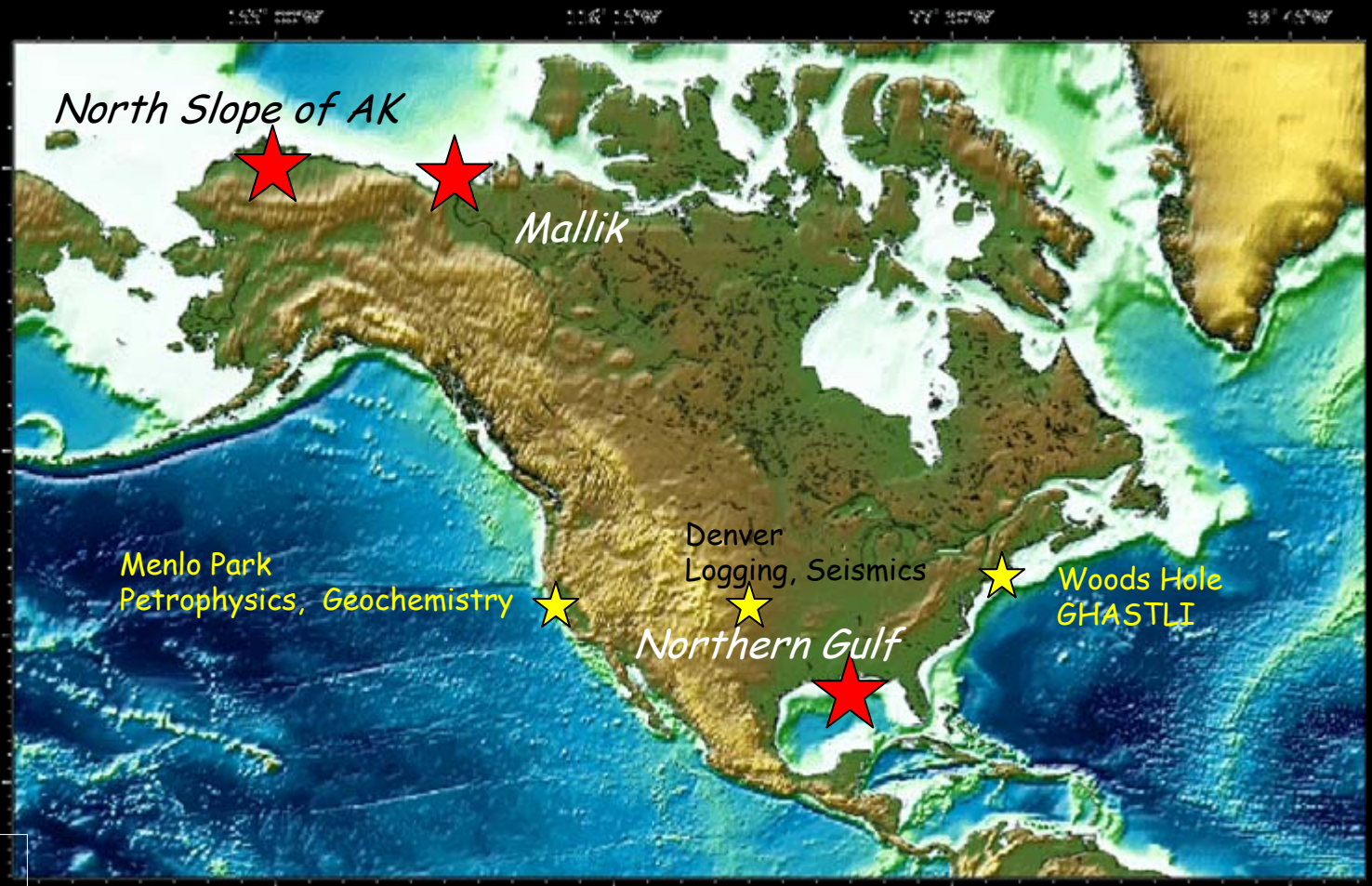
-Gas hydrate royalty relief rule making

-International gas hydrate energy development research is accelerating in Japan and India; along with a new Mallik project sponsored by Japan

-DOI (MMS, BLM-USGS) gas hydrate assessments area moving ahead

USGS Gas Hydrate Studies

2002 Mallik

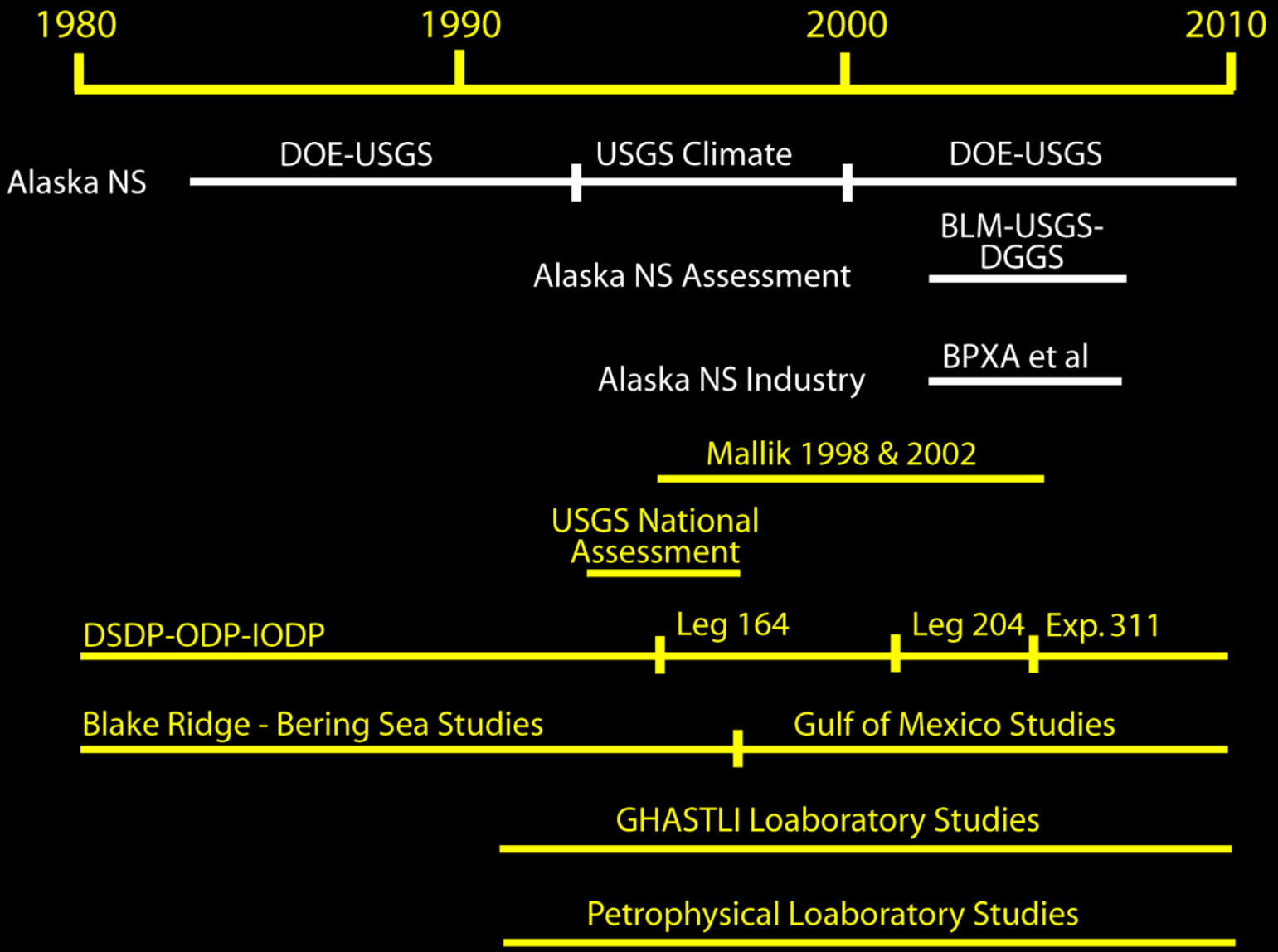


AK Assessment

BPXA-USDOE

Gulf of Mexico JIP

1980-2010 USGS Gas Hydrate Research



Outline of Presentation

1. Gas Hydrate Petroleum System
   - A. Marine Case Study – Blake Ridge
   - B. Arctic Case Study – Alaska NS
   - C. Marine Case Study - India
2. How Much Gas Hydrate and Gas?
3. Production Methods
4. Motivations – Economics and Political

Outline of Presentation

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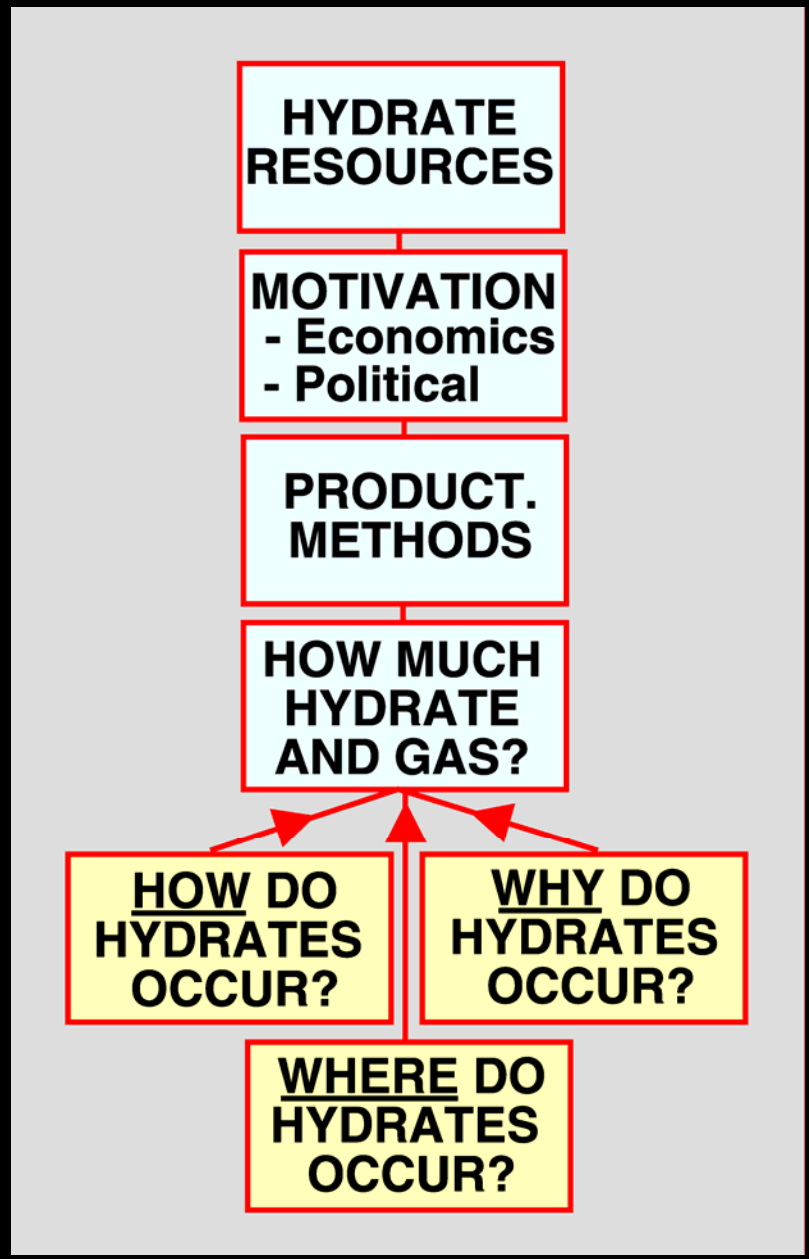
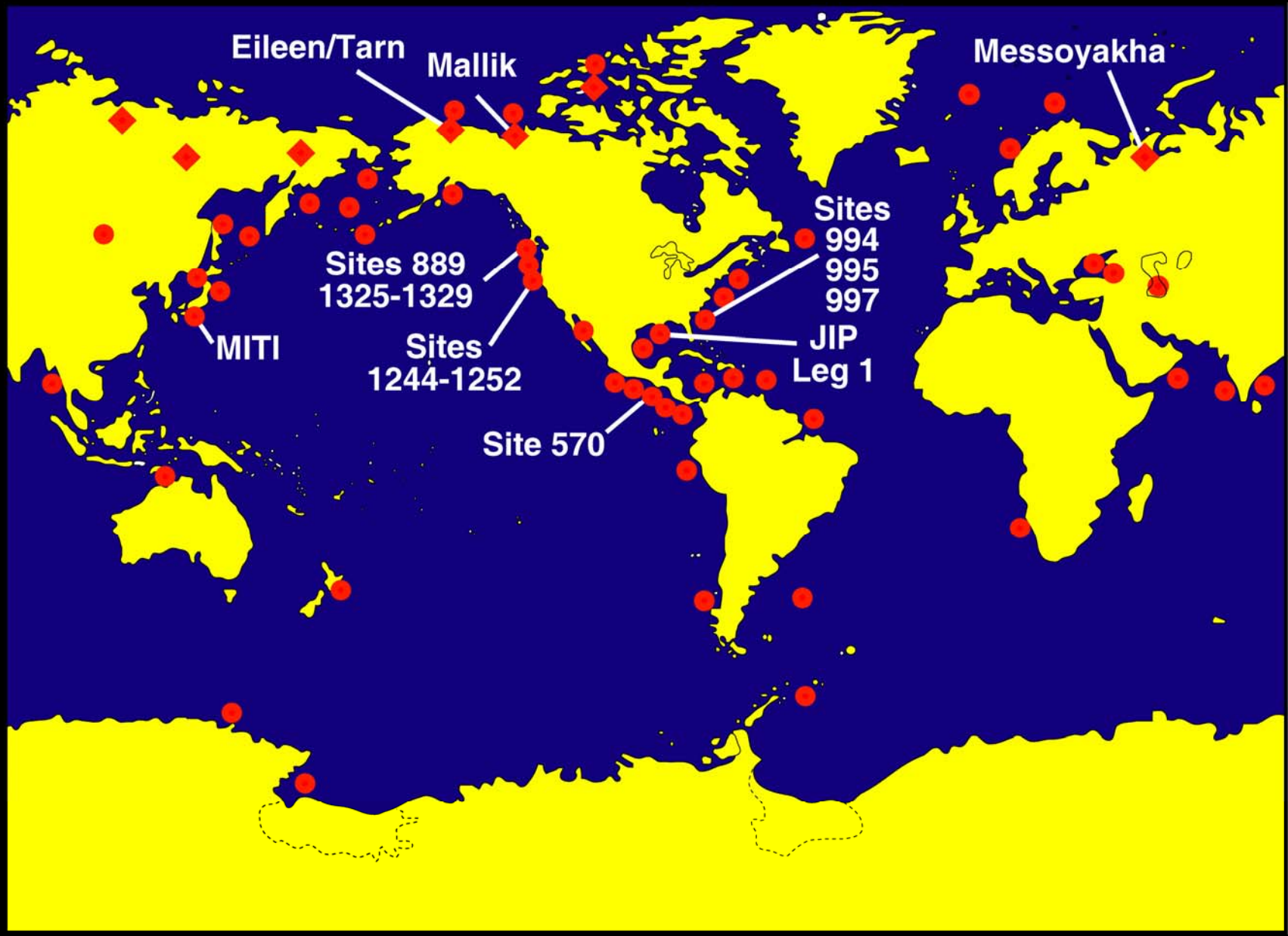
Gas hydrate energy resource flow chart

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



Gas Hydrate Occurrences



Controls on the Occurrence Gas Hydrate

-Gas Hydrate Petroleum System-

-Formation temperature

-Formation pressure

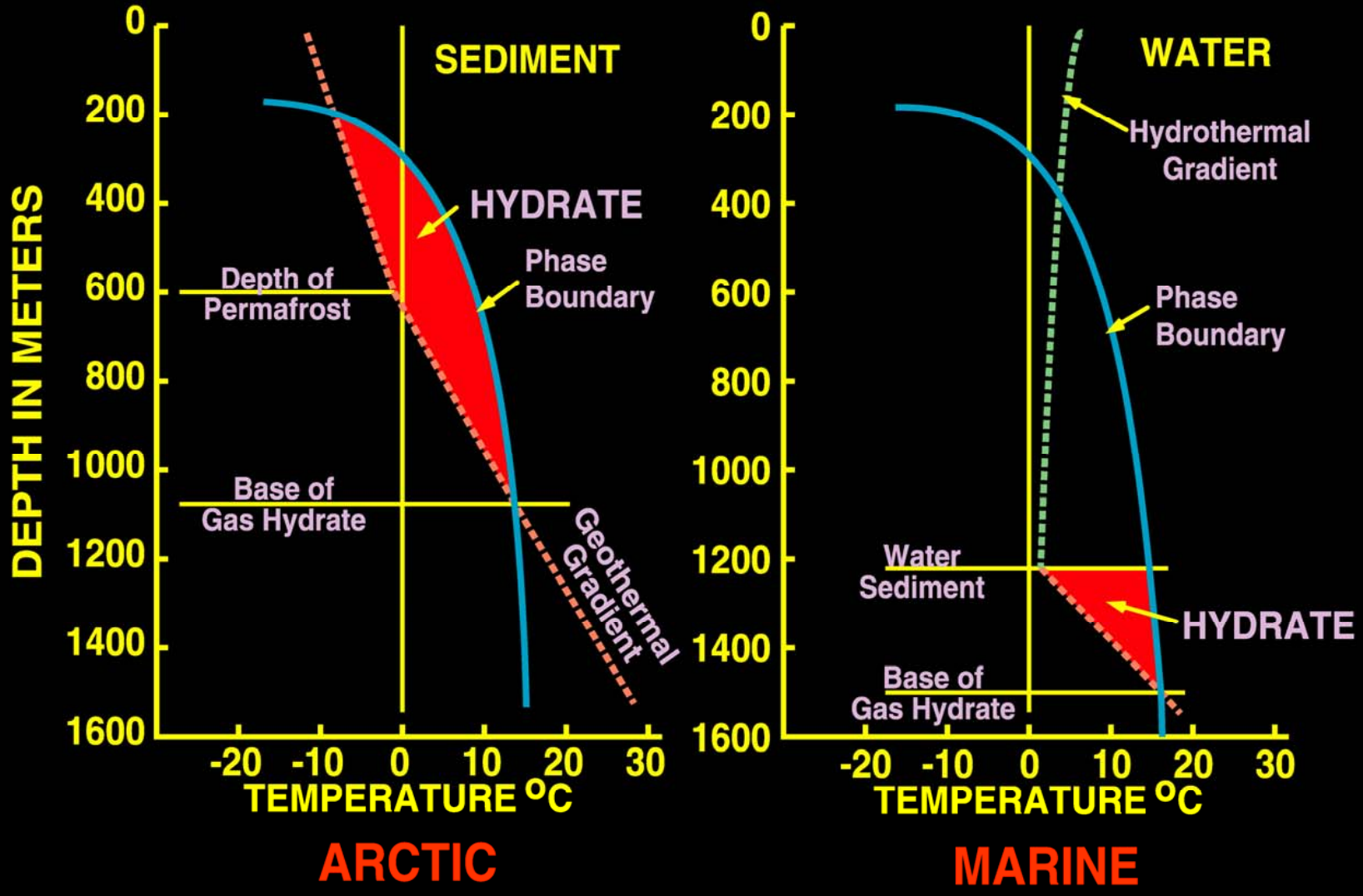
-Pore water salinity

-Gas chemistry

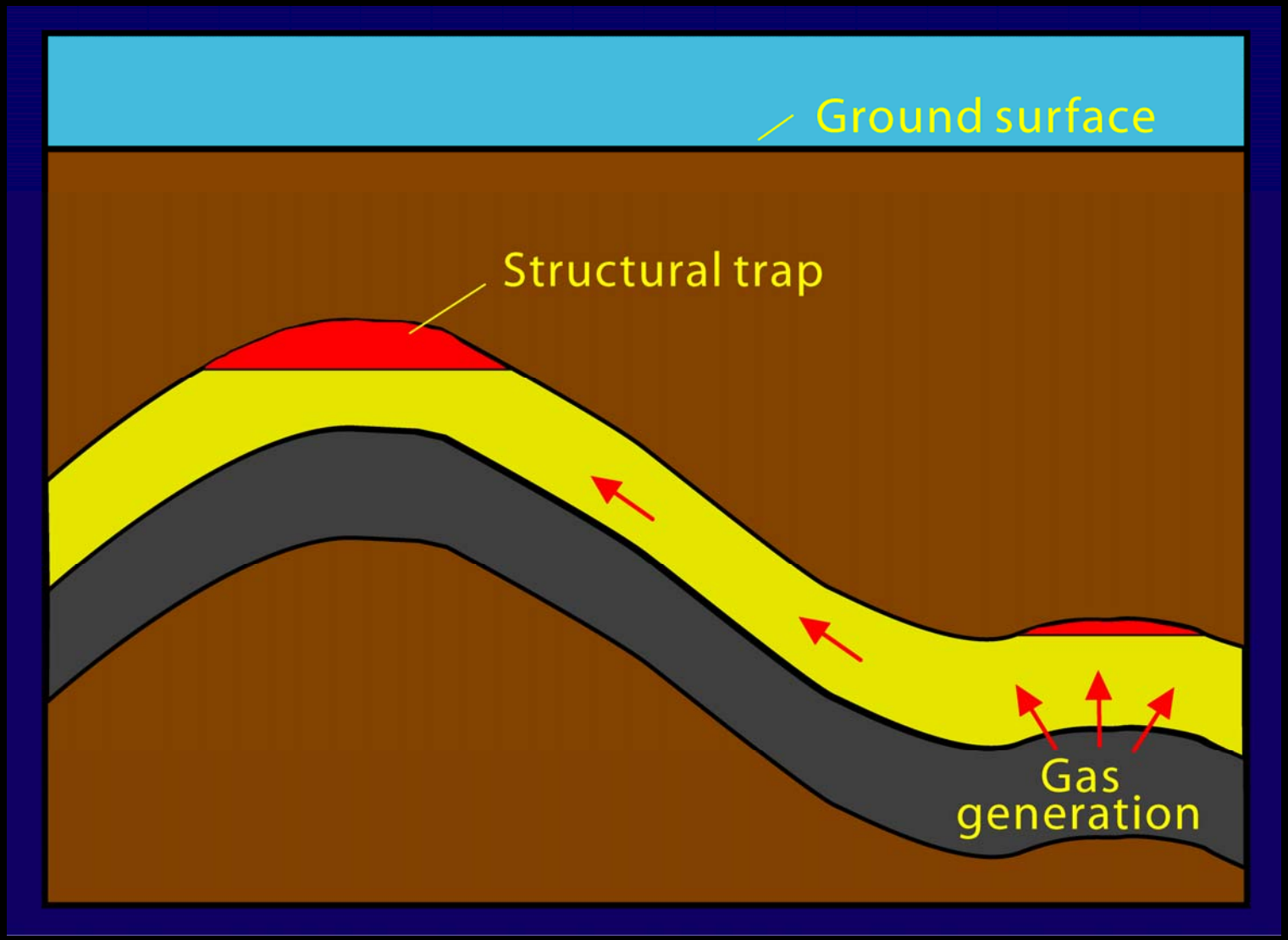
-Availability of gas and water

-Gas and water migration pathways

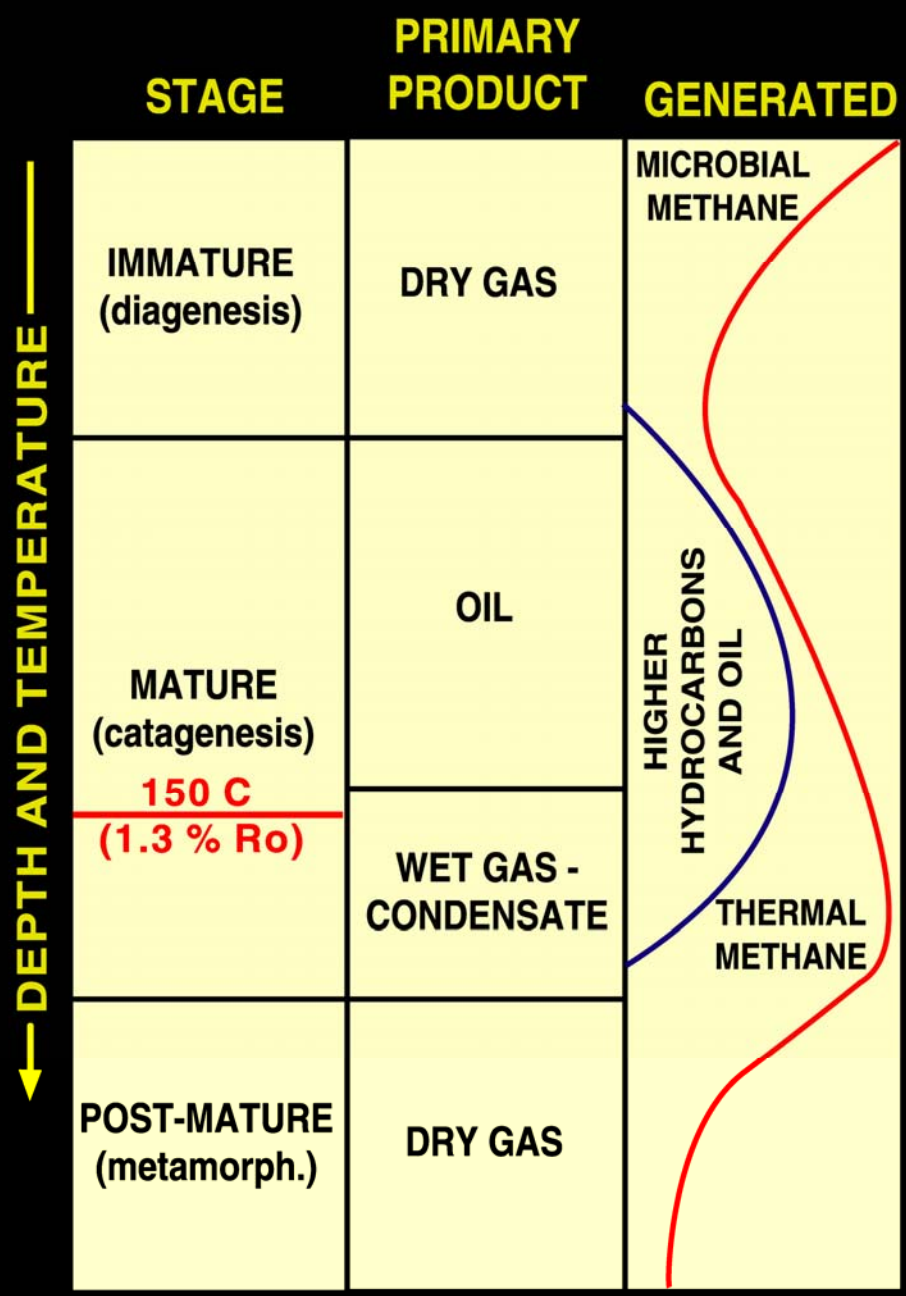
-Presence of reservoir rocks and seals



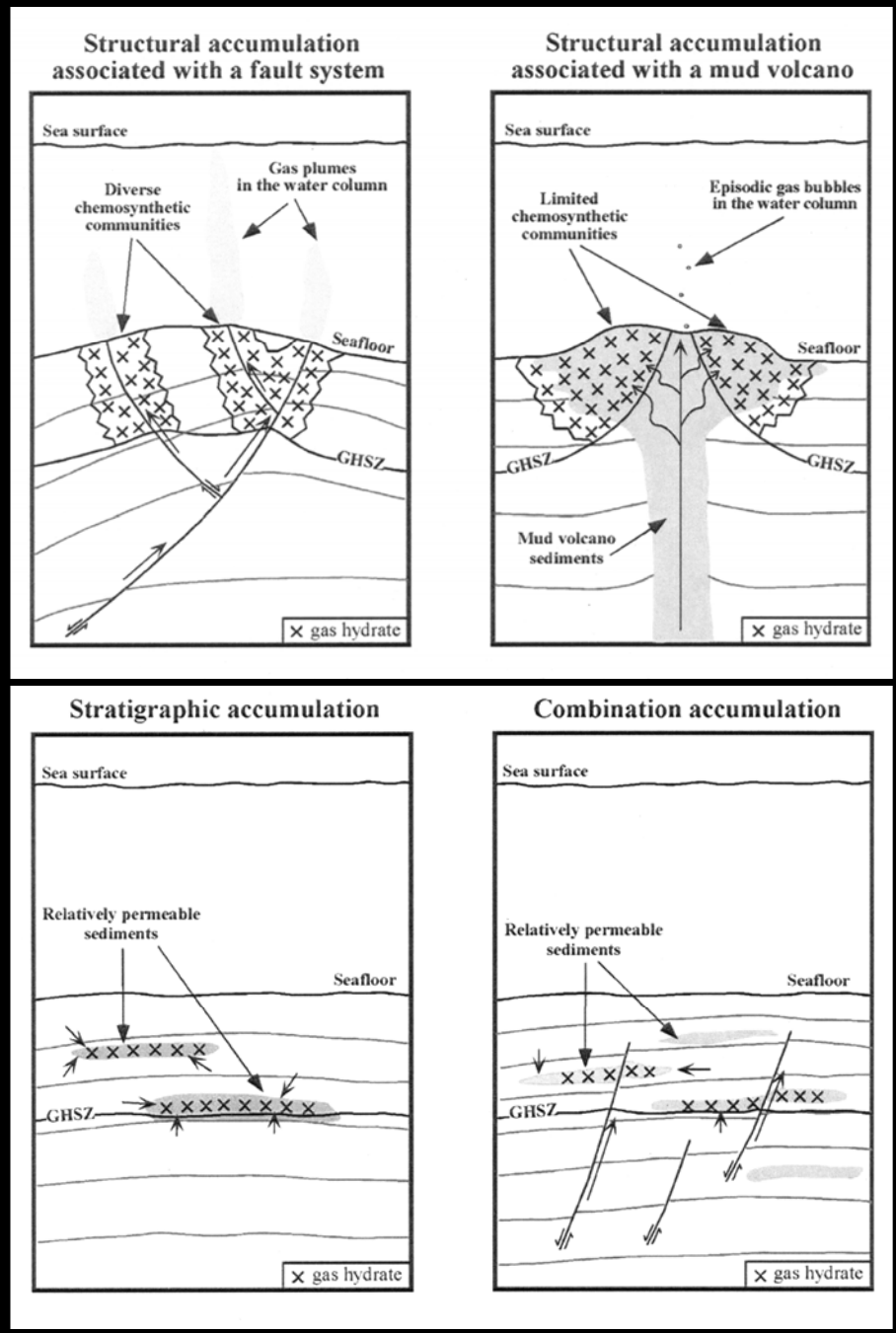
Conventional Petroleum System
-Source-Migration-Reservoir-Trap-



Gas generation

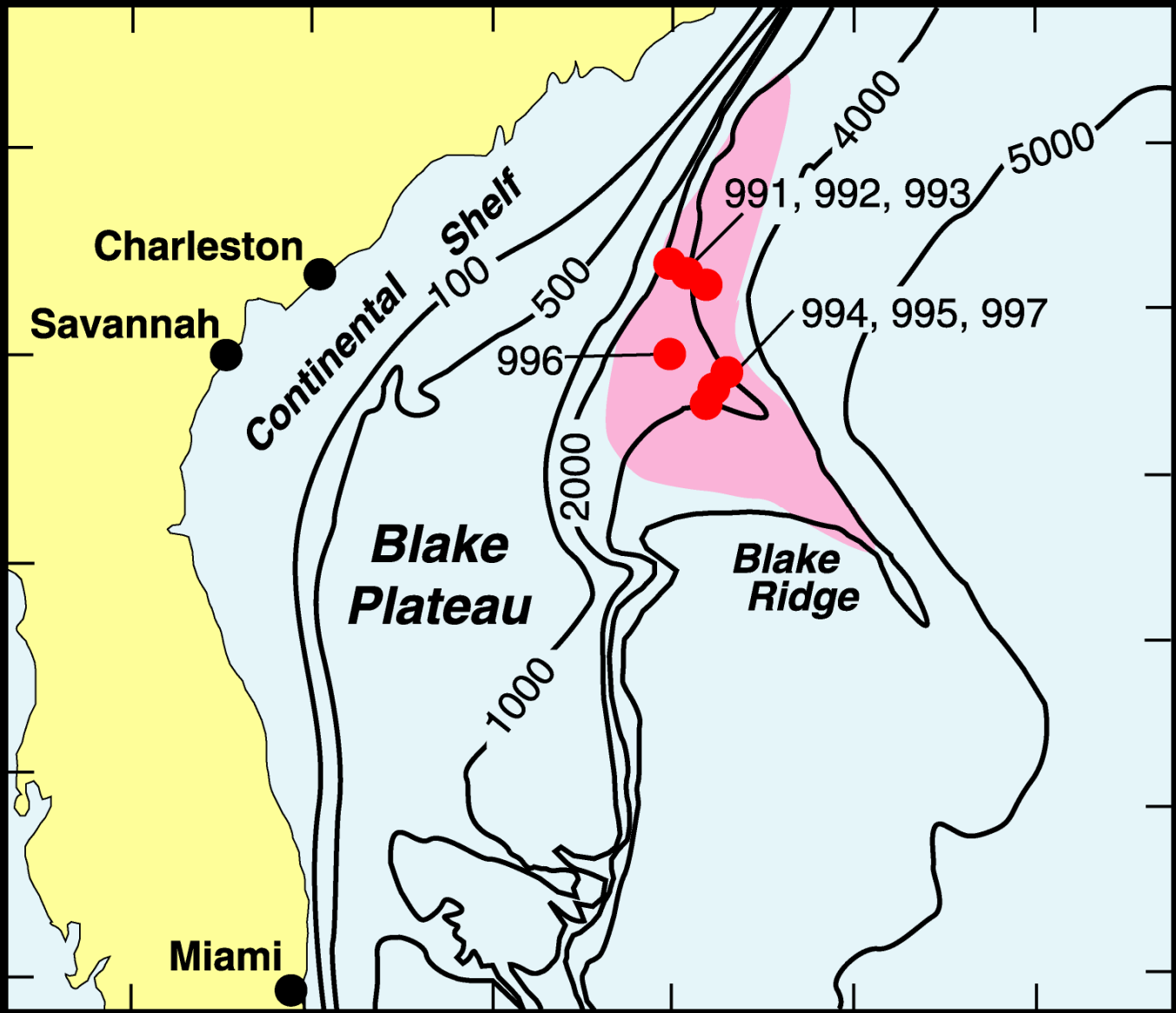


"Three types of gas hydrate accumulations" (Milkov and Sassen, 2002)



Clay dominated gas hydrate reservoirs

Blake Ridge Gas Hydrate Accumulation



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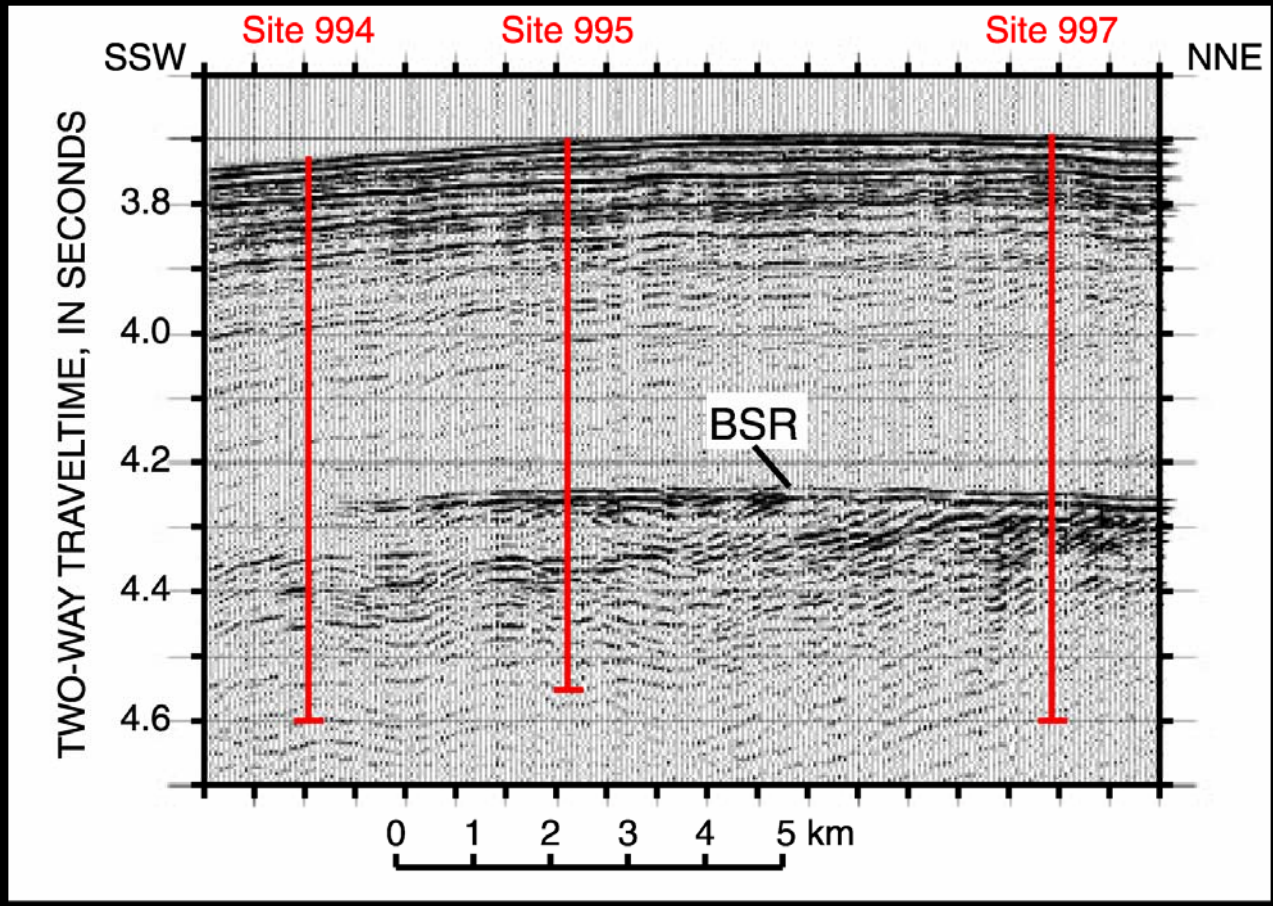
science for a changing world

Blake Ridge Gas Hydrate Accumulation

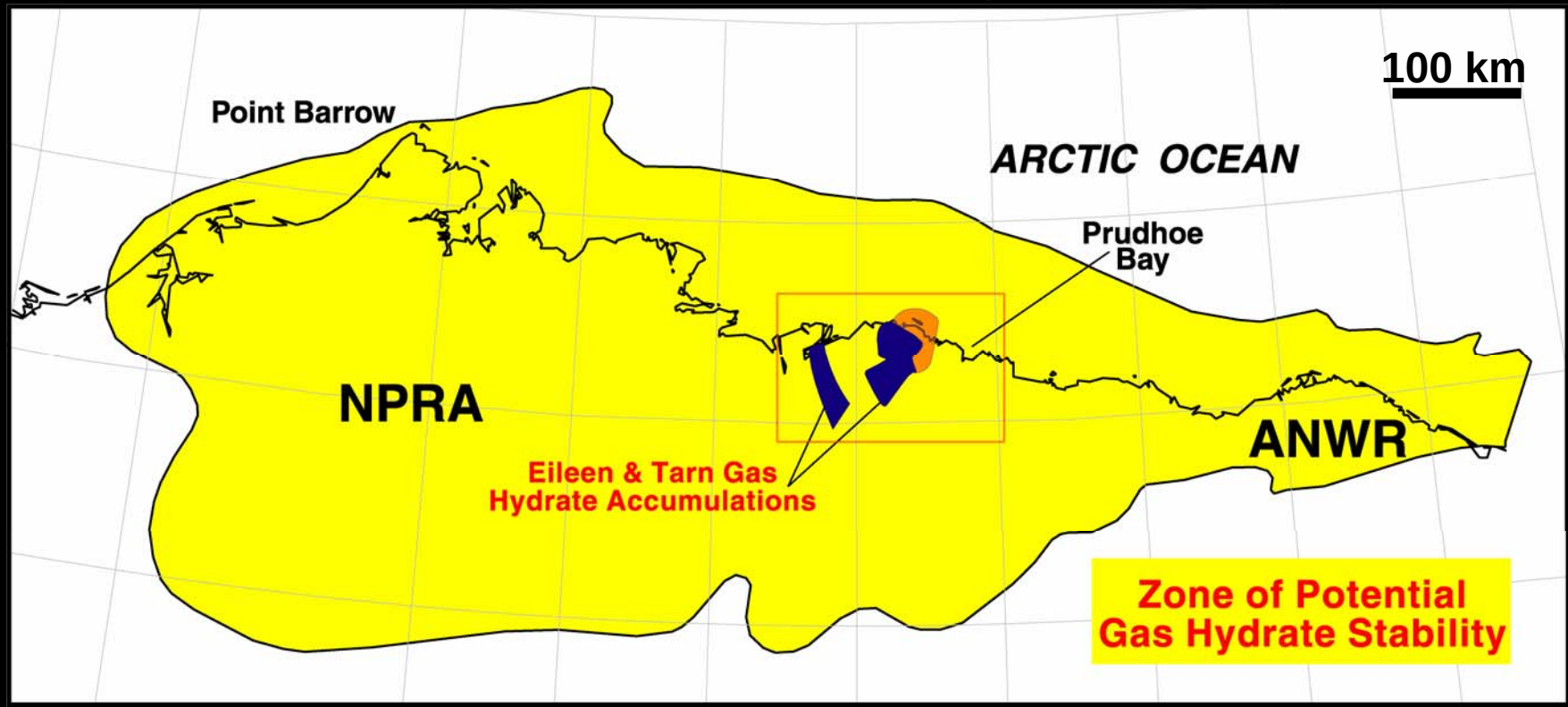


Clay dominated gas hydrate reservoirs

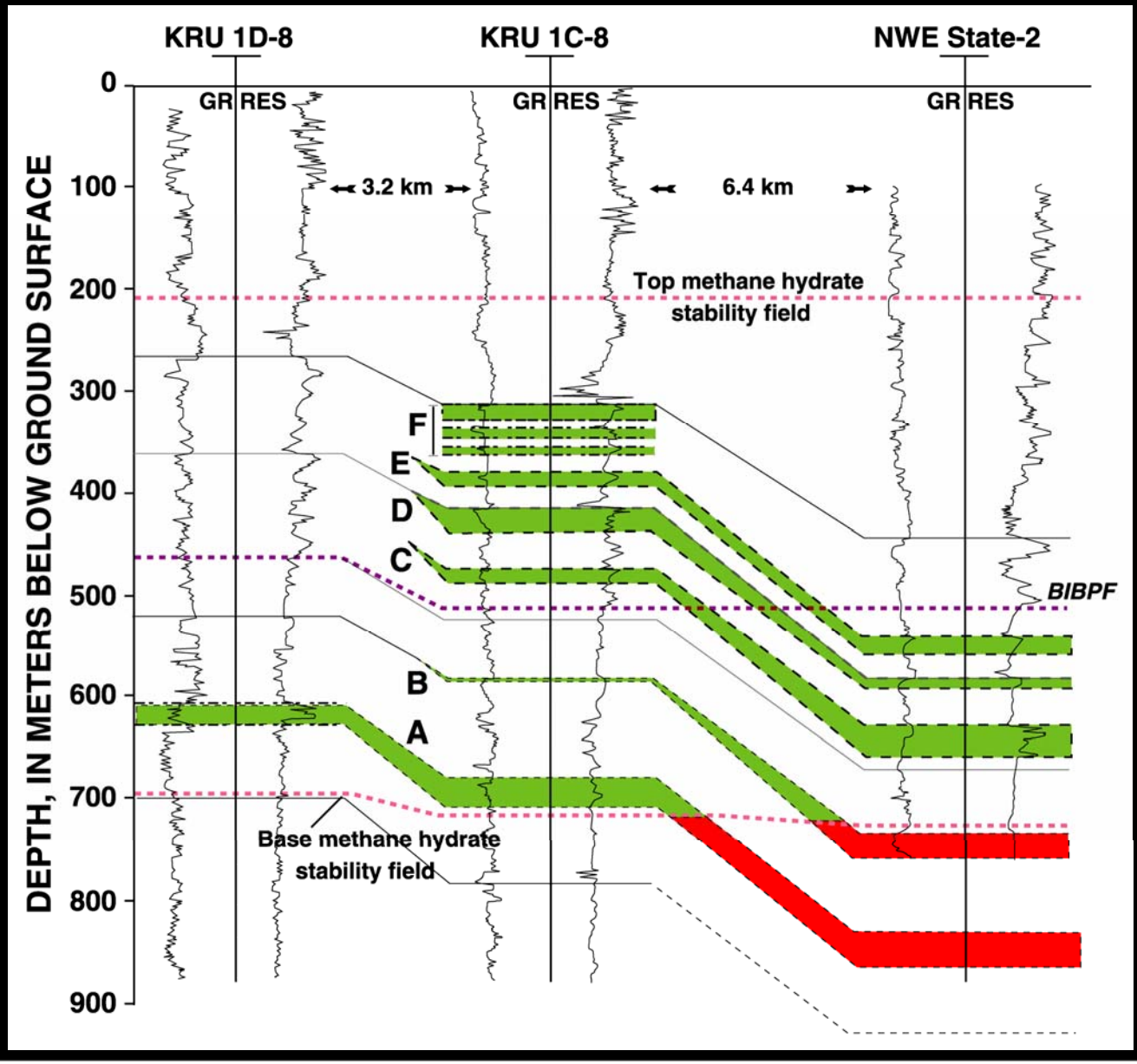
Site/Well	Depth of gas hydrate (m)	Thickness of hydrate (m)	Porosity (%)	Hydrate saturation (%)	Volume of of gas per square km (cubic m)
ODP Site 994	212.0-428.8	216.8	57.0	3.3	669,970,673
ODP Site 995	193.0-450.0	257.0	58.0	5.2	1,267,941,673
ODP Site 997	186.4-450.9	264.5	58.1	5.8	1,449,746,073
ODP Site 889	127.6-228.4	100.8	51.8	5.4	466,635,705

Sand dominated gas hydrate reservoirs

Alaska NS Gas Hydrates



Eileen Gas Hydrate Accumulation



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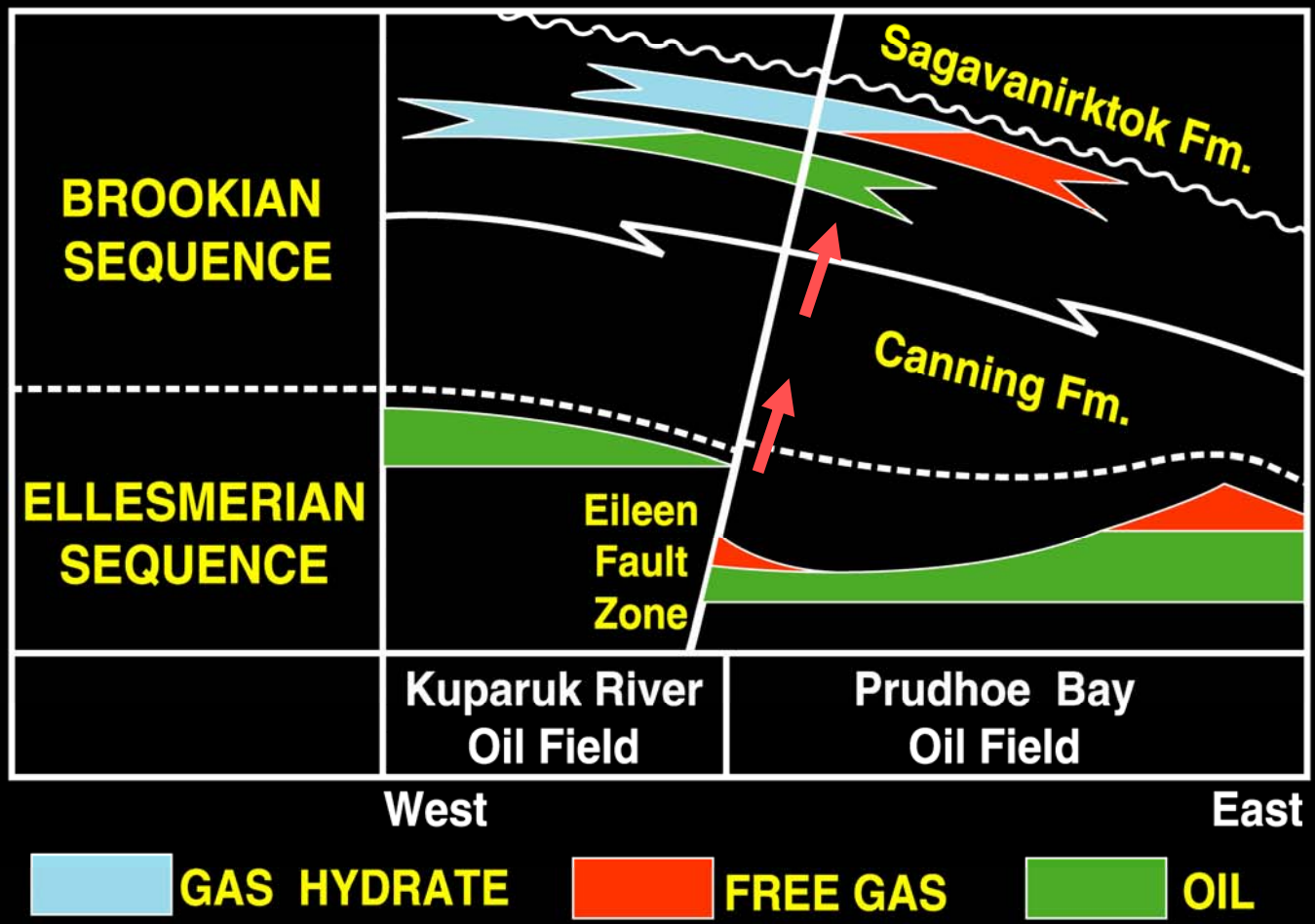
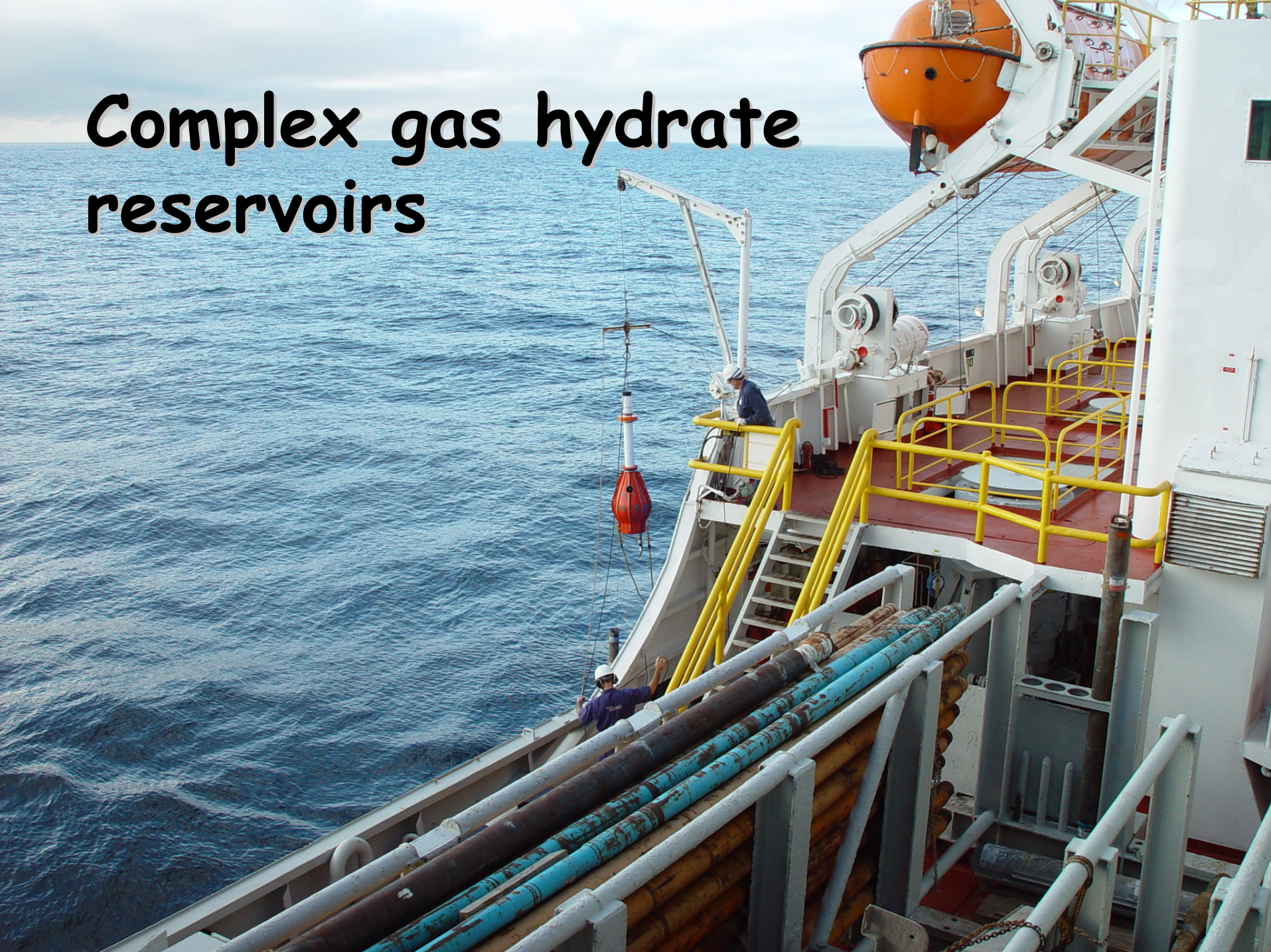
Eileen & Tarn Gas Hydrate Petroleum System



Sand dominated gas hydrate reservoirs

Site/Well	Depth of gas hydrate (m)	Thickness of hydrate (m)	Porosity (%)	Hydrate saturation (%)	Volume of of gas per square km (cubic m)
Eileen-2 Unit C	651.5-680.5	29.0	35.6	60.9	1,030,904,796
Eileen-2 Unit D	602.7-609.4	6.7	35.8	33.9	133,382,462
Eileen-2 Unit E	564.0-580.8	16.8	38.6	32.6	346,928,811
				Total --	1,511,216,069
Mallik 2L-38	888.8-1,101.9	213.1	29.3	47.0	4,812,744,164
METI Nankai	190.0-268.0	10-20	35.0	75.0	----------

Complex gas hydrate reservoirs



India: "National Gas Hydrate Program"

- Historical Background -

-The National Gas Hydrate Program (NGHP) was initiated by the Ministry of Petroleum and Natural Gas (MOP&NG) in 1997.

-In 2000, the National Gas Hydrate Program (NGHP) was reconstituted by MOP&NG with the direction of the Directorate General of Hydrocarbons (DGH)

A. Steering Committee – PN&G, as directed by MOP&NG

B. Technical Committee – MOP&NG, DGH, ONGC, GAIL, OIL, NGHI, CSIR, NIO, NIOT, DOD

C. Operational Subgroups – Drilling (ONGC), Production (ONGC), Geoscience (ONGC), Environment (ONGC), Transportation (GAIL)

India: "National Gas Hydrate Program"

- Road Map -

-Complete resource estimate by December 2004

-Assessment of Realities

A. Laboratory studies to understand thermodynamics/kinetics of gas hydrates, December 2004

B. Deep water coring and drilling operations in 900-2,500 m water depths, December 2005 (April 2006)

C. Gas hydrate production pilot, 2006-2007

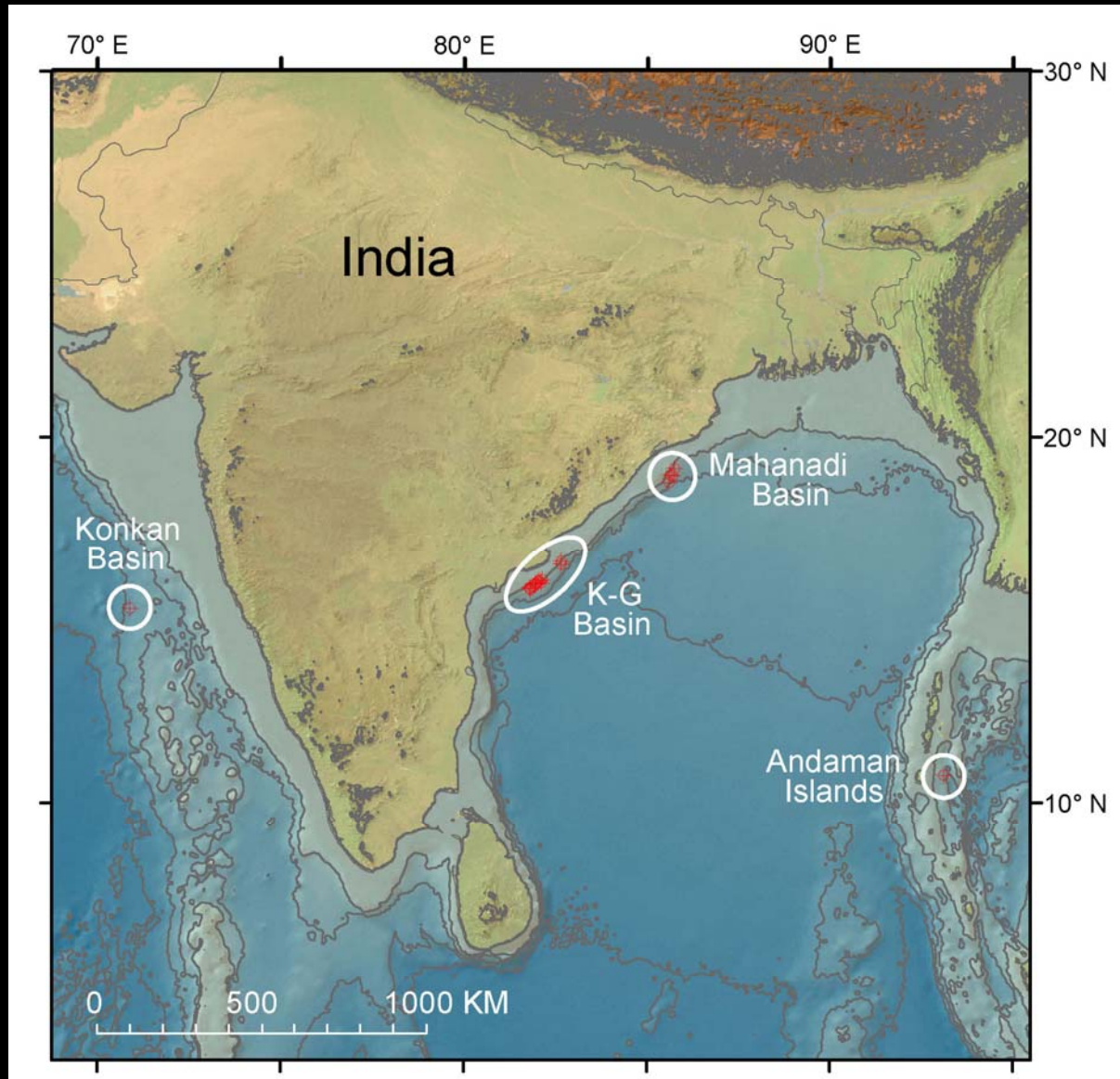
D. Gas hydrate production technology/economics studies, 2008+

NGHP - EXPEDITION I

Scientific Coring-Logging

Kerala-Konkan Basin:
One site
Krishna-Godawari Basin:
Fifteen Sites
Mahanadi Basin:
Four Sites
Andaman Islands:
One Site

-Total 113.5 Days
-Total 21 Sites



Summary NGHP Expedition 1

- Expedition began in Mumbai, India (April 28, 2006) and ended in Chennai, India (August 19, 2006).
- A total of 113.5 operational days. 19.0 days (16.8%) in port; 24.2 days (21.3%) was spent in transit; 70.4 days (62%) spent on site.
- 13.04 days (18.5%) were spent on LWD/MWD drilling operations; 38.46 days (54.7%) was spent drilling and coring; 0.65 days (0.9%) lost time.
- 21 "Sites" were established during NGHP Expedition 1, Total of 39 holes, 12 LWD-MWD holes were drilled; 27 core holes; 13 wireline logged holes and six VSP surveys.
- Water depths of sites ranged from 906.6 m to 2,674.2 m.
- Penetration depths varied from 9.5 mbsf to 718.0 mbsf.

India National Gas Hydrate Program
Expedition NGHP-01
Summary of Operational Statistics
(28 April 2006 to 19 August 2006)

Expedition Summary	Days	Percent
Total Days in Port	19.0	16.8%
Total Days In Transit	24.2	21.3%
Total Days on Site	70.4	62.0%
Total Days	113.5	100.0%

Breakdown of Operating Days On-Site	Days	Percent
Drilling/Coring & Tripping	38.46	54.7%
Logging (LWD/MWD)	13.04	18.5%
Logging (Wireline)	12.46	11.0%
In Situ Temperature Tools (APC/3, APC/T, DVTP)	2.22	2.0%
Reentry Cone/Casing/Cementing	0.00	0.0%
Hole Trouble/Remedial Action	0.15	0.2%
Lost Time (WOW/Ice or Breakdown)	0.65	0.9%
Misc/Other (hole displacement, DP moves, etc.)	3.40	4.8%

Other Expedition Statistics	
Total Distance Traveled (Nm):	5351.9
Average Transit Speed (knots):	9.5
Total Number of Sites:	21
Total Number of Holes:	39
Total No. of Cores Attempted:	494
Total Interval Cored (meters):	3618.4
Total Core Recovery (meters):	2847.01
Percent Core Recovery:	78.7%
Total Pressure Cores Attempted:	97
Cores Recovered Under Pressure:	49
Percent Cores Rec'd Under Press:	50.5%
Total Interval Drilled (meters):	5810.6
Total Penetration (meters):	9257.8
Max Penetration (meters):	718.0
Min Penetration (meters):	32.6

Dynamic Positioning (DP) Statistics	
No. Moves Between Sites in DP Mode:	4
Nautical Miles Moved In DP Transit:	11.9
Total VIT Deployments	1
No. of Positioning Beacons Used:	2
No. of Beacon Deployments:	26
No. of Lost Beacon's:	0
Total Number of Reentries:	0
Max Sea Floor Depth (m to DES):	2674.2
Min Sea Floor Depth (m to DES):	906.6

NGHP - EXPEDITION I

Leg-1: Mumbai to Chennai: April 28-May 16
Kerala-Konkan Basin - Coring Leg

Leg-2: Chennai to Chennai: May 17-June 6
Krishna-Godawari and Mahanadi Basins - LWD Logging Leg

Leg-3A: Chennai to Chennai: June 7-June 25
Krishna-Godawari Basin - Coring Leg

Leg-3B: Chennai to Chennai: June 26-July 17
Krishna-Godawar and Mahanadi Basins - Coring Leg

Leg-4: Chennai to Port Blair: July 18-August 19
Mahanadi Basin and Andaman Islands - Coring Leg

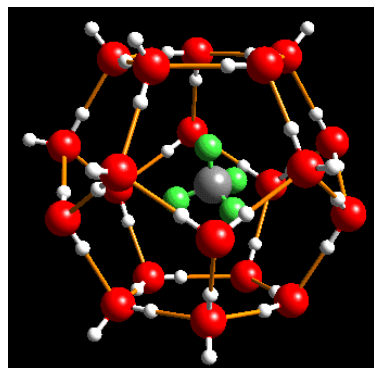
NGHP Expedition 1 Research Team

Binghamton University
Colorado School of Mines
Directorate General for Hydrocarbons
Fugro-McClelland, Inc.
GAIL Ltd
Geological Survey of Canada
Geotek Ltd
Idaho National Laboratory
Integrated Ocean Drilling Program
Joint Oceanographic Institutions, Inc.
Lamont-Doherty Earth Observatory
Ministry of Petroleum and Natural Gas
McGill University
National Energy Technology Laboratory
National Institute of Oceanography
National Institute of Ocean Technology
Oil and Natural Gas Corporation
Ocean Drilling Limited
Oregon State University
OIL India Ltd
Pacific Northwest National Laboratory
Reliance Industries Limited
Schlumberger
Technical University of Berlin
Texas A&M University
University of California, San Diego
University of Cardiff
University of New Hampshire
Universität Bremen
University of Rhode Island
U.S. Department of Energy
U.S. Geological Survey
U.S. National Science Foundation
Woods Hole Oceanographic Institution

D/V *JOIDES Resolution* Labstack
"A Floating University for Geoscience Research"

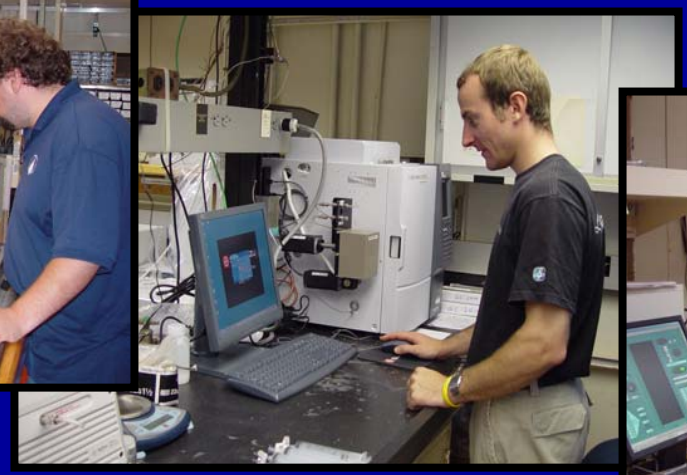
Summary of the NGHP Exp-1 Tool Deployments

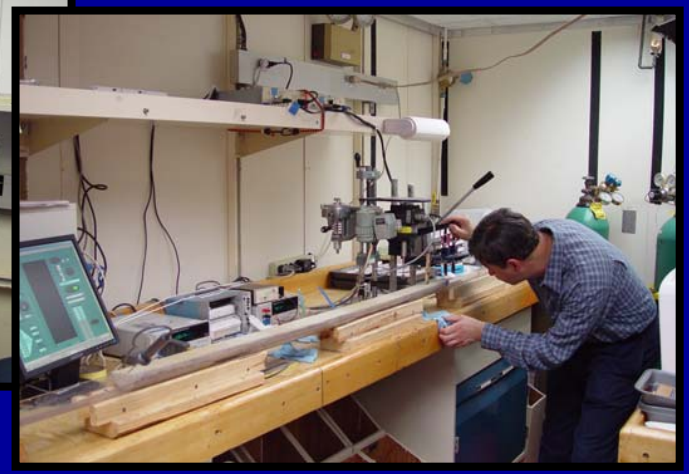
- APC: Advanced Piston Corer
- XCB: Extended (Rotary) Core Barrel
- APCT/APC3: Temperature Tool (APC coring shoe)
- APC-Methane Tool: TPC Sensors in APC Piston
- DVTP: Davis-Villinger Temperature Probe
- PCS: ODP Pressure Core Sampler
- HRC: HYACE Rotary Corer
- FPC: FUGRO Pressure Corer
- LWD/MWD: Logging/Measurement While Drilling
- CWL: Conventional Wireline Logging
- VSP: Vertical Seismic Profiling



JOIDES Resolution Core Laboratories

- Physical Properties Measurements
- Sedimentologic Descriptions
- Organic Geochemisty
- Inorganic Geochemistry
- Microbiology Studies





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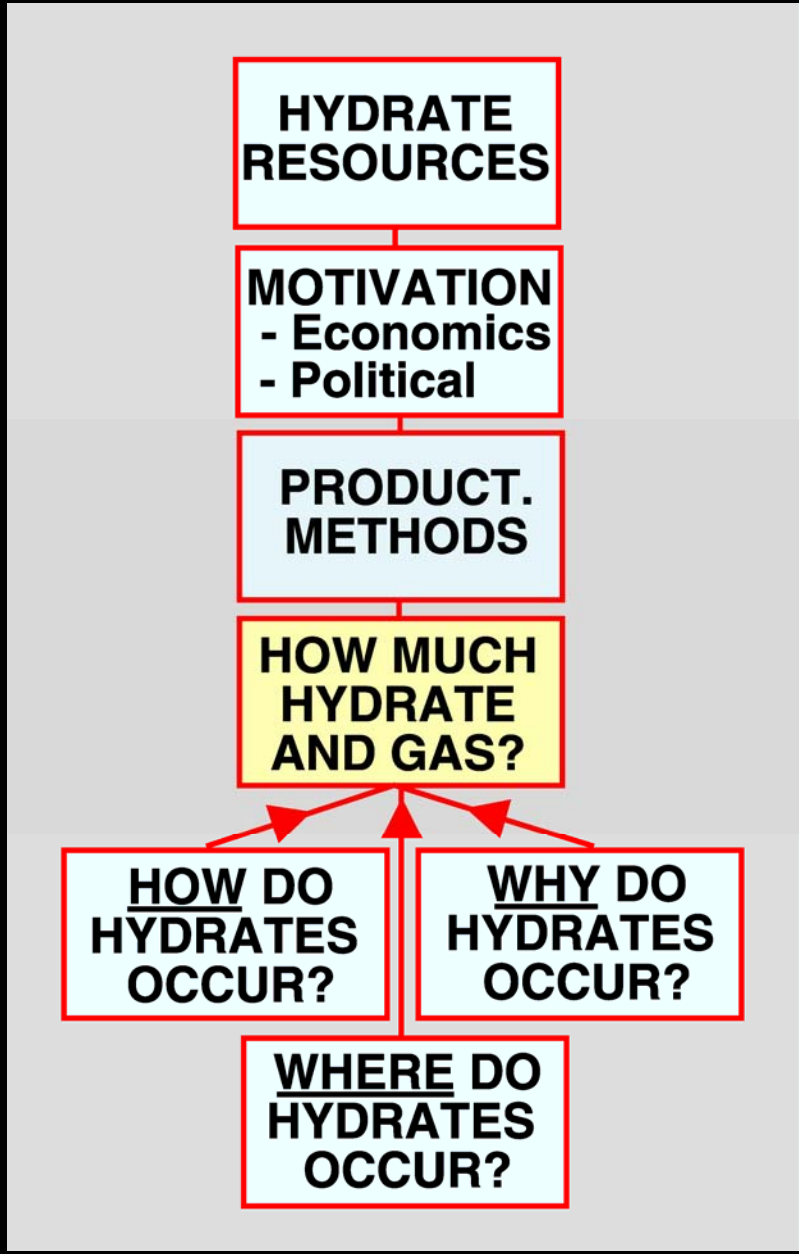
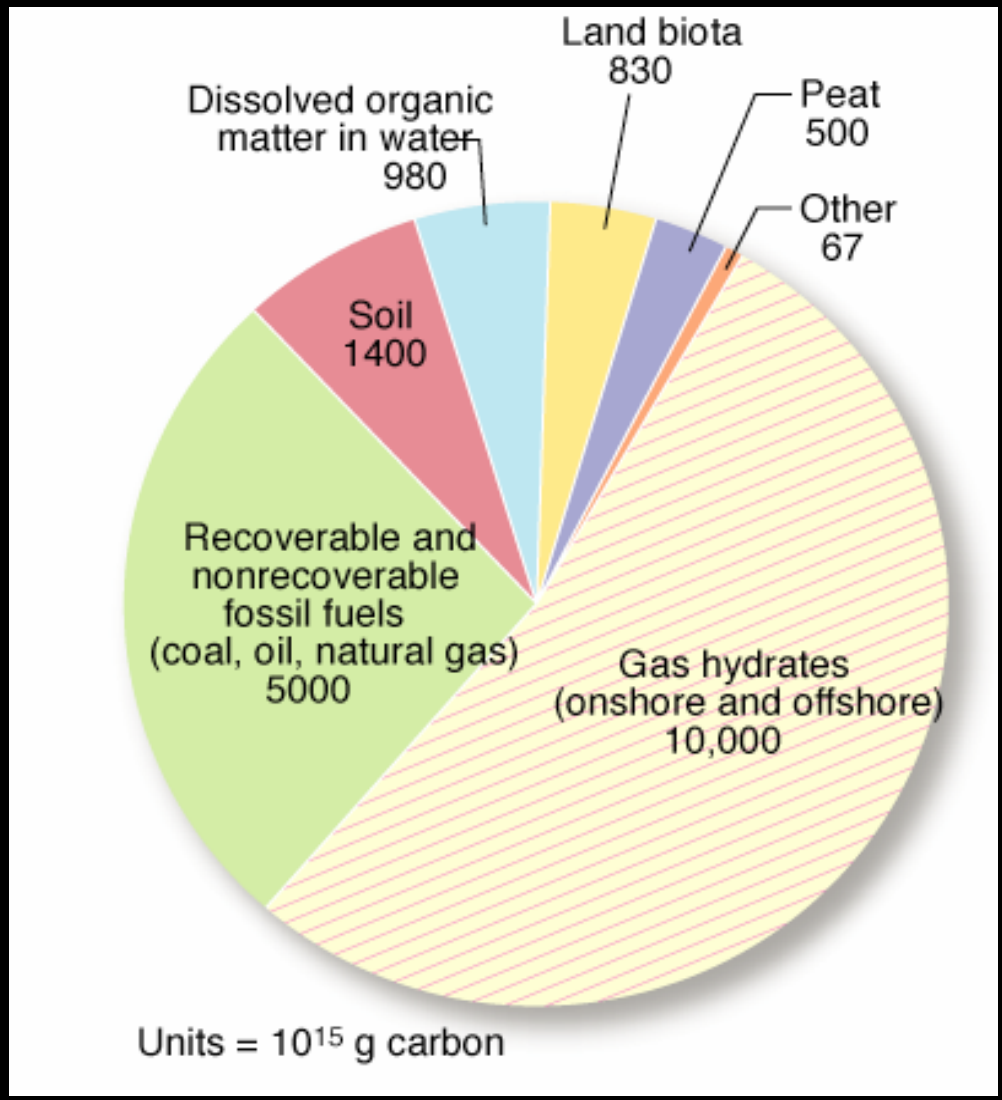
Gas hydrate energy resource flow chart

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



Organic Carbon Distribution



Gas hydrate "resource" assessments – national & regional scale

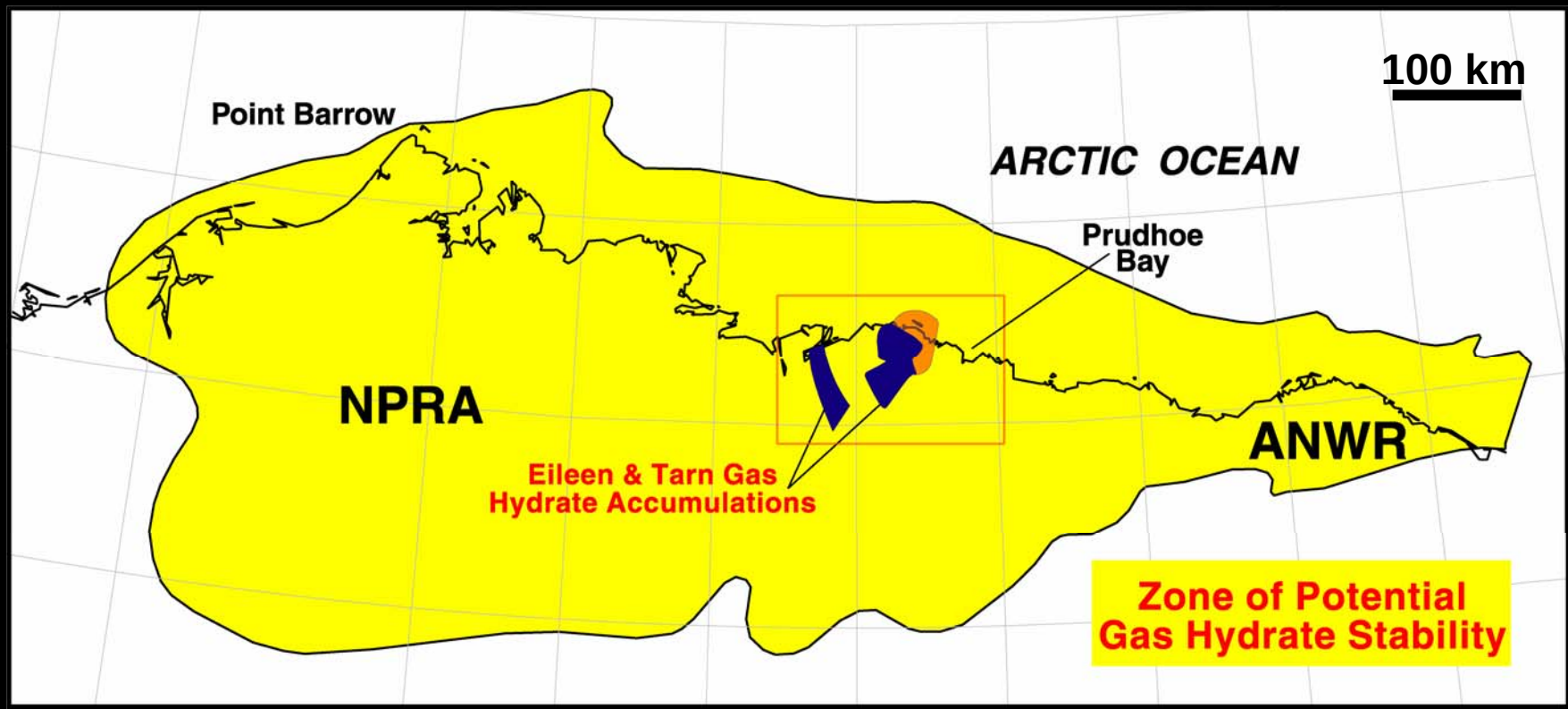
NATIONAL/REGIONAL ESTIMATES OF THE AMOUNT OF GAS WITHIN HYDRATES

(cubic feet)

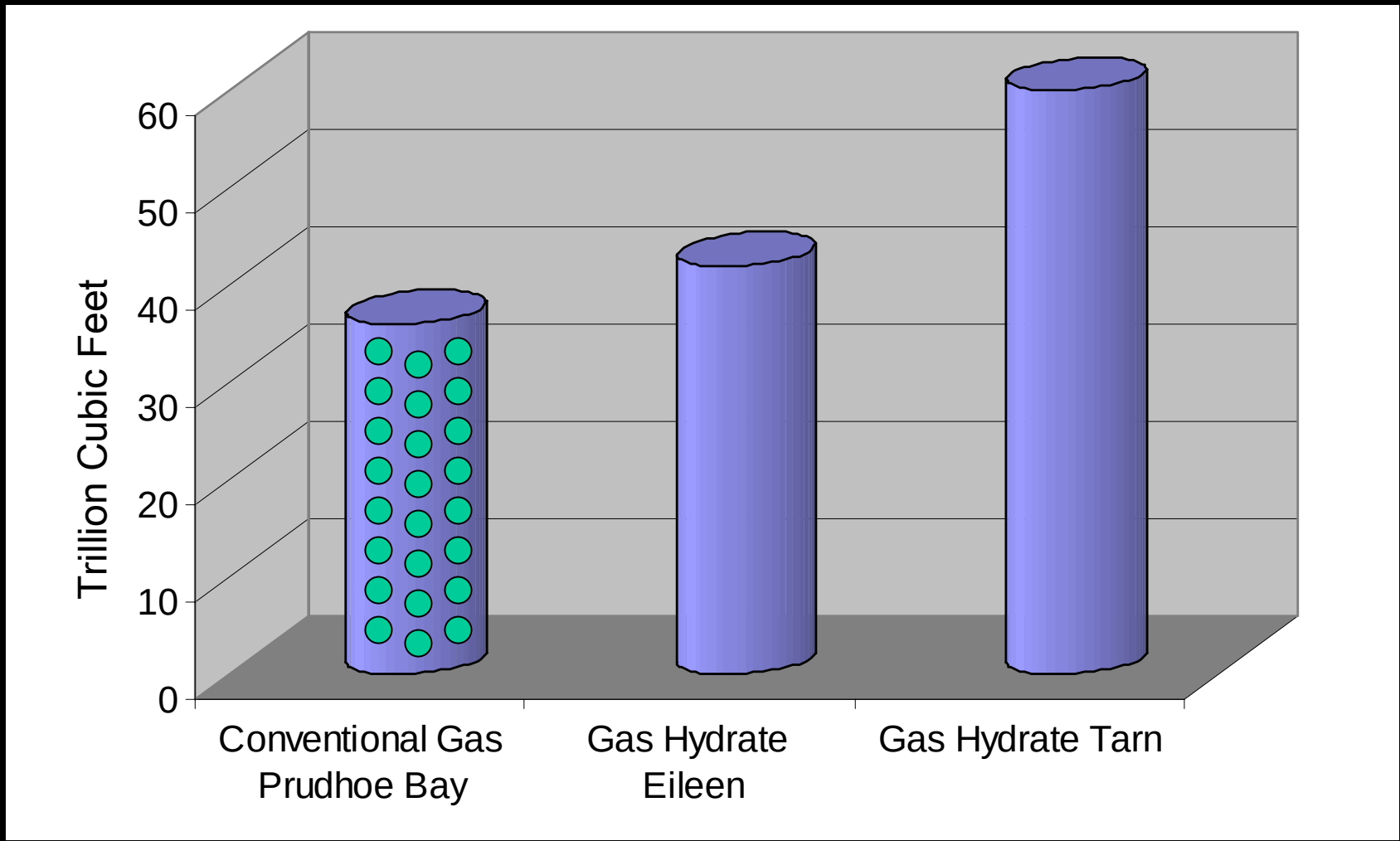
UNITED STATES		
	$317{,}700 \times 10^{12}$	Collett 1995
INDIA		
	$4{,}307 \times 10^{12}$	ONGC 1997
BLAKE RIDGE, USA		
	635×10^{12}	Dillon & others 1993
	$2{,}471 \times 10^{12}$	Dickens & others 1997*
	$2{,}824 \times 10^{12}$	Holbrook & others 1996*
	$2{,}012 \times 10^{12}$	Collett 2000*
	$1{,}331 \times 10^{12}$	Collett 2000
NANKAI TROUGH, JAPAN		
	$1{,}765 \times 10^{12}$	MITI/JNOC 1998
ANDAMAN SEA, INDIA		
	$4{,}307 \times 10^{12}$	ONGC 1997
NORTH SLOPE, ALASKA		
	590×10^{12}	Collett 1997

* Includes associated free-gas

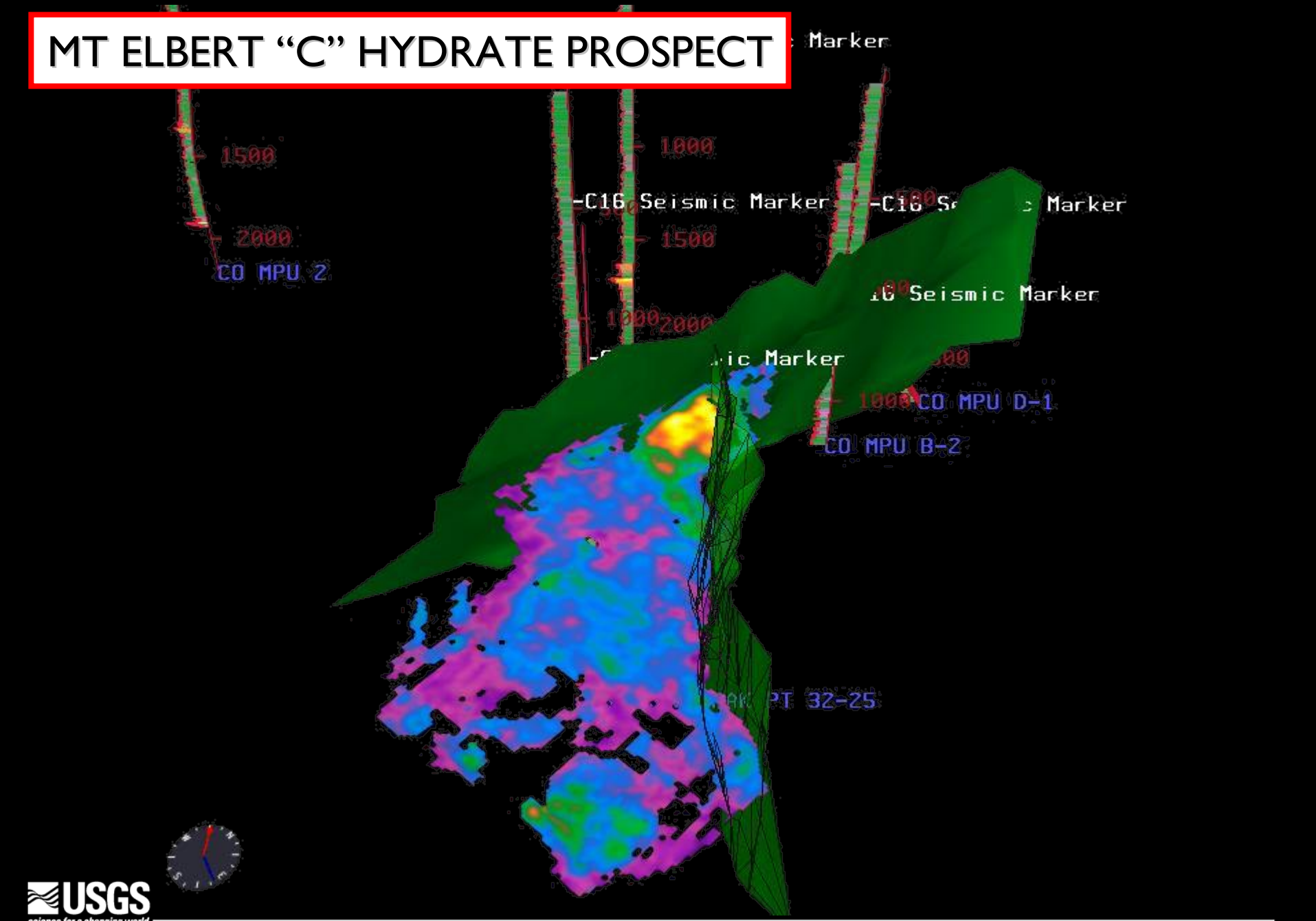
Alaska NS Gas Hydrates



Alaska Gas Hydrate "Resource" Assessments



MT ELBERT "C" HYDRATE PROSPECT



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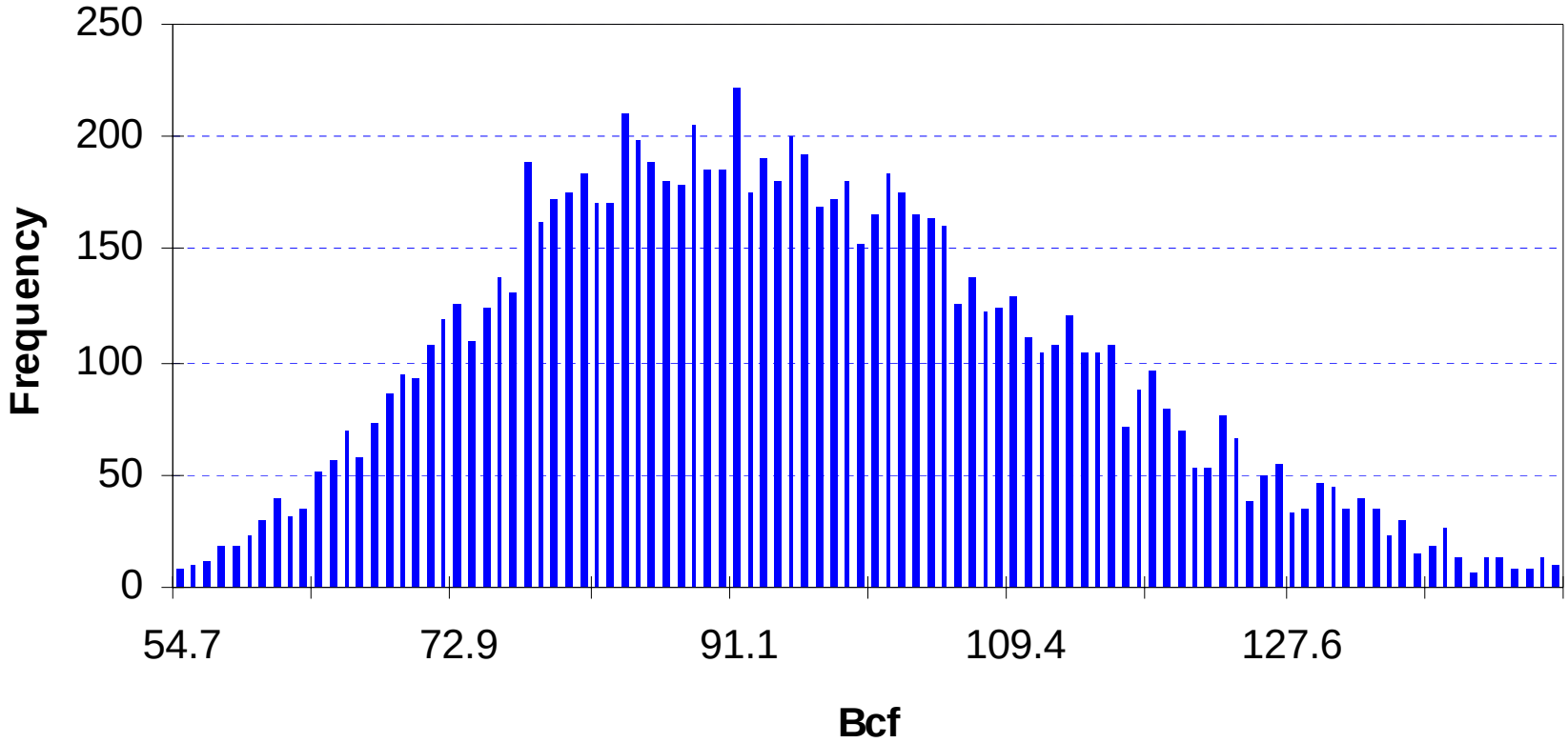
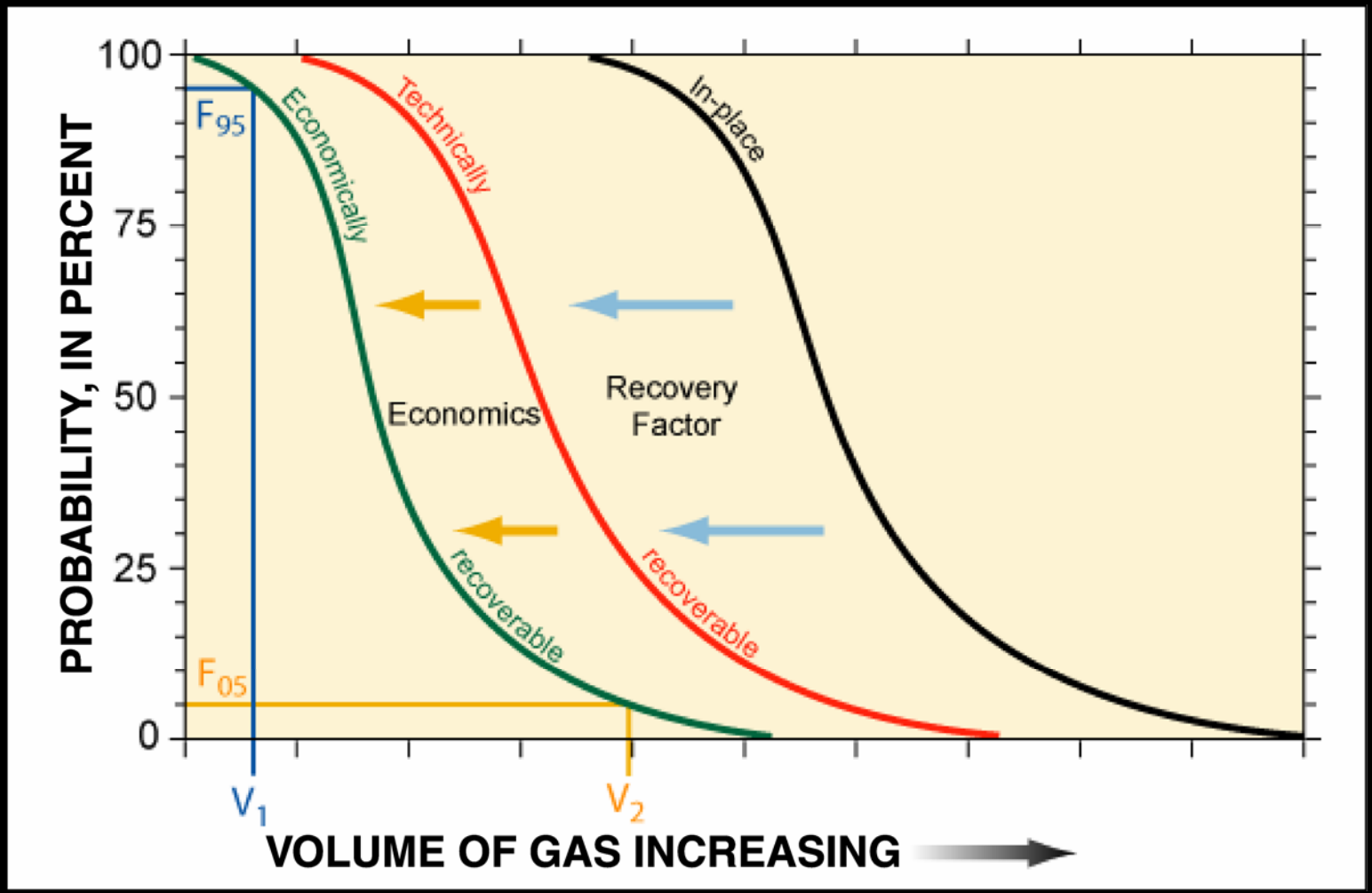
MT ELBERT "C" HYDRATE PROSPECT VOLUME SUMMARY



Hydrate Resource Assessment
"Economically Recoverable Assessment"



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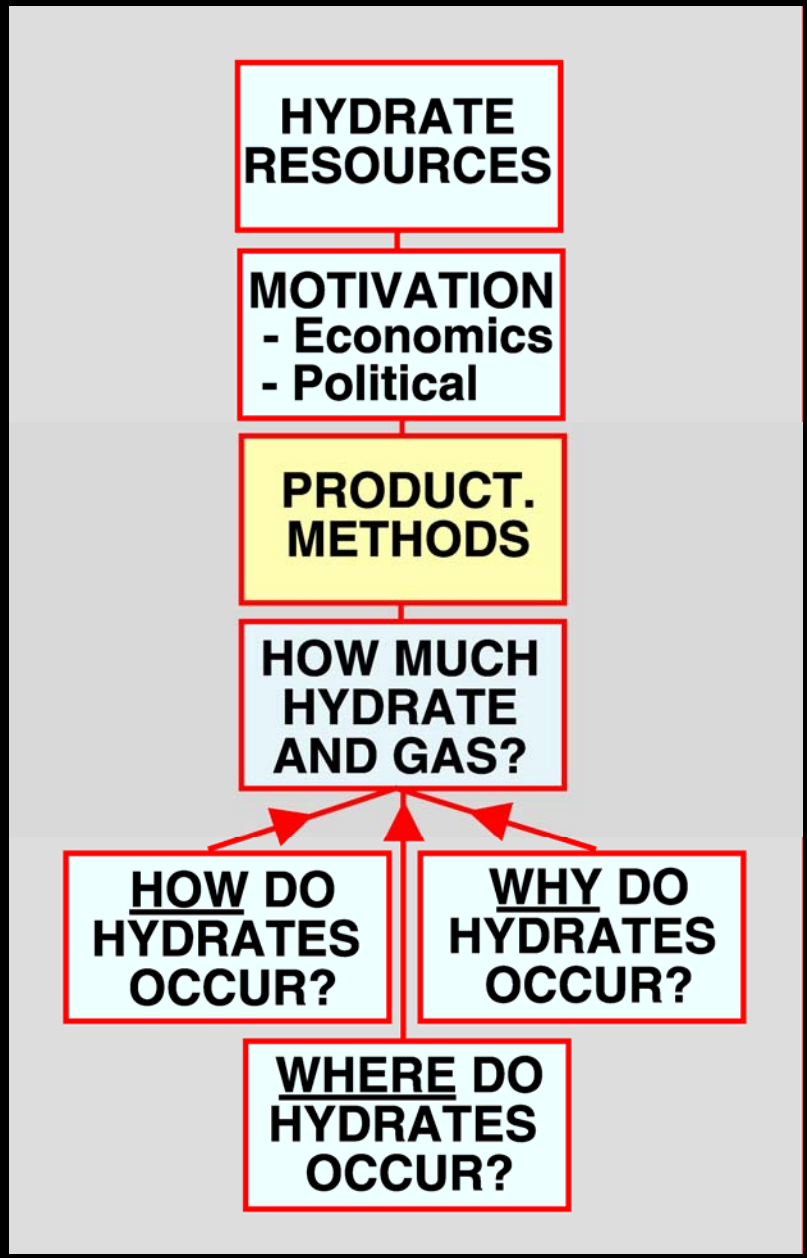
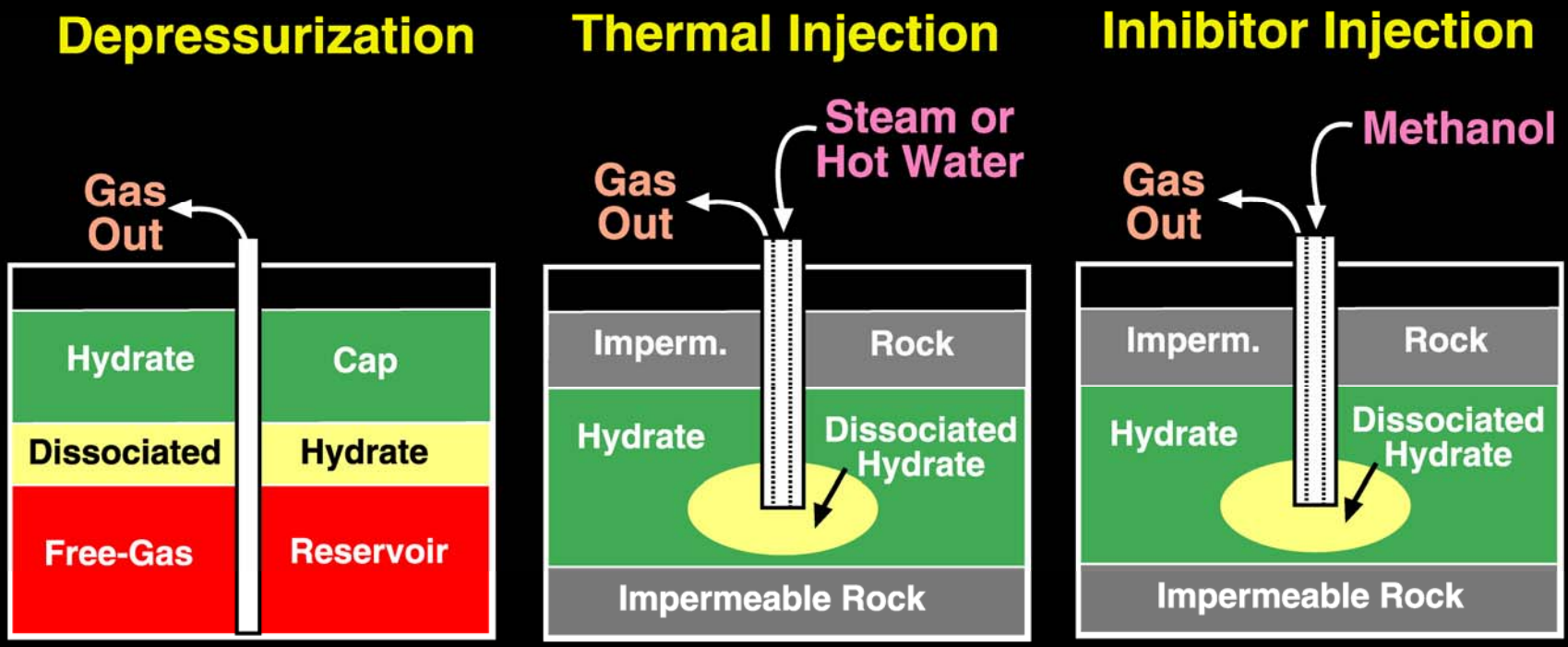


Gas Hydrate Production Methods

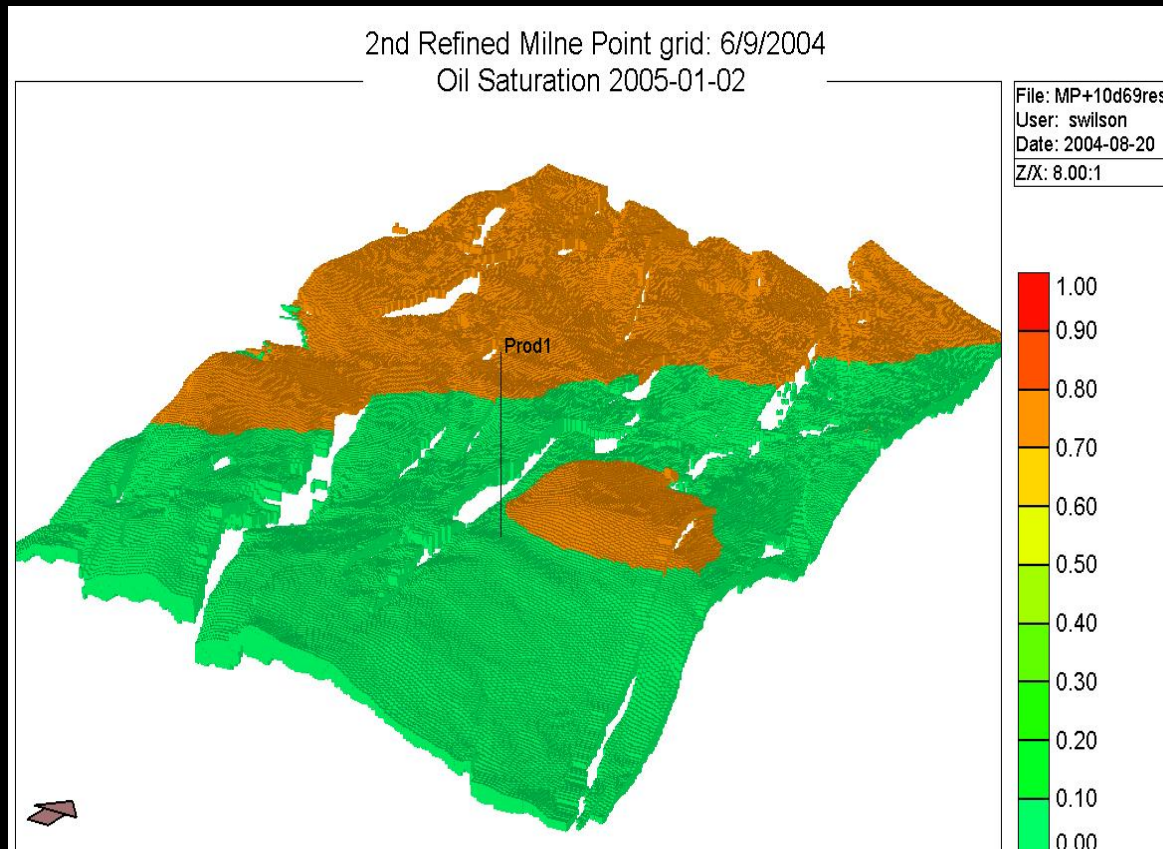


Mallik 2002 Gas Hydrate Production Test Well

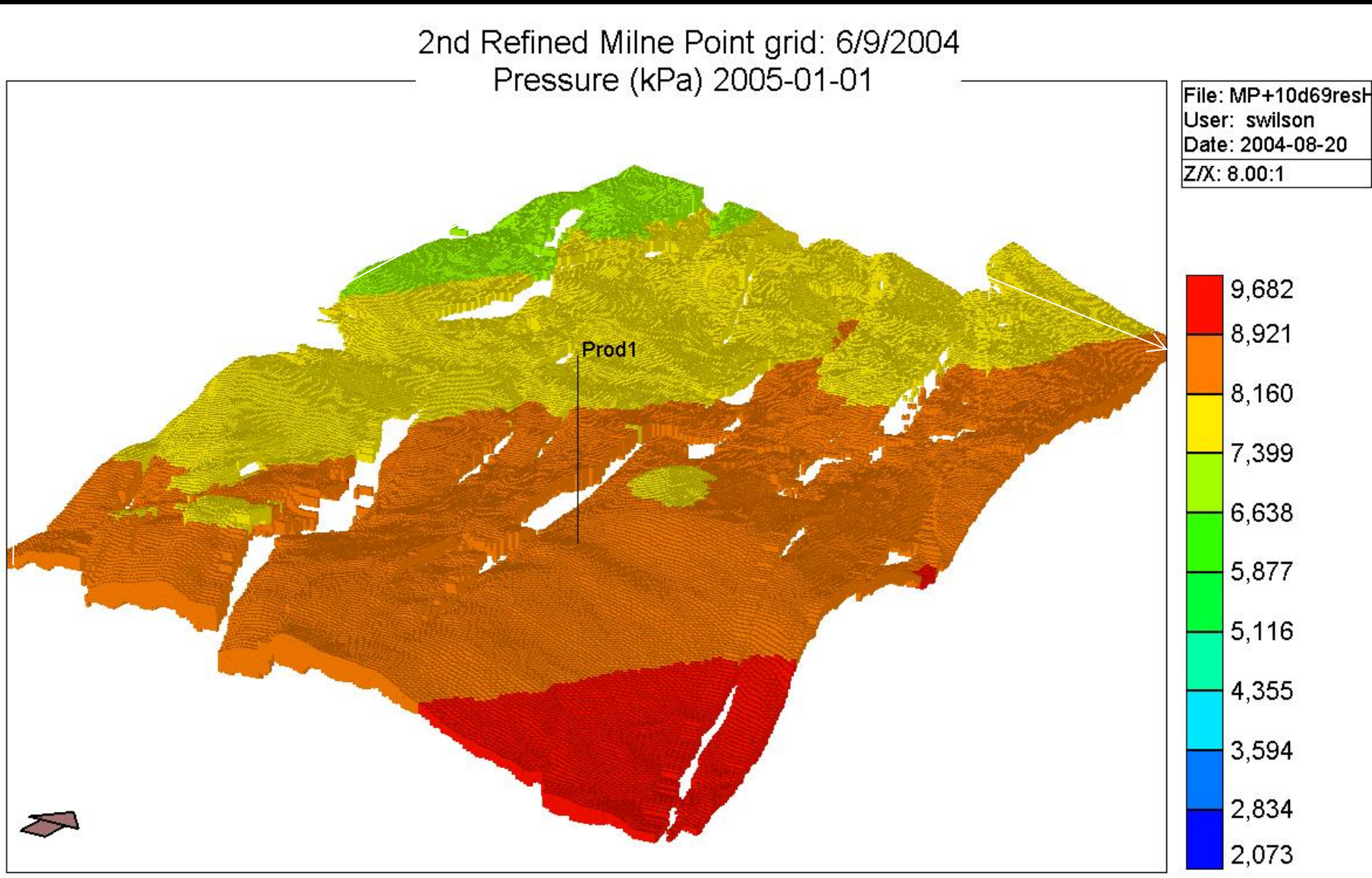
- Japan
  - JNOC/JOGMEC (METI)
  - JNOC collaborators
- Canada
  - GSC
  - BP/Chevron/Burlington
  - (Japex Canada, Imperial Oil)
- USA
  - USGS
  - USDOE
- Germany
  - GeoForschungsZentrum Potsdam
- India
  - National Gas Hydrate Program (NGHP), with DGH, MOP&NG, ONGC, and GAIL
- International Continental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

General Milne Point Area Model

- 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



RS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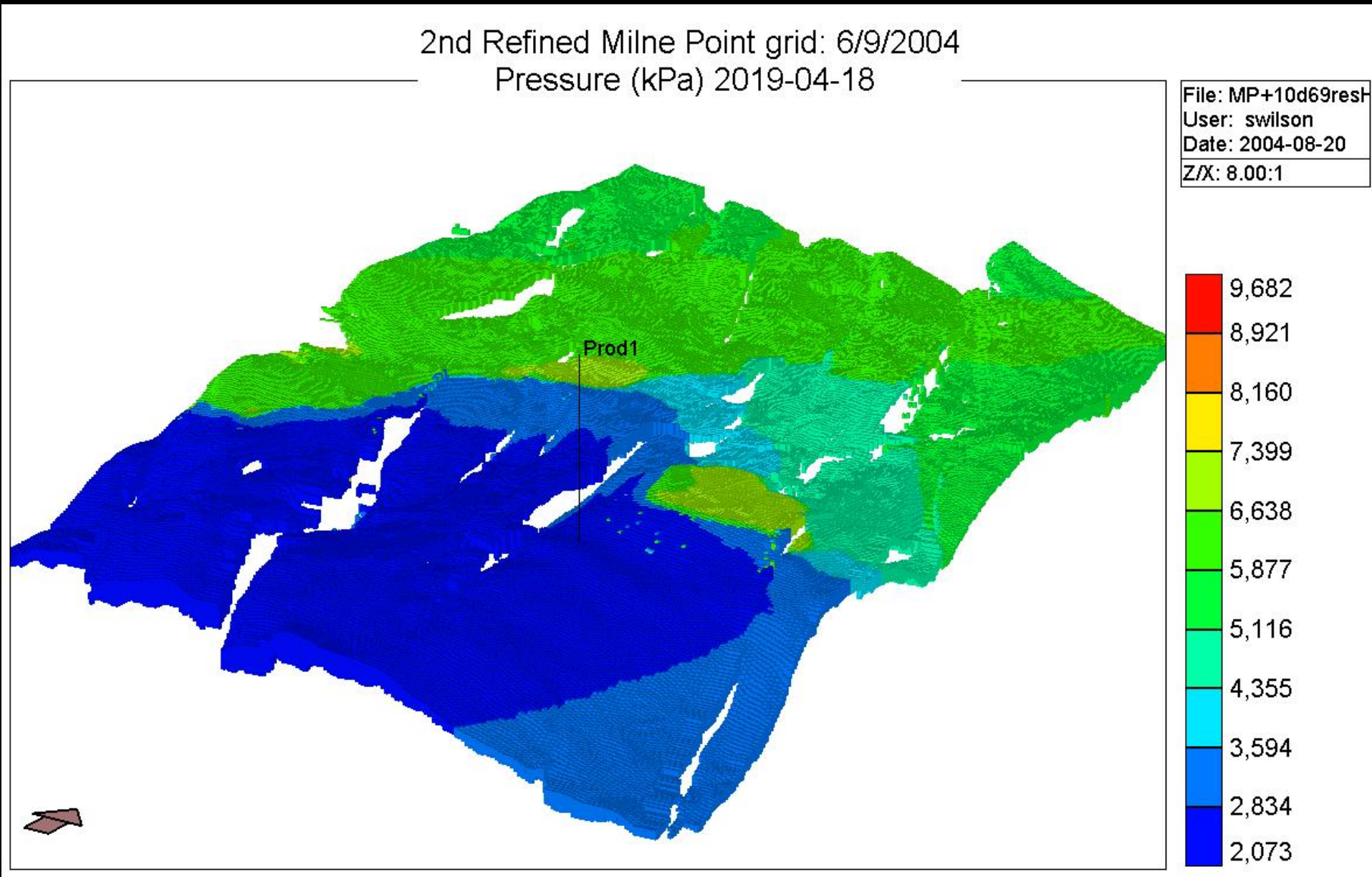
Pressure (kPa) 2005-01-01
File: MP+10d69resH
User: swilson
Date: 2004-08-20
Z/X: 8.00:1
Prod1
9,682
8,921
8,160
7,399
6,638
5,877
5,116
4,355
3,594
2,834
2,073

RS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Pressure (kPa) 2019-04-18
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Z/X: 8.00:1
Prod1
9,682
8,921
8,160
7,399
6,638
5,877
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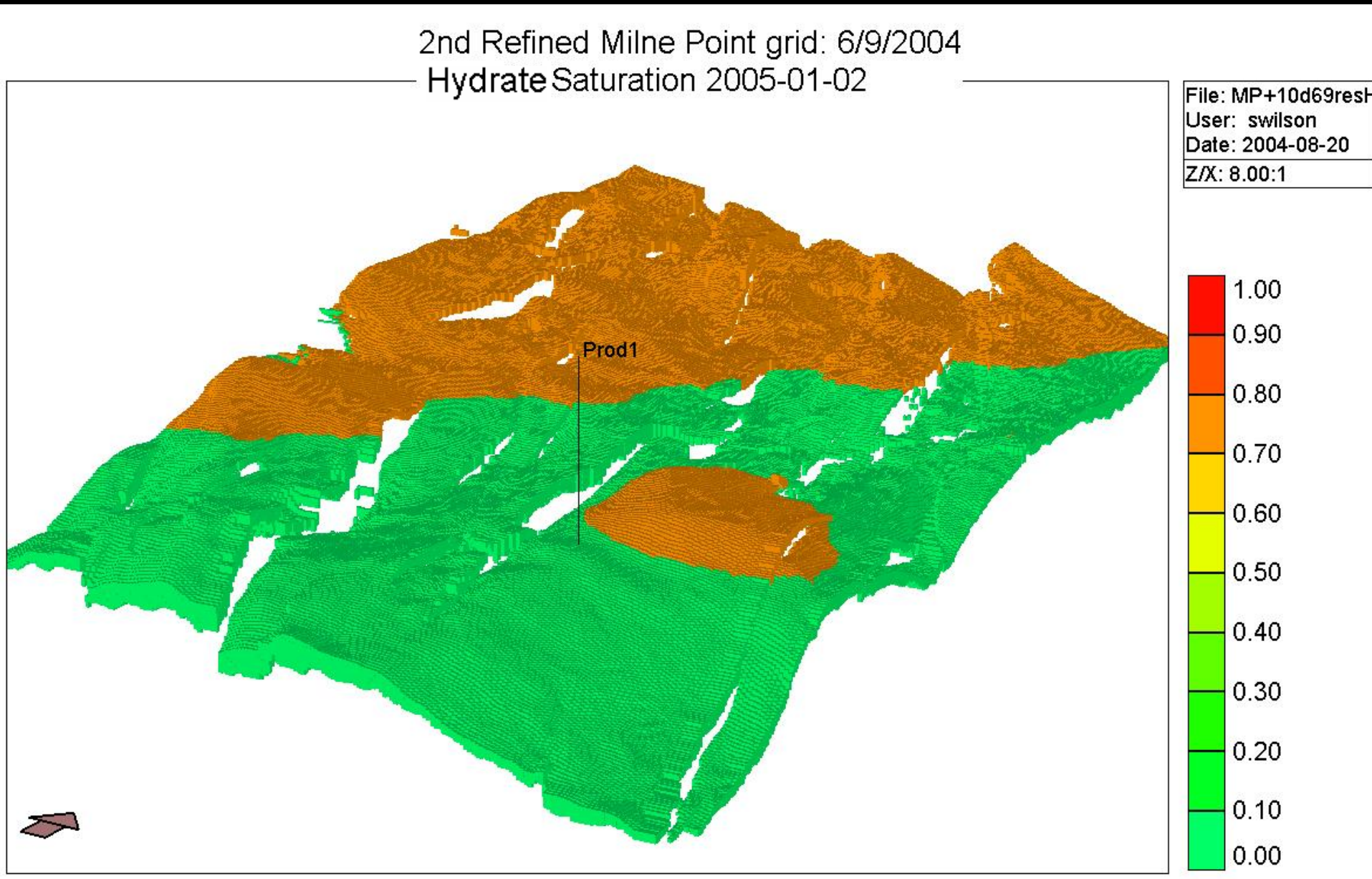
RS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Hydrate Saturation 2005-01-02
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User: swilson
Date: 2004-08-20
Z/X: 8.00:1
Prod1
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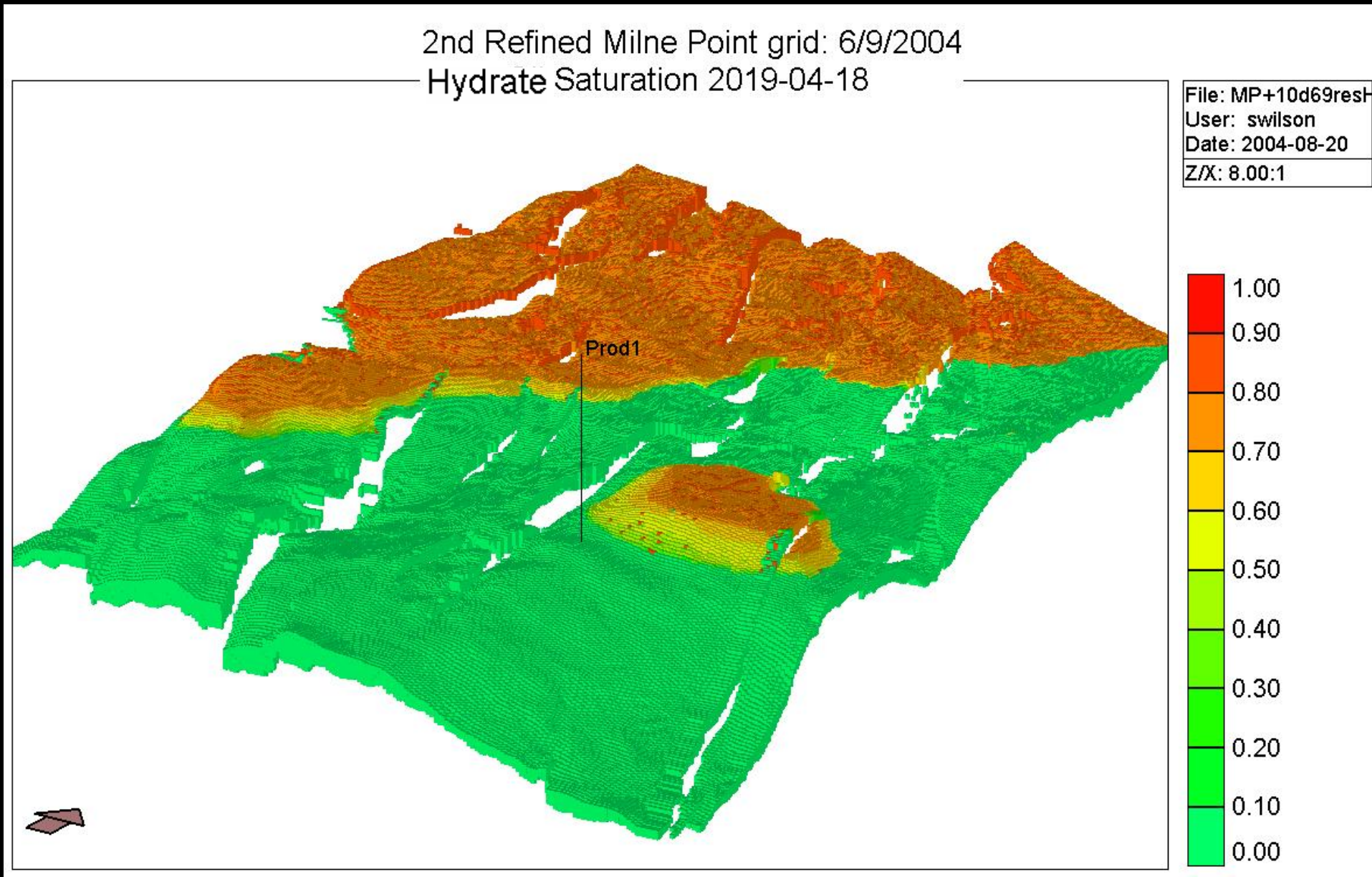
RS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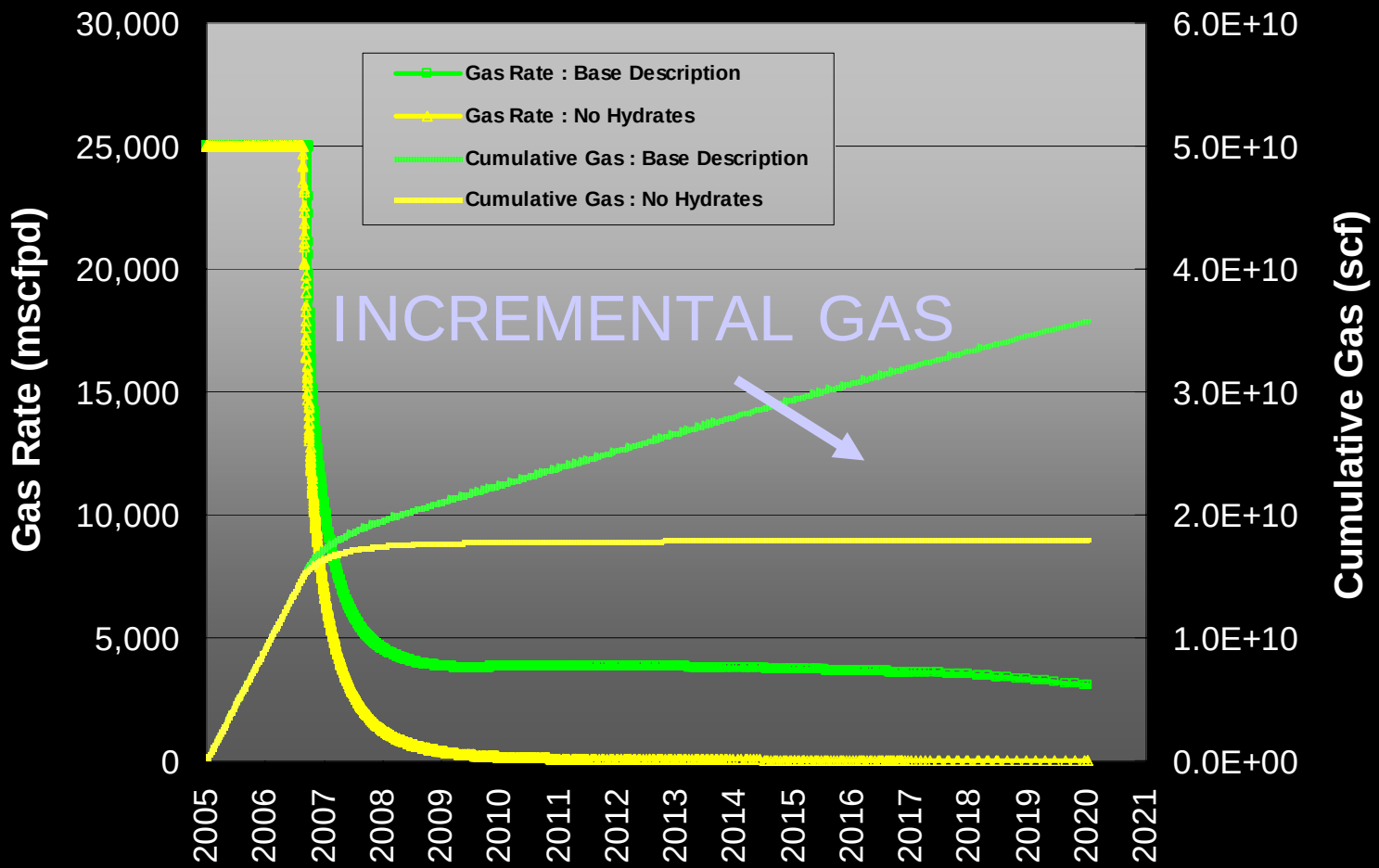
Reservoir Model - Depressurization
Production Profile Comparison



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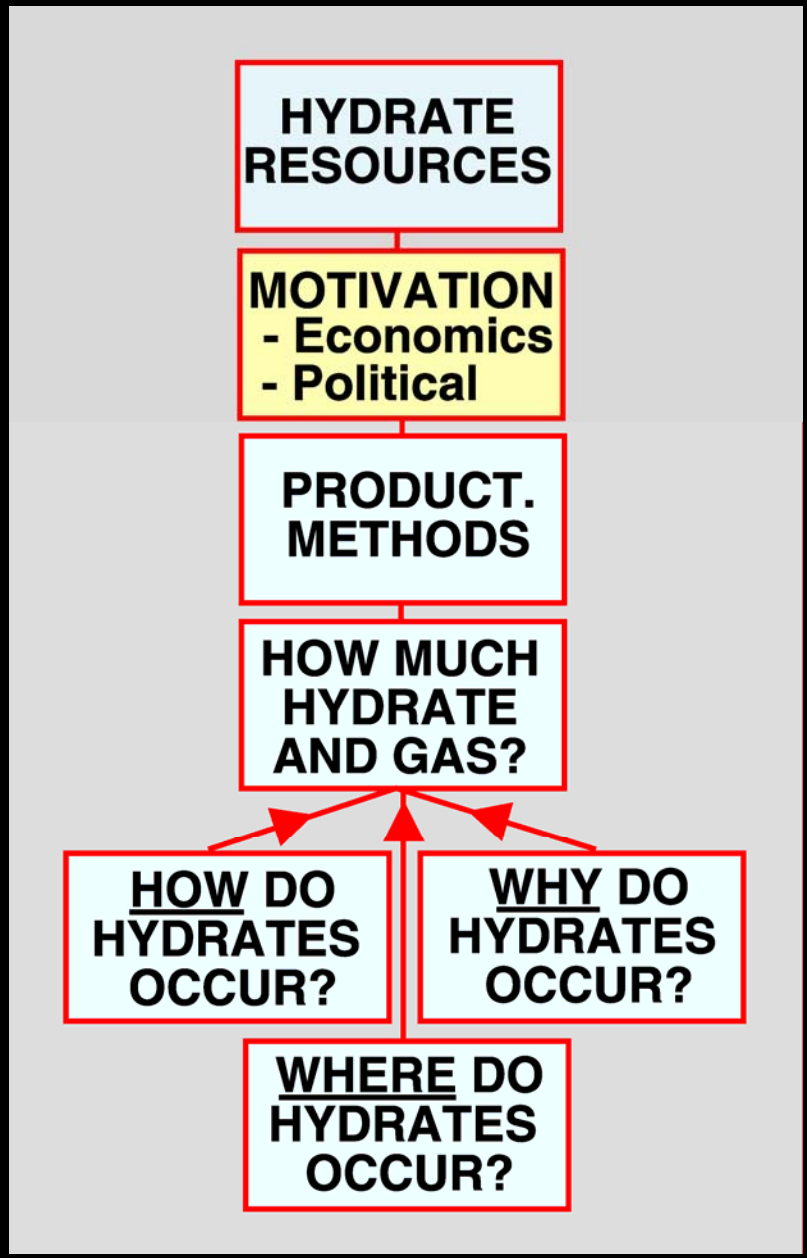
Outline of Presentation

1. Gas Hydrate Petroleum System
   A. Marine Case Study – Blake Ridge
   B. Arctic Case Study – Alaska NS
   C. Marine Case Study - India
2. How Much Gas Hydrate and Gas?
3. Production Methods
4. Motivations – Economics and Political

Gas hydrate energy resource flow chart

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



ECONOMIC STUDY OF HYDRATE PRODUCTION*

	Thermal injection	Depres-surization	Conventional gas
Investment (M US$)	5,084	3,320	3,150
Annual cost (M US$)	3,200	2,510	2,000
Total production (MMcf/year)**	900	1,100	1,100
Production cost (US$/Mcf)	3.60	2.28	1.82
Break-even wellhead price (US$/Mcf)	4.50	2.85	2.25

* Assumed reservoir properties: h=25ft, φ=40%, k=600md

** Assumed process: injection of 30,000 b/d of water at 300 F

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

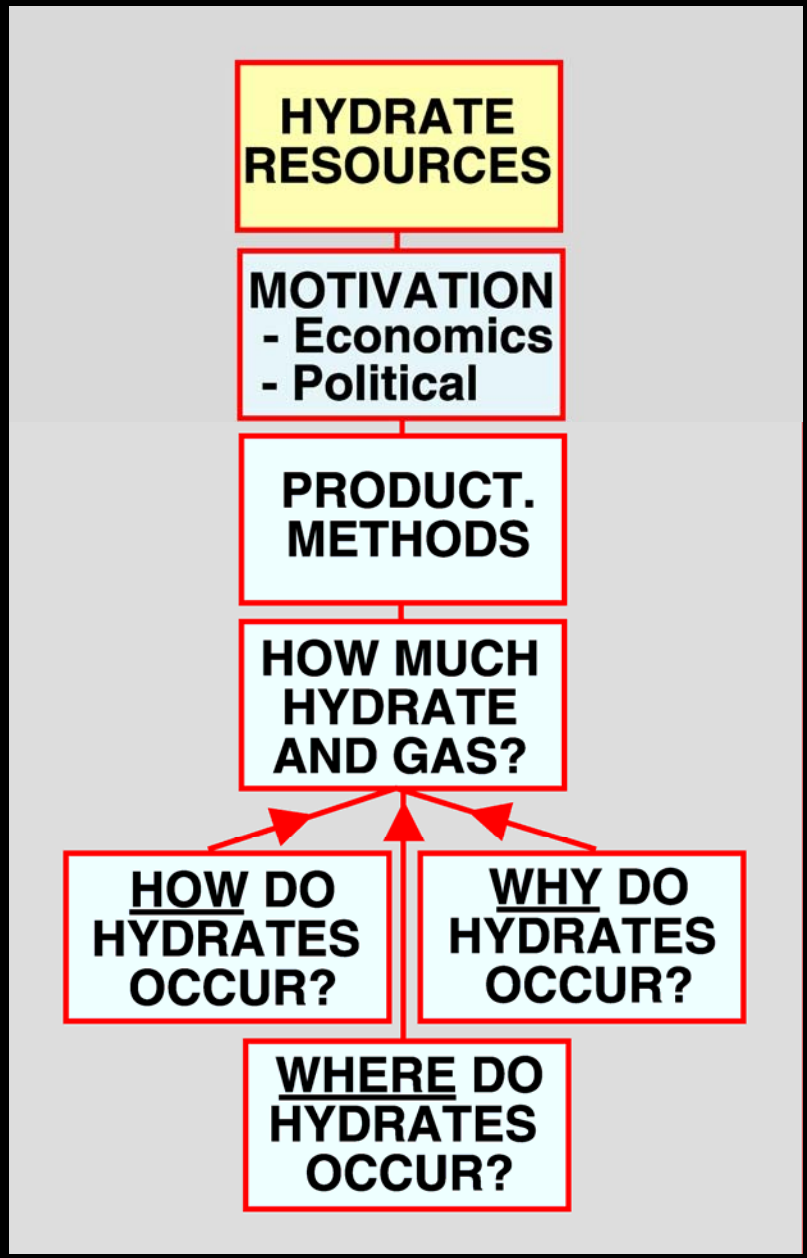
ALASKA GAS EXPORT

UNIQUE MOTIVATIONS LEADING TO GAS HYDRATE PRODUCTION

- 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 for EOR projects
  - ?

Gas hydrate energy resource flow chart

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



Conclusions

- The occurrence of highly concentrated gas hydrate accumulations in prospects lend themselves to production

- Recent gas hydrate assessments have focused on understanding the geologic controls on the occurrence and potential production of gas hydrates

- The occurrence of gas hydrates in a definable petroleum system provides us with a gas hydrate exploration model

- Results of the Mallik 2002 effort, and associated reservoir production modeling, demonstrate that gas hydrates can be produced by pressure depletion and thermal stimulation

Conclusions

- Development/calibration of gas hydrate production models requires ongoing effort:
  - Demonstration project
  - Long term production tests are critical to understanding field economics
- Innovative application of new and current technologies required to maximize rates and recoveries

INDIA - Next Steps

Government and industry focusing on integrated research, development and testing of gas hydrates as a necessary precursor to commercial production

Actions Already Underway

- **Link industry, academic, and government efforts into overall effective research team.**
- **Assess the amount of technically recoverable natural gas hydrates in the Outer Continental Shelf of “India”.**

INDIA - Next Steps (cont'd)

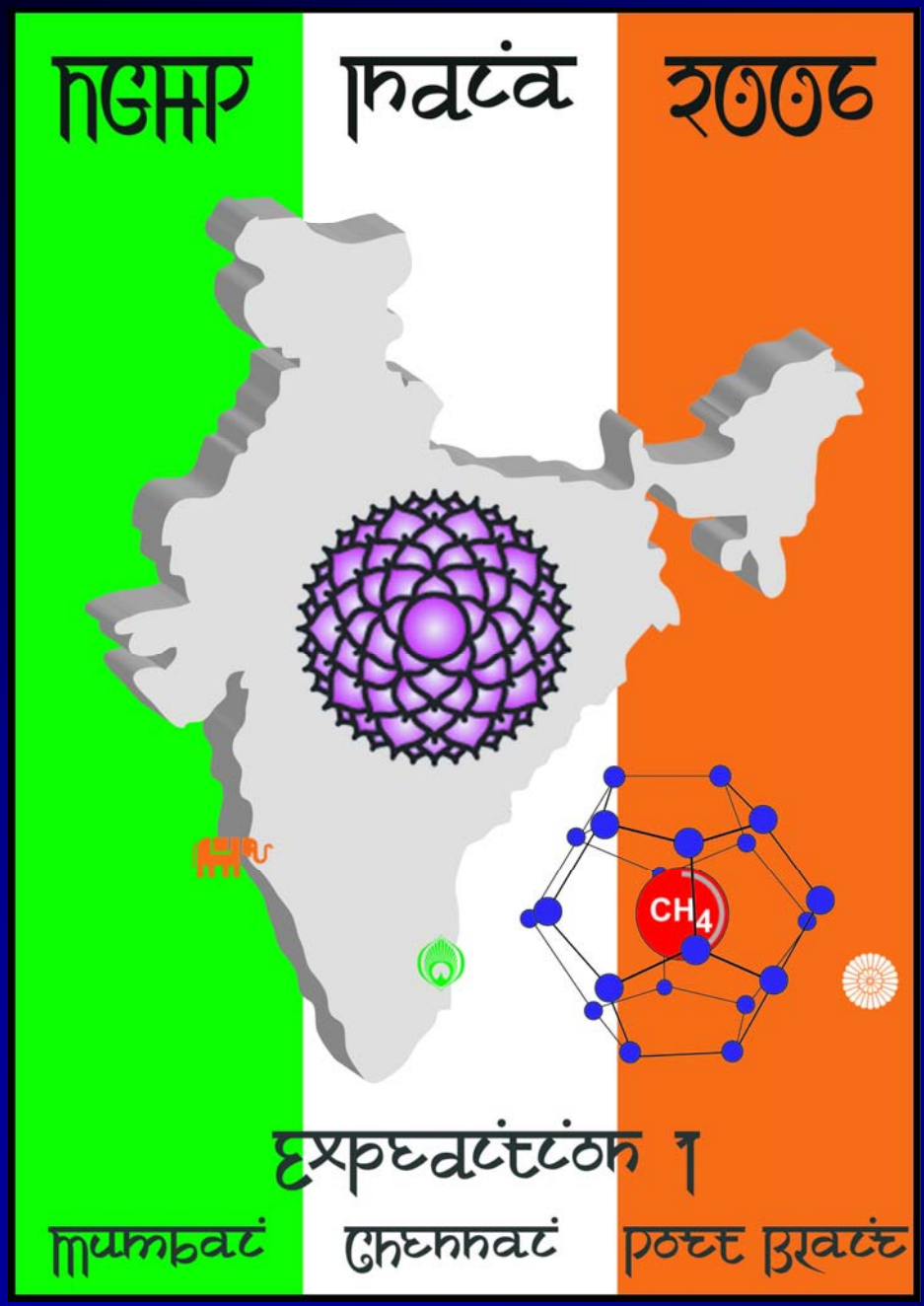
Actions Needed

- Work with industry and the international community to research production technology for safe and economic gas hydrate development.

- Conduct exploratory drilling, well testing and production testing operations by first identifying viable sites for production testing. This work will include:

  - Expanded seismic and geologic understanding of gas hydrates.

  - Contribute to the commercial analysis of gas production from gas hydrates.



THANK YOU