Evaluation and Modeling of Alaska North Slope Gas Hydrate Resource Potential

Alaska Gas Hydrate Planning Workshop
Anchorage, Alaska

August 17-18, 2005

U.S. Department of Energy

Robert Hunter

ASRC Energy Services
E & P Technology

U.S. Department of Energy

Presentation Outline

- ➢ Introduction / Collaboration
- Gas Hydrate Resource
- Resource Characterization
- Production Technology
- Reservoir/Development Models
- Conclusions

Collaborative Research Team

U.S. Department of Energy

GOVERNMENT

National Labs

USGS
science for a changing world

Unconventional Resource Determination

bp

ASRC Energy Services
E & P Technology

PETROLEUM ENGINEERING

The University of Arizona

University of Alaska Fairbanks

INDUSTRY

3D Seismic & Well Data, Infrastructure

UNIVERSITIES

Research Innovation

Collaborative Research Team

GOVERNMENT

USGS Lead
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USGS
Geophysics
Myung Lee

USGS
Geophysics
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Geophysics
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National Labs

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LBNL
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Tao Zhu (UAF)
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Brent Sheets (AETDL)
UAF-PNNL Projects

Arun Wagh (ANL)
Ceramicrete Cement

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Ken Mallon

Project Timing & Phases

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Phase/Year

2001

pre

2002

Project Proposal

DOE-Industry Alignment

Wells of Opportunity – Acquire Data

I

2003

Characterize Reservoir/Fluid

Calculate In-Place Resource

2004

Drilling/Production RE/PE Studies

Reservoir and Development Modeling

II

2005

Validate Regional Prize, Determine Alignment, Plan/Acquire Data

III

2006

Apply/Test Concepts/Technology, Characterize & Calculate Resource

2007

Possible Pilot Development Testing?

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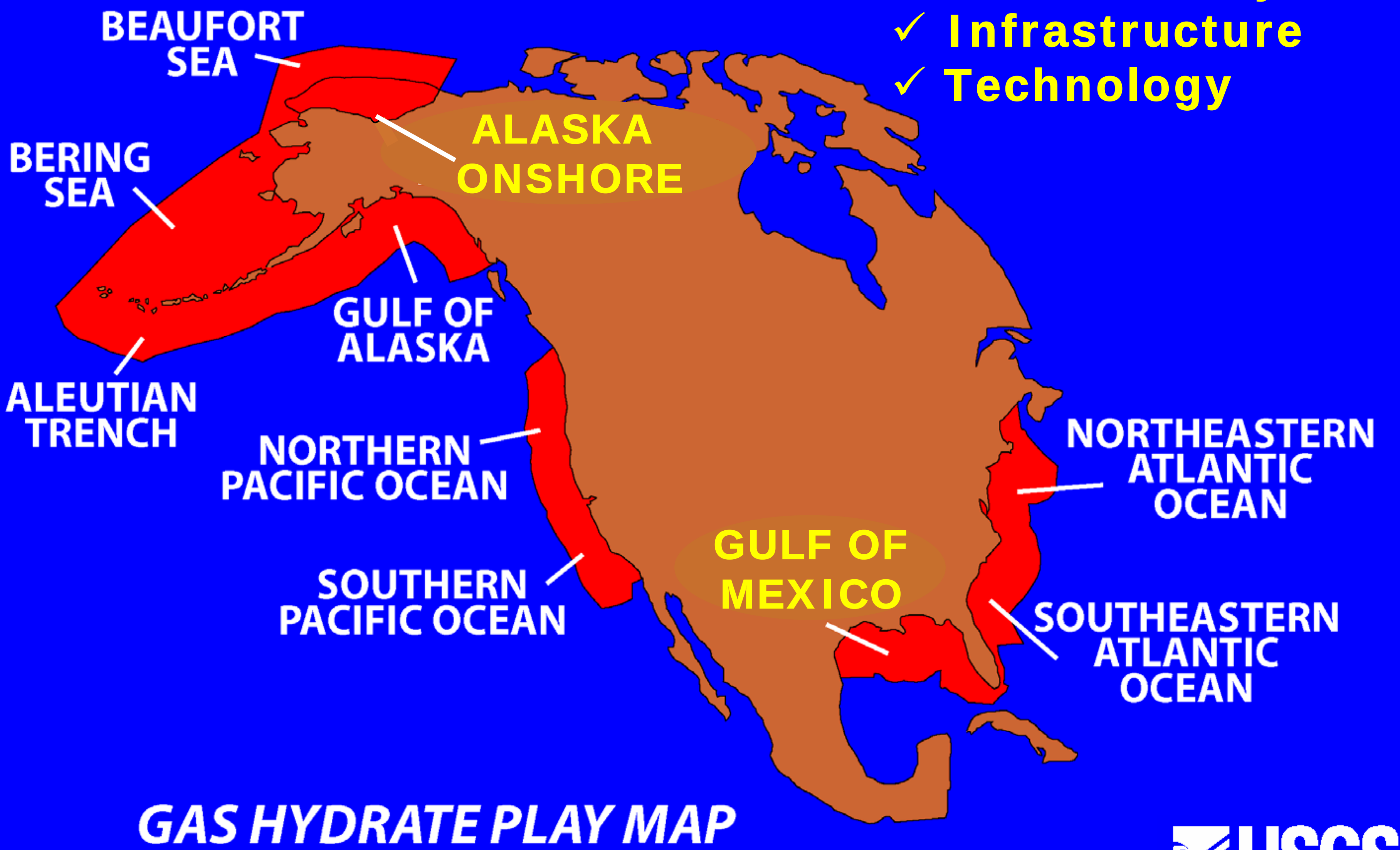
Gas Hydrate in U.S.

- ✓ Petroleum System
- ✓ Infrastructure
- ✓ Technology



USGS
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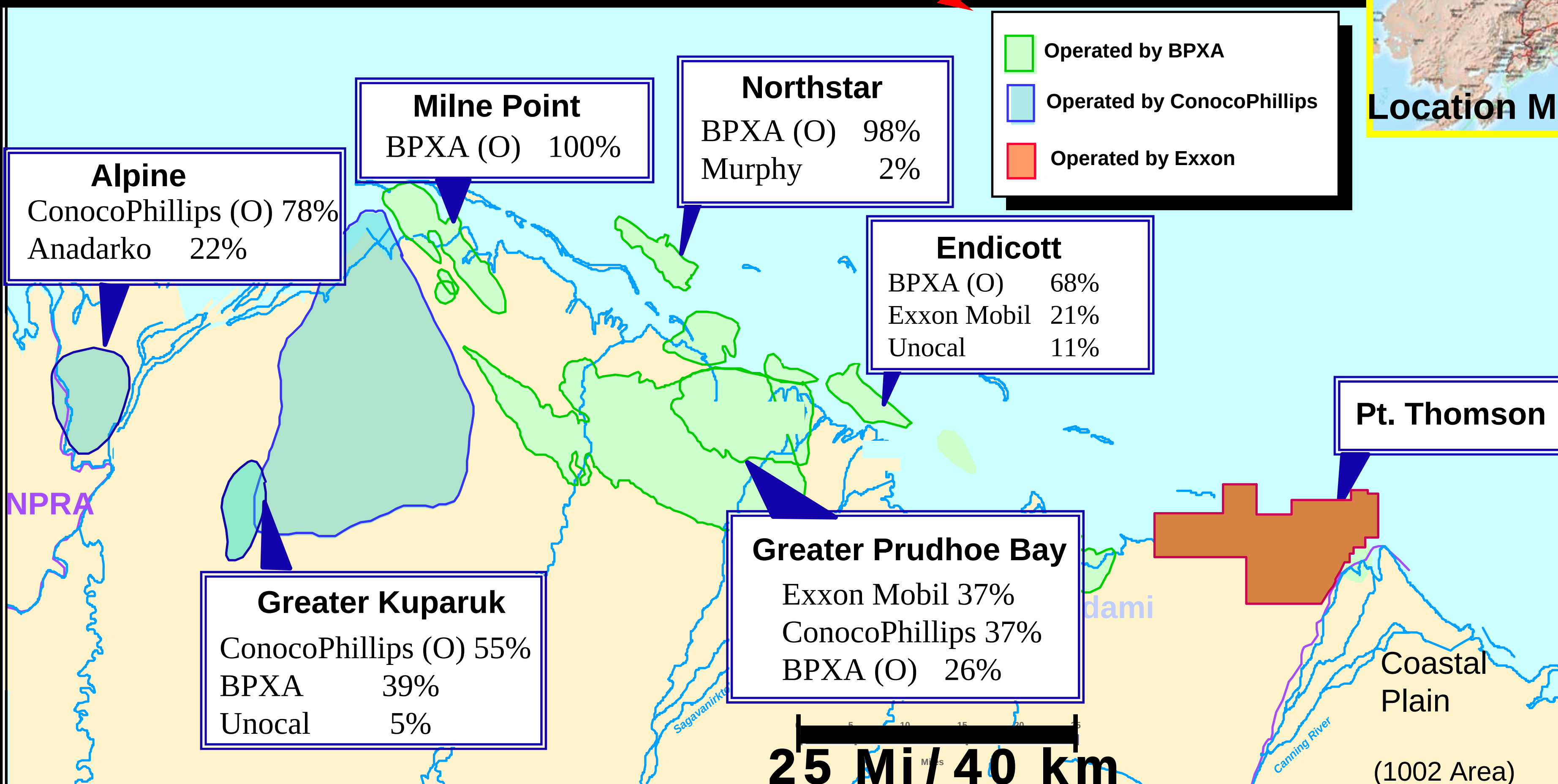
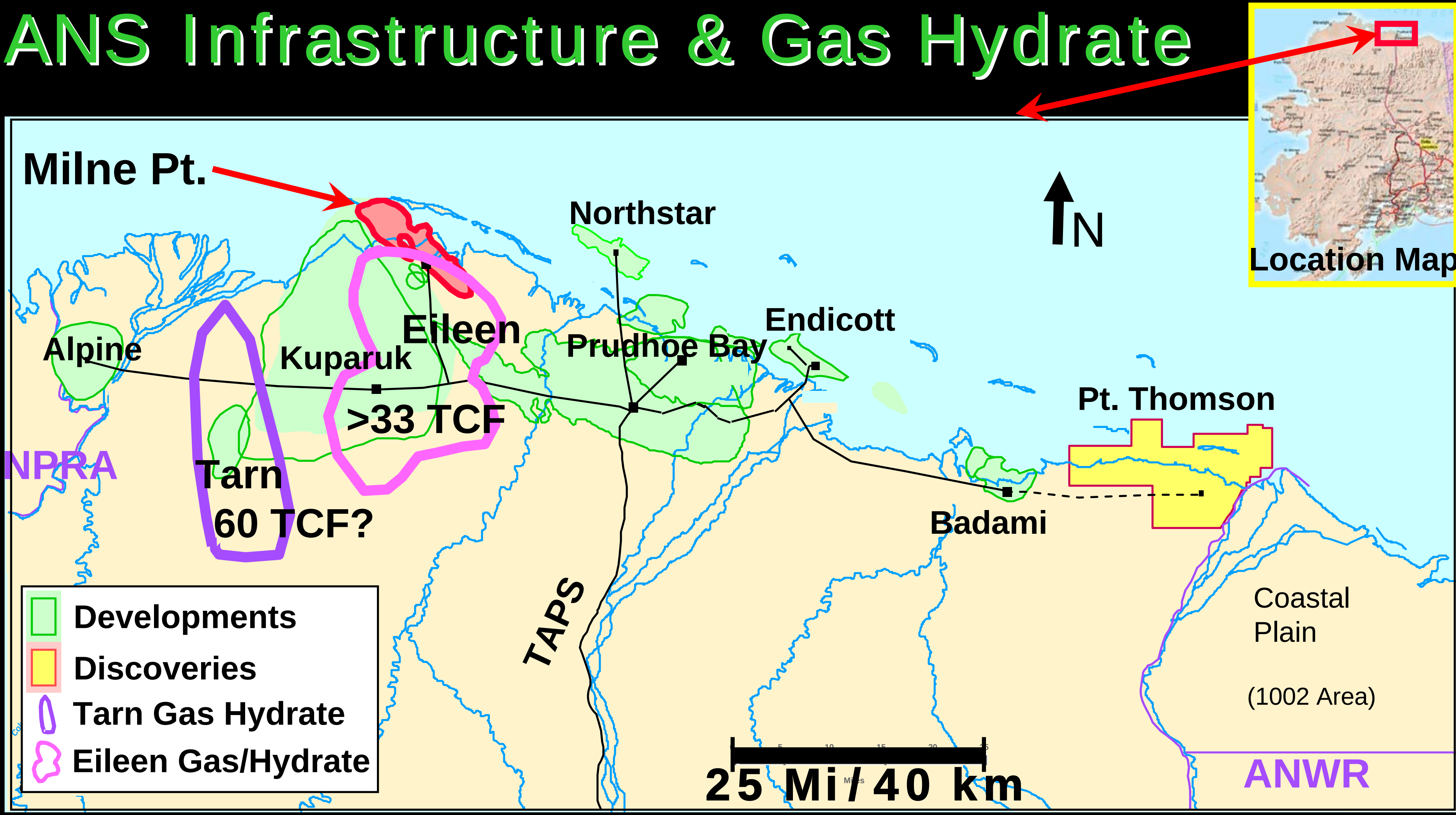
Alaska North Slope Operators



- North Slope Gas **Resource** → 35 TCF
- PBU Production = 8 BCF/Day → Reinjected → Reservoir Energy

ANS Infrastructure & Gas Hydrate



- Gas Hydrate **In-Place**, ANS Basin (USGS) → 590 TCF
- Gas Hydrate **In-Place**, ANS Infrastructure area (USGS) → 100 TCF
- Gas Hydrate **In-Place,** Eileen Trend → 33-44 TCF
- Gas Hydrate/Gas **In-Place** Milne Point → ~ 617/90 BCF (mean)

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ANS Research Program Collaboration

US Bureau of Land Management, US Geological Survey, State of Alaska Division of Geological & Geophysical Surveys

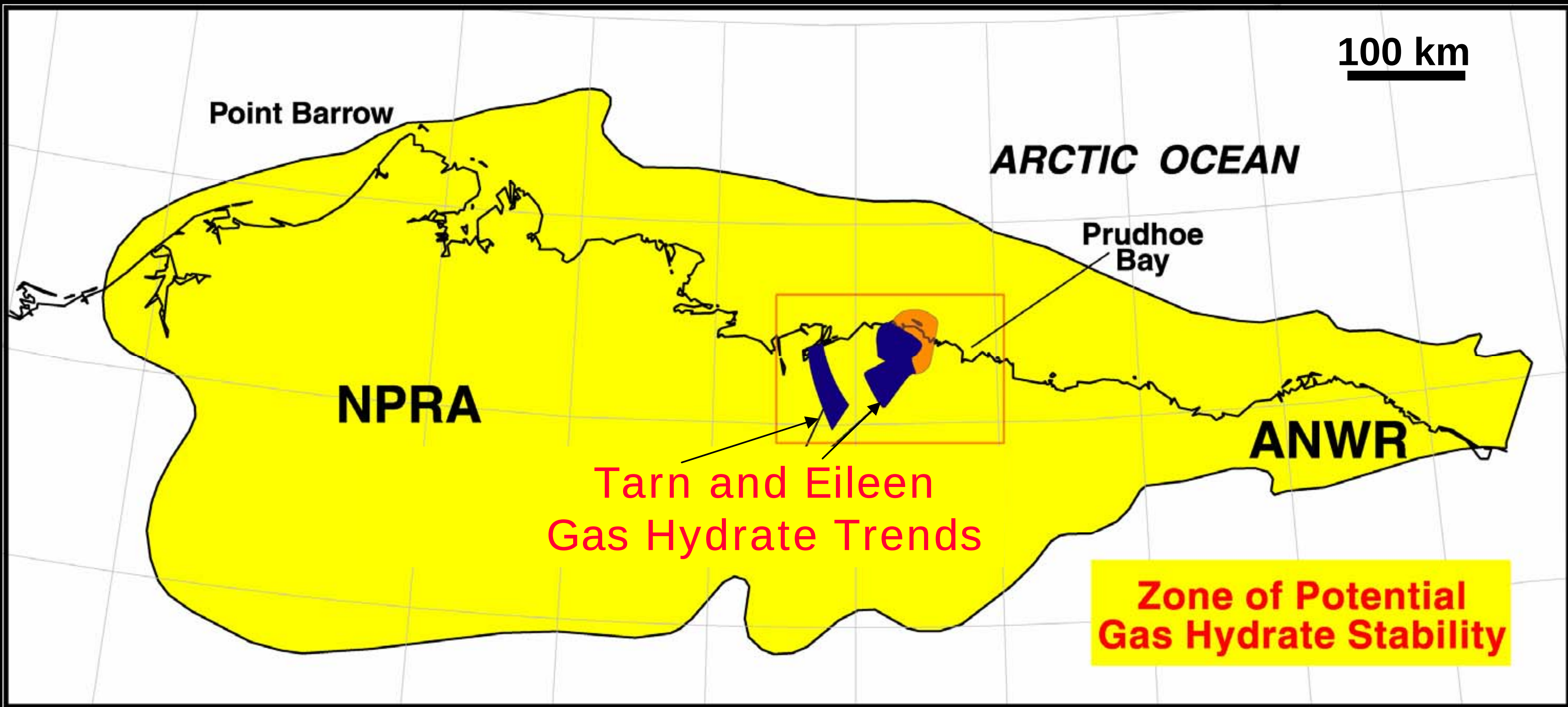
Phase-I. Assess existing geologic, geophysical, and engineering data to characterize the resource potential of the Eileen and Tarn gas-hydrate/free-gas accumulations (FY 03-05).

BPXA – USDOE project synergy.

Phase-II. Assess existing geologic, geophysical, and engineering data to characterize the resource potential of the undiscovered gas hydrate accumulations in NPRA, ANWR, and the State lands between the Canning and Colville Rivers (FY 05-06).

Phase-III. Assess the economically recoverable resource potential of gas hydrates and associated free-gas accumulations in northern Alaska (FY 07).

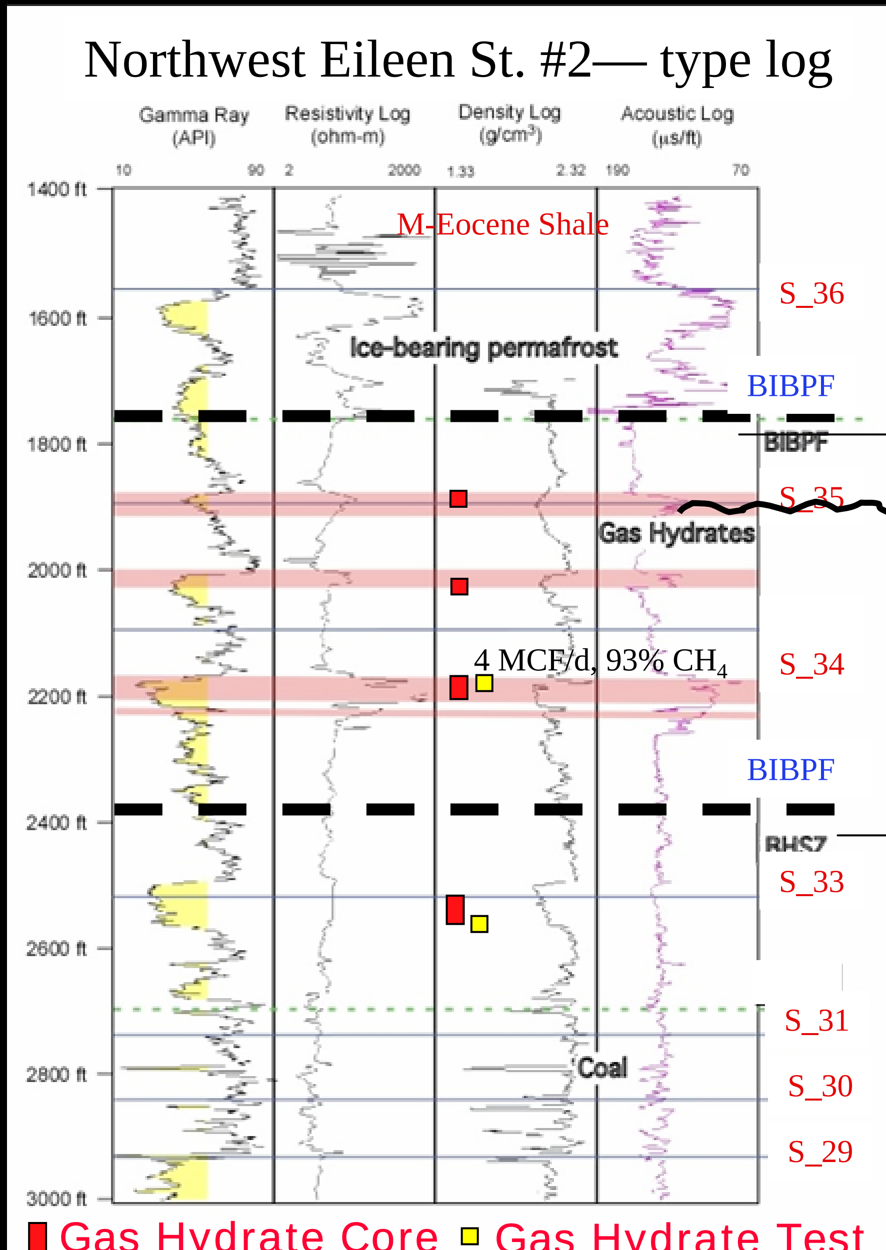
Gas Hydrate Stability Zone
Alaska North Slope



Petroleum System also Required:
Gas Source, Migration, Reservoir, Trap, Seal

Eileen Trend Type Log

Sagavanirktok Fm.



Ice-bearing permafrost

Gas hydrate stability zone

Free-gas, oil, or water-bearing

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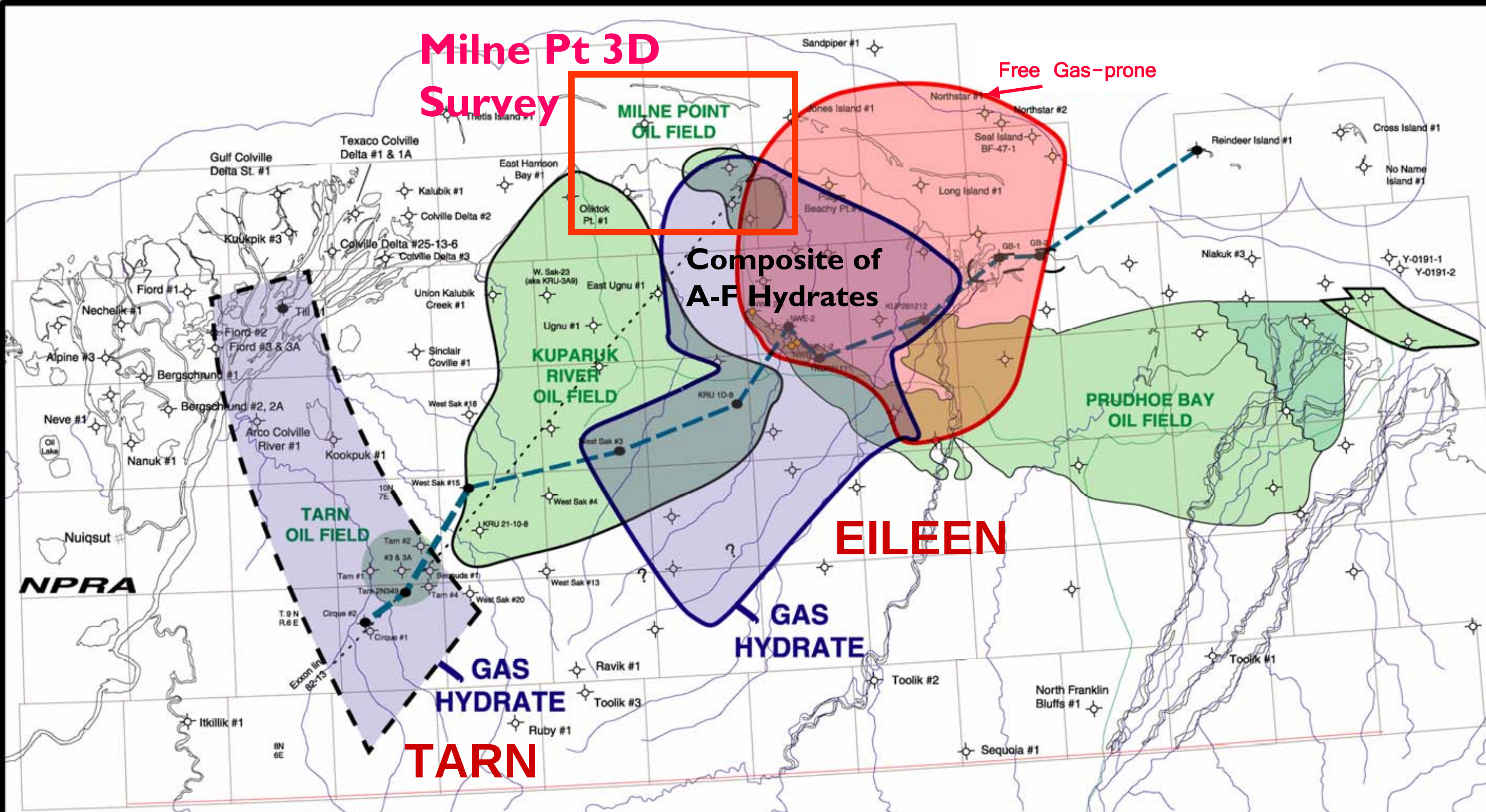
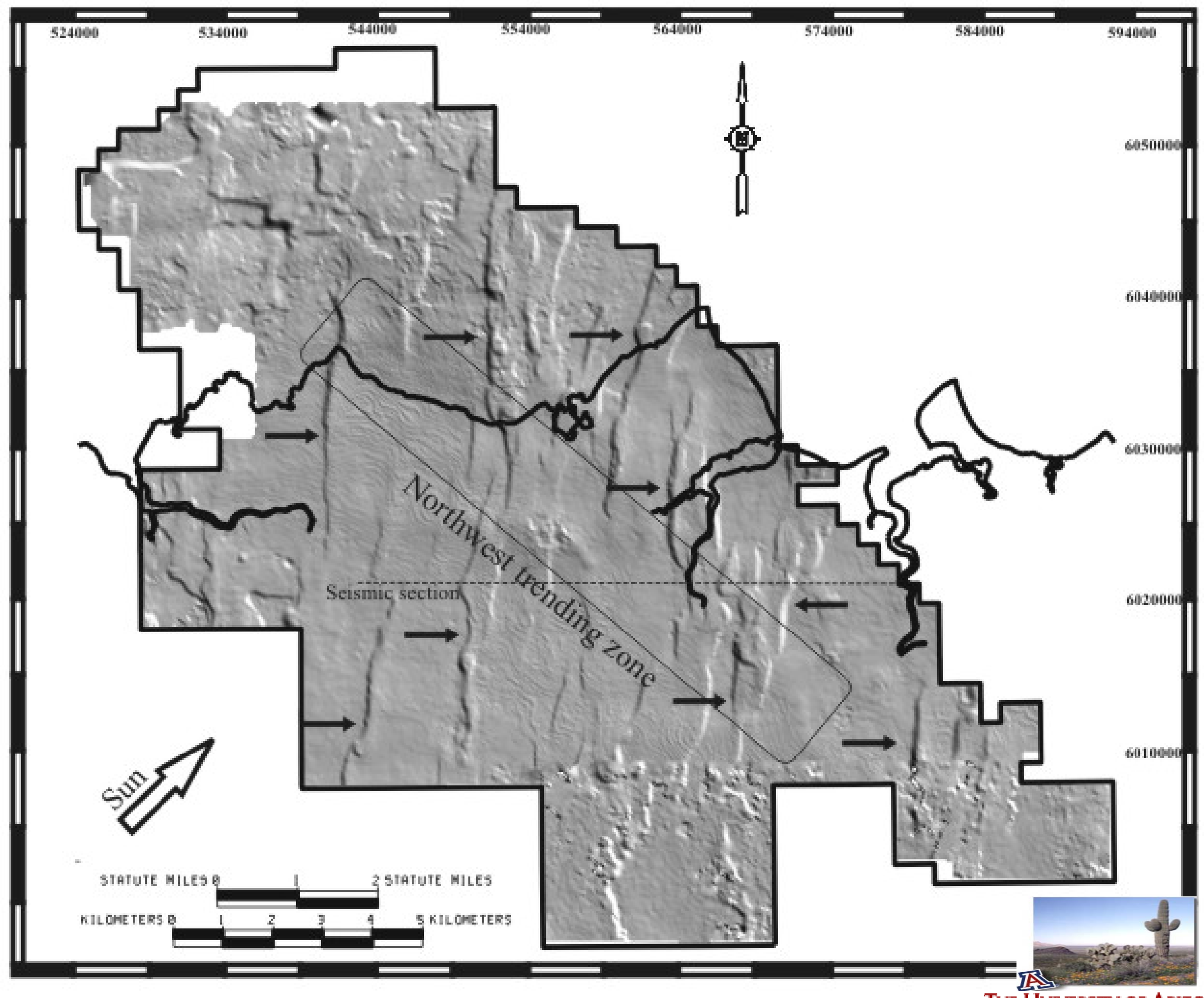
Milne Point Gas Hydrate Accumulation



Collett et al 1-2004

Structural Complexity



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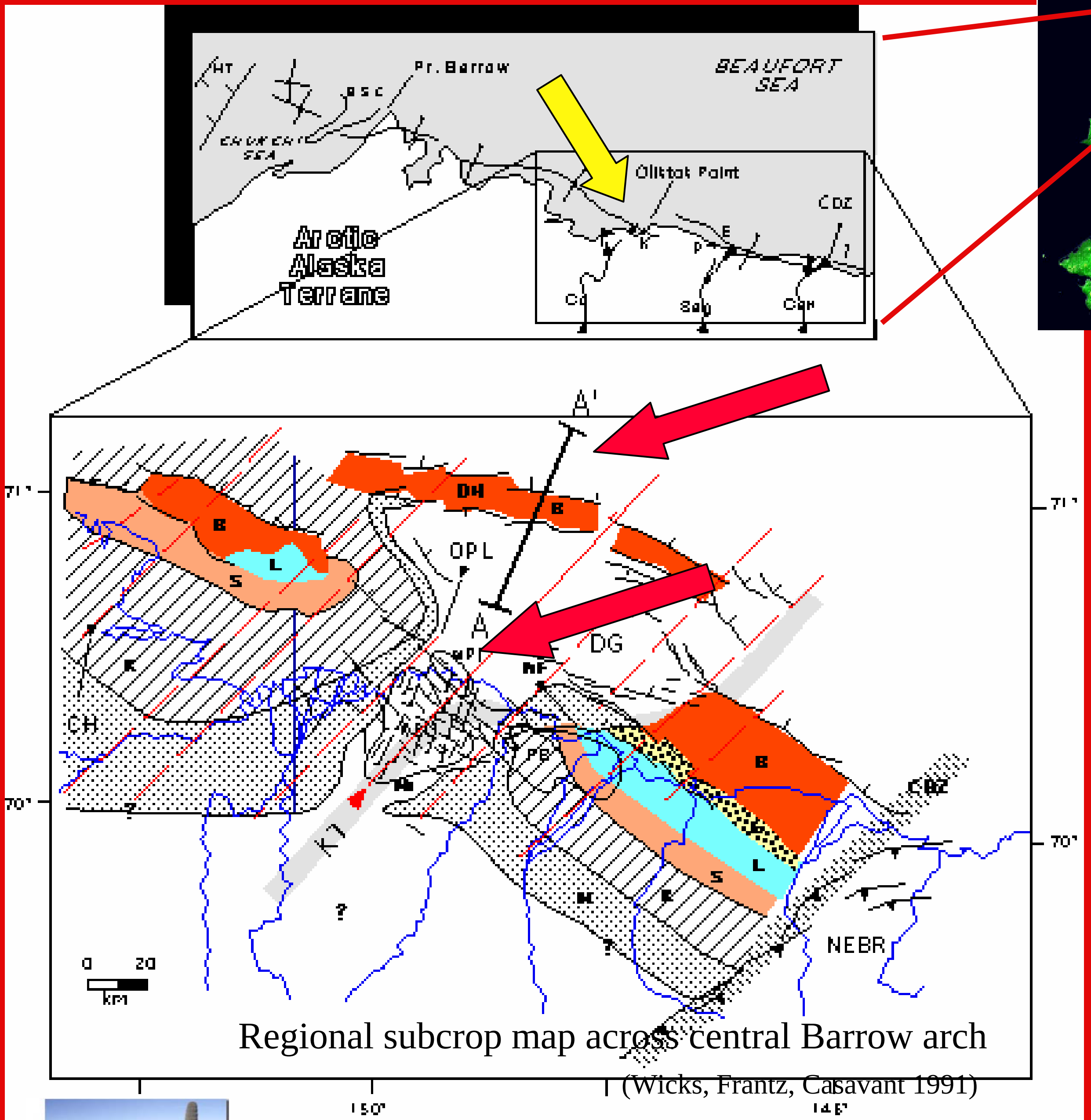
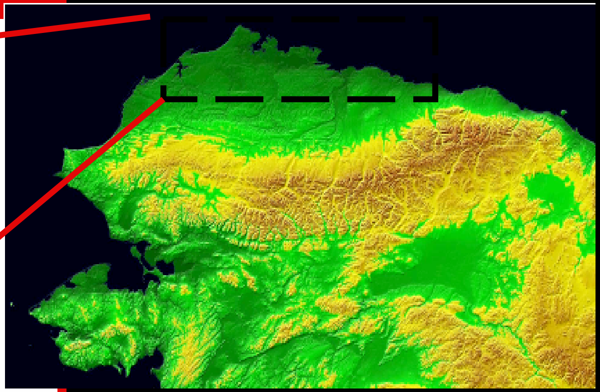


Regional subcrop map across central Barrow arch
(Wicks, Frantz, Casavant 1991)



AOI located along major rift margin discontinuity

Northern tip of major transcurrent FZ that segments foreland basin and fold-thrust belt to south (Casavant, 2001)

Basement blocks at variety of scales are differentially uplifted, rotated, translated indicating that arch is faulted rather than just a jog

Long-lived depocenter

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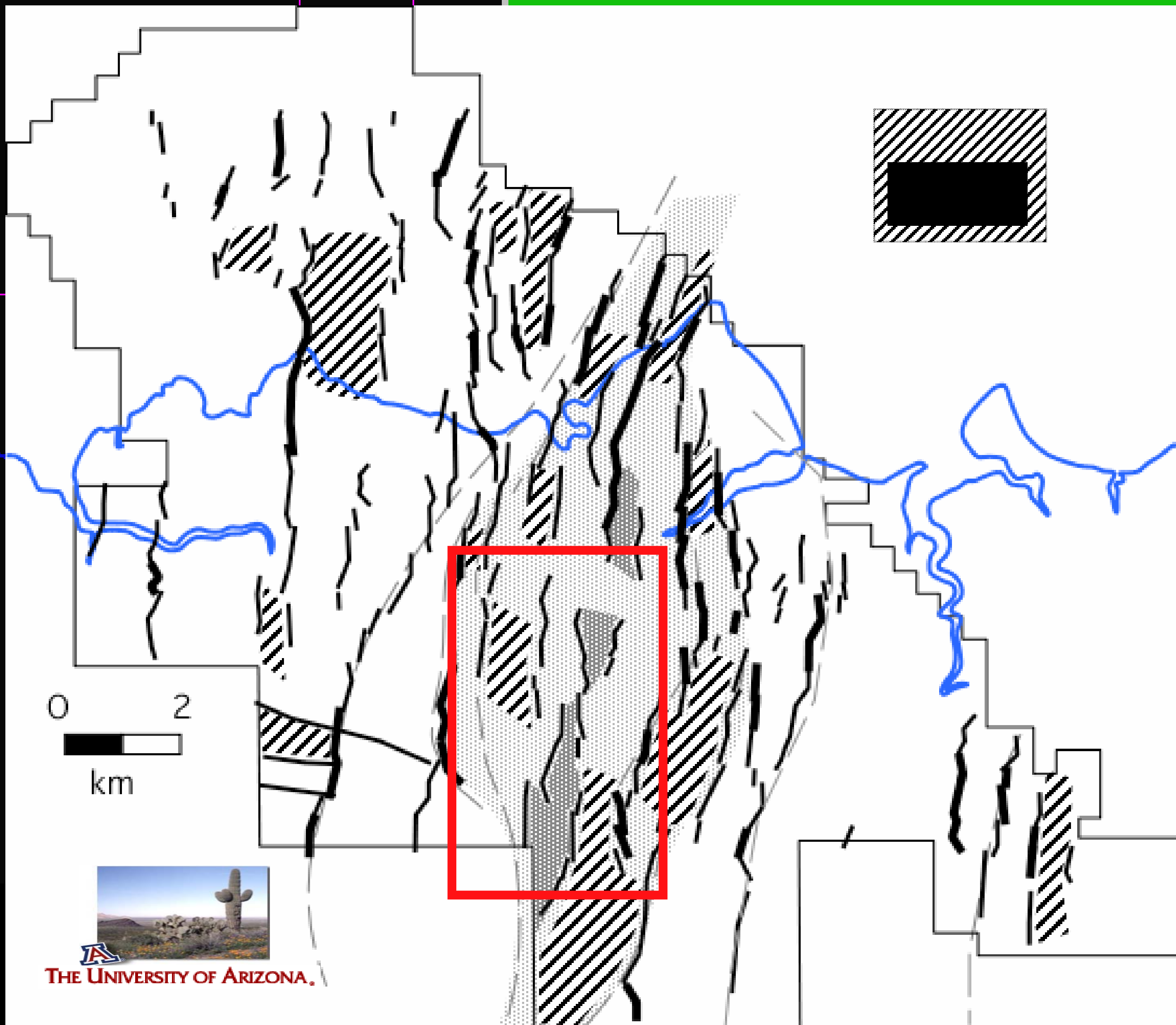
Seismic structure (mkr 34)

- ~USGS “C” pay unit

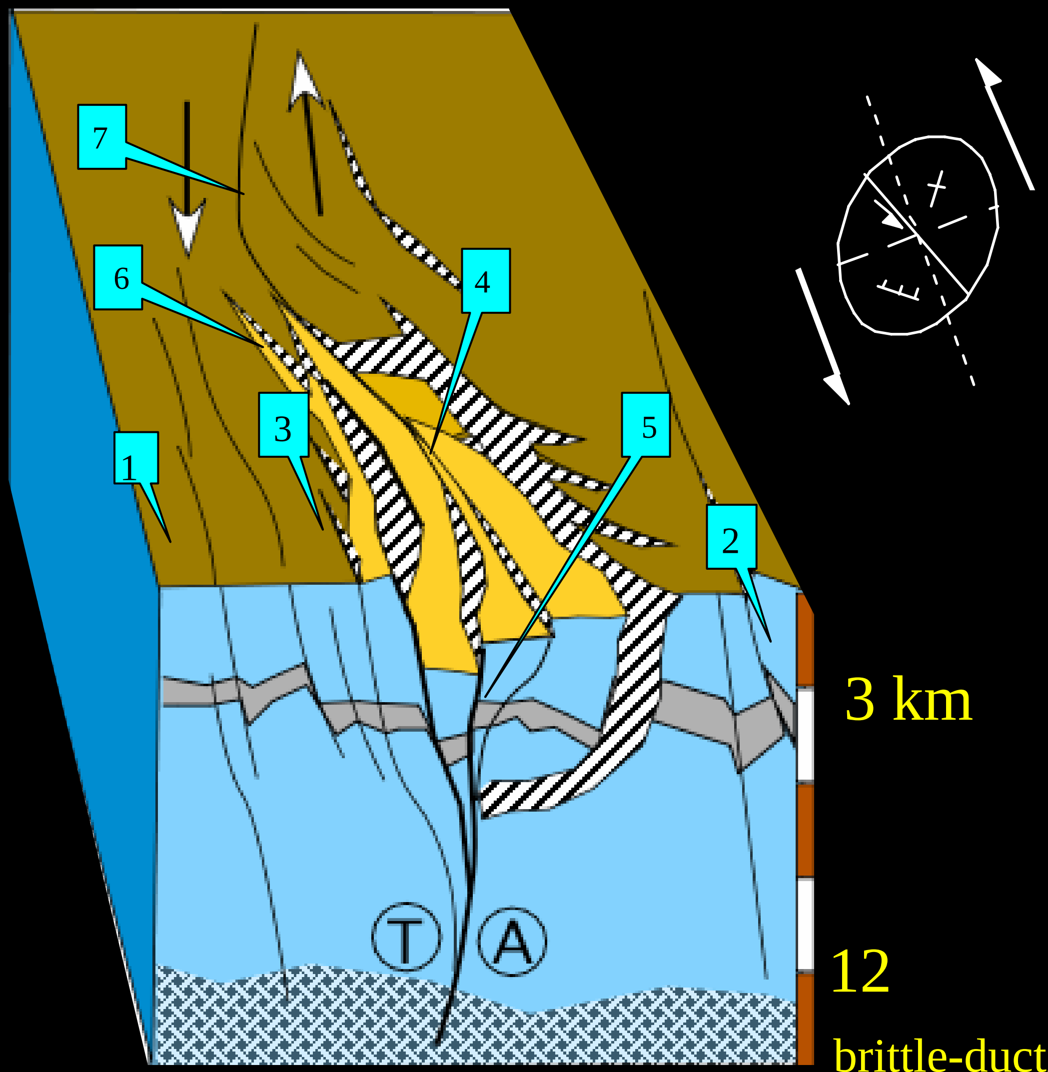


Hagbo, ‘03

north

Idealized pull-apart basin attributes from analog modeling

1. Inactive borderland structures
2. Oblique-reverse fault
3. Terraced sidewall fault zone
4. Cross-basin fault zone
5. Negative flower structure
6. Relay ramp
7. PDZ in-line graben/push-ups



"East Basin" MPU (schematic)

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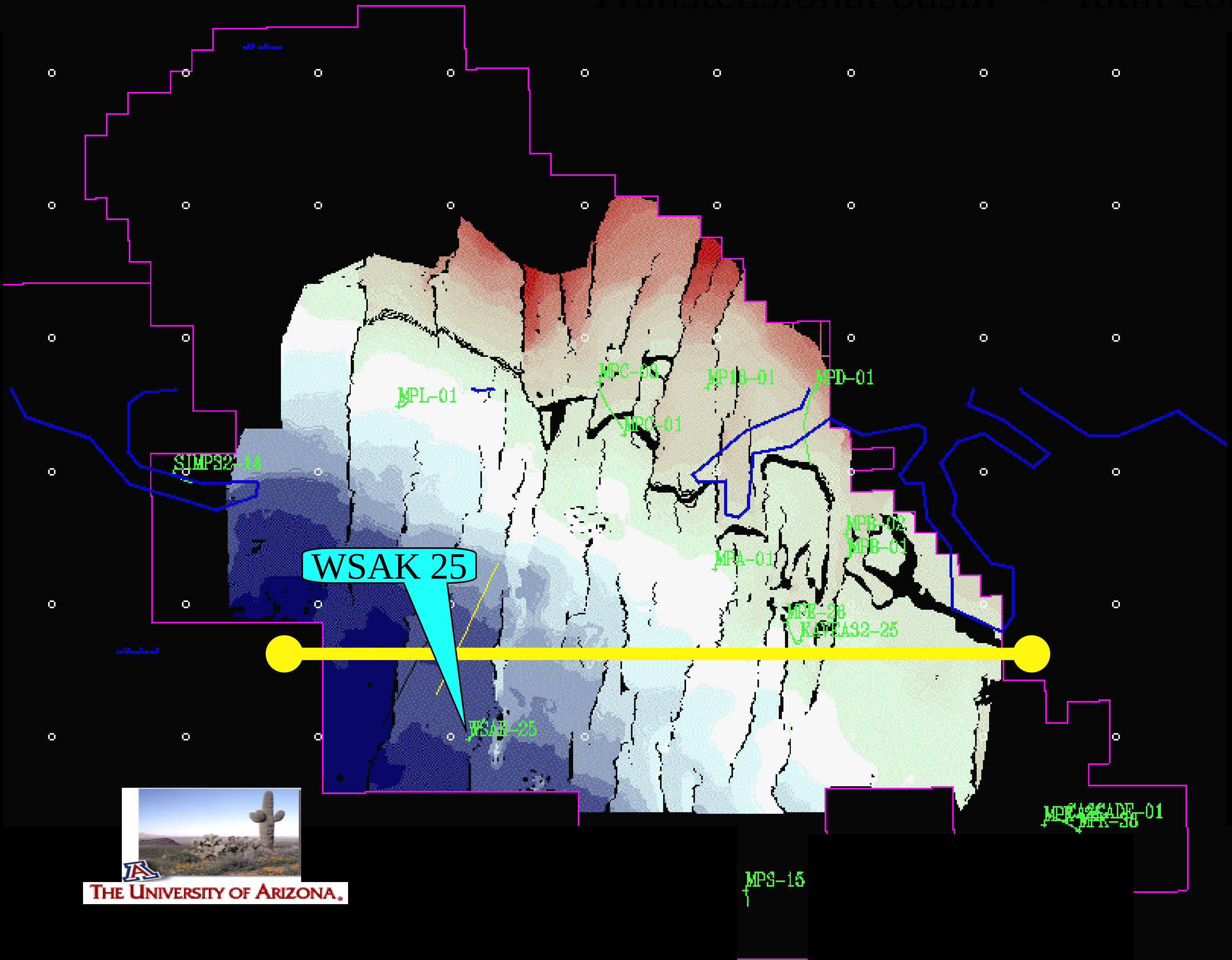
Transtensional basin => fault complexity



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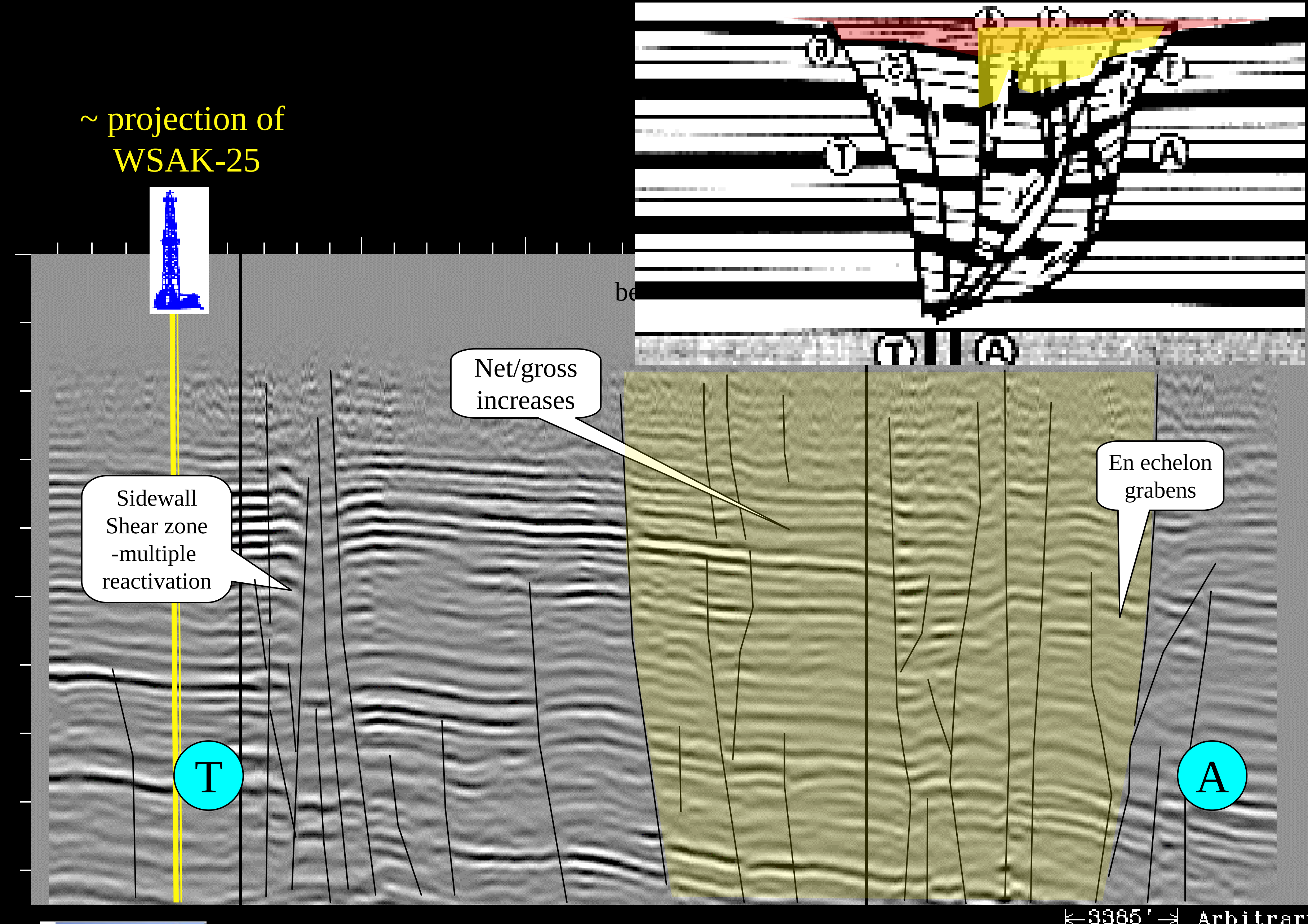
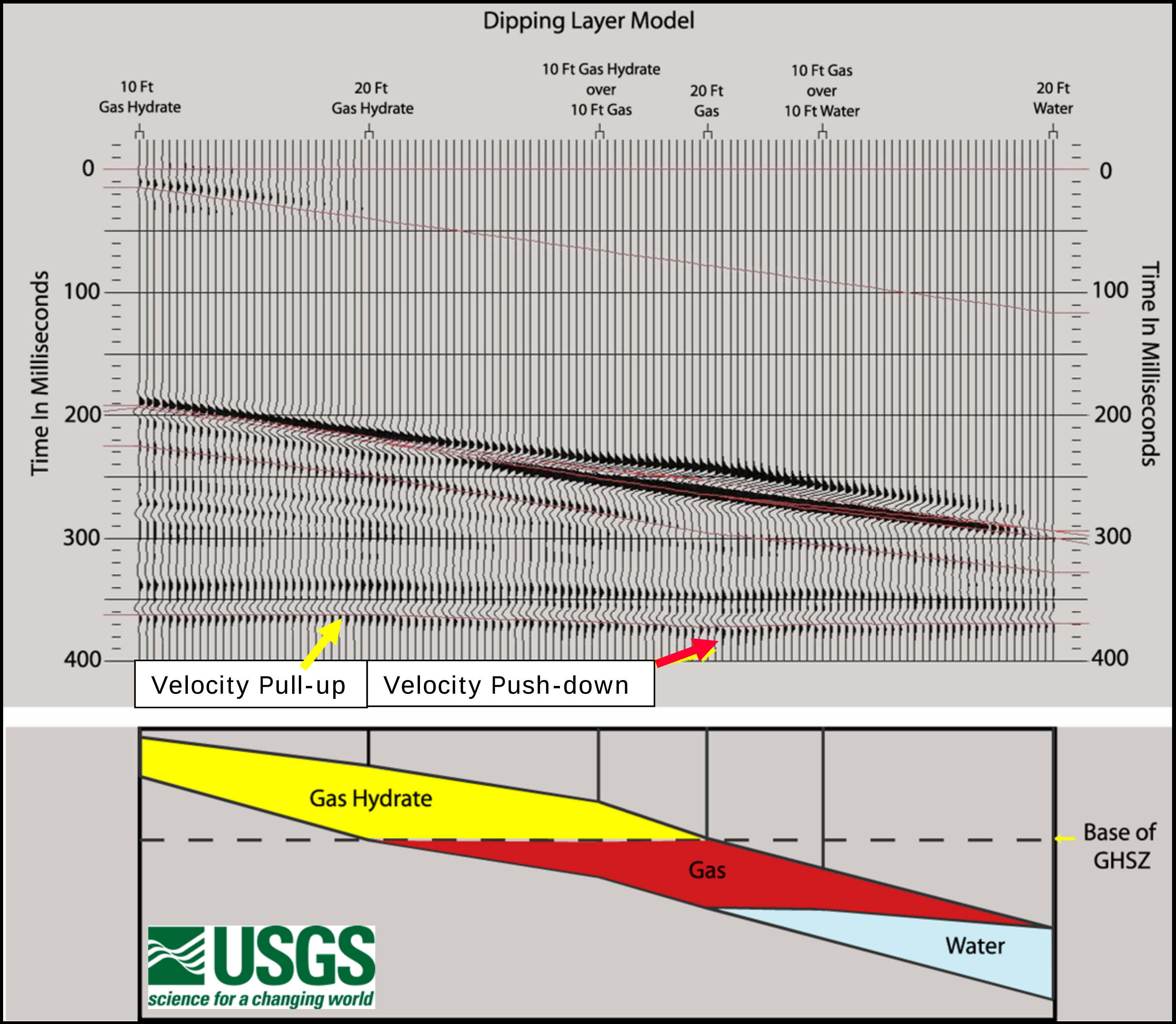
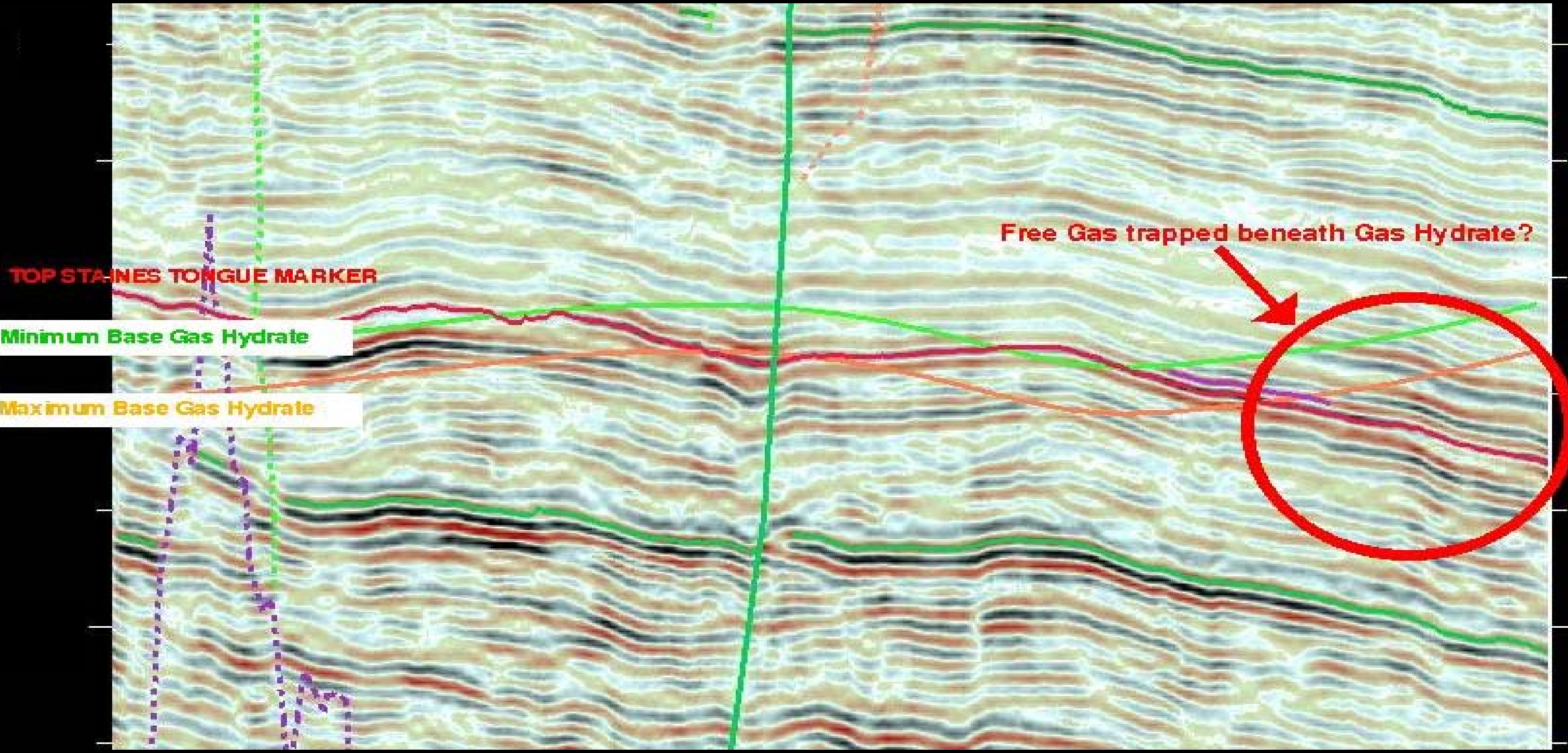

~ projection of
WSAK-25
Net/gross
increases
Sidewall
Shear zone
-multiple
reactivation
En echelon
grabens
T
A
|←3385'→| Arbitrary

Seismic Modeling and Velocities

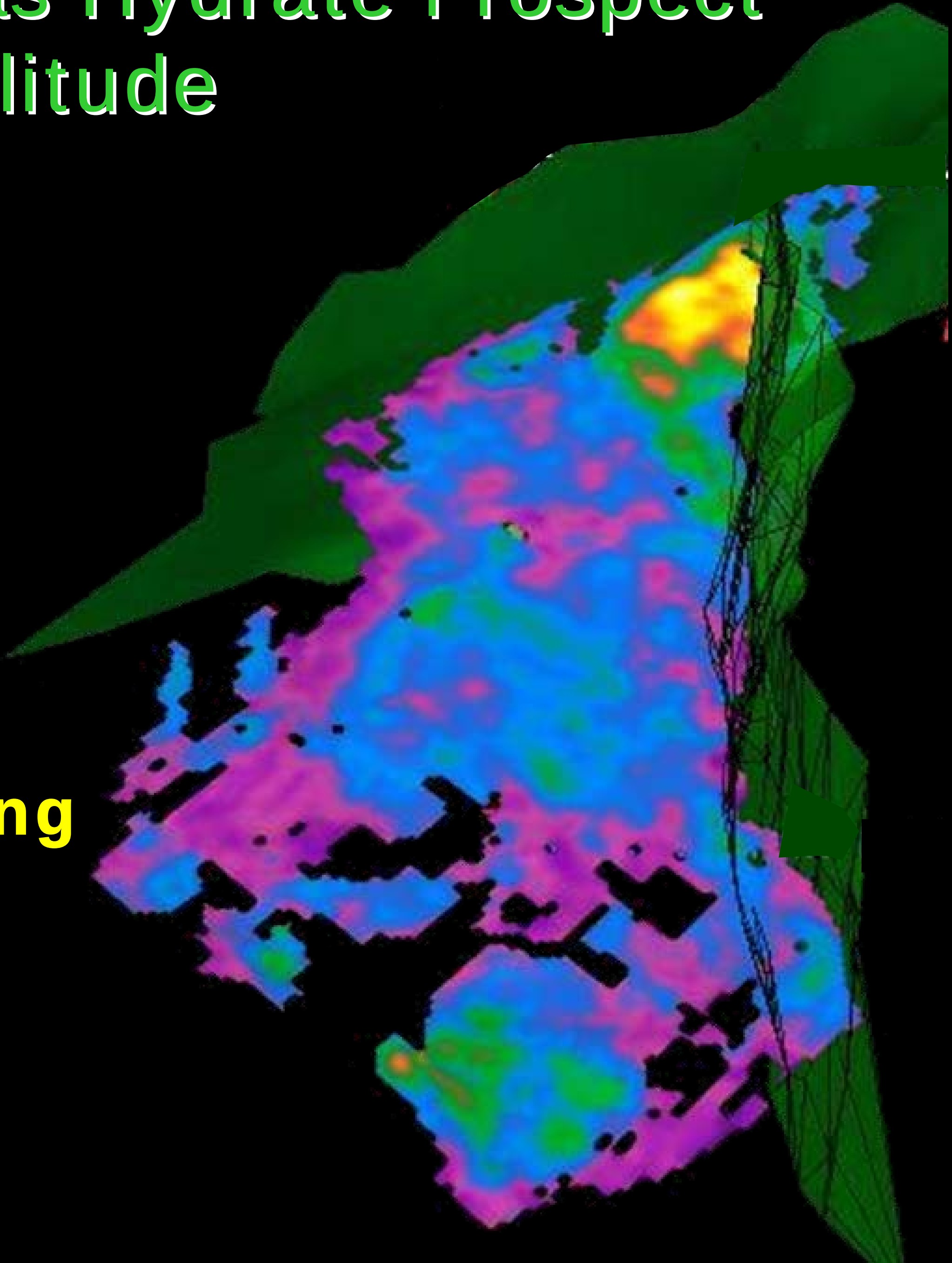


Seismic Amplitude Assessment



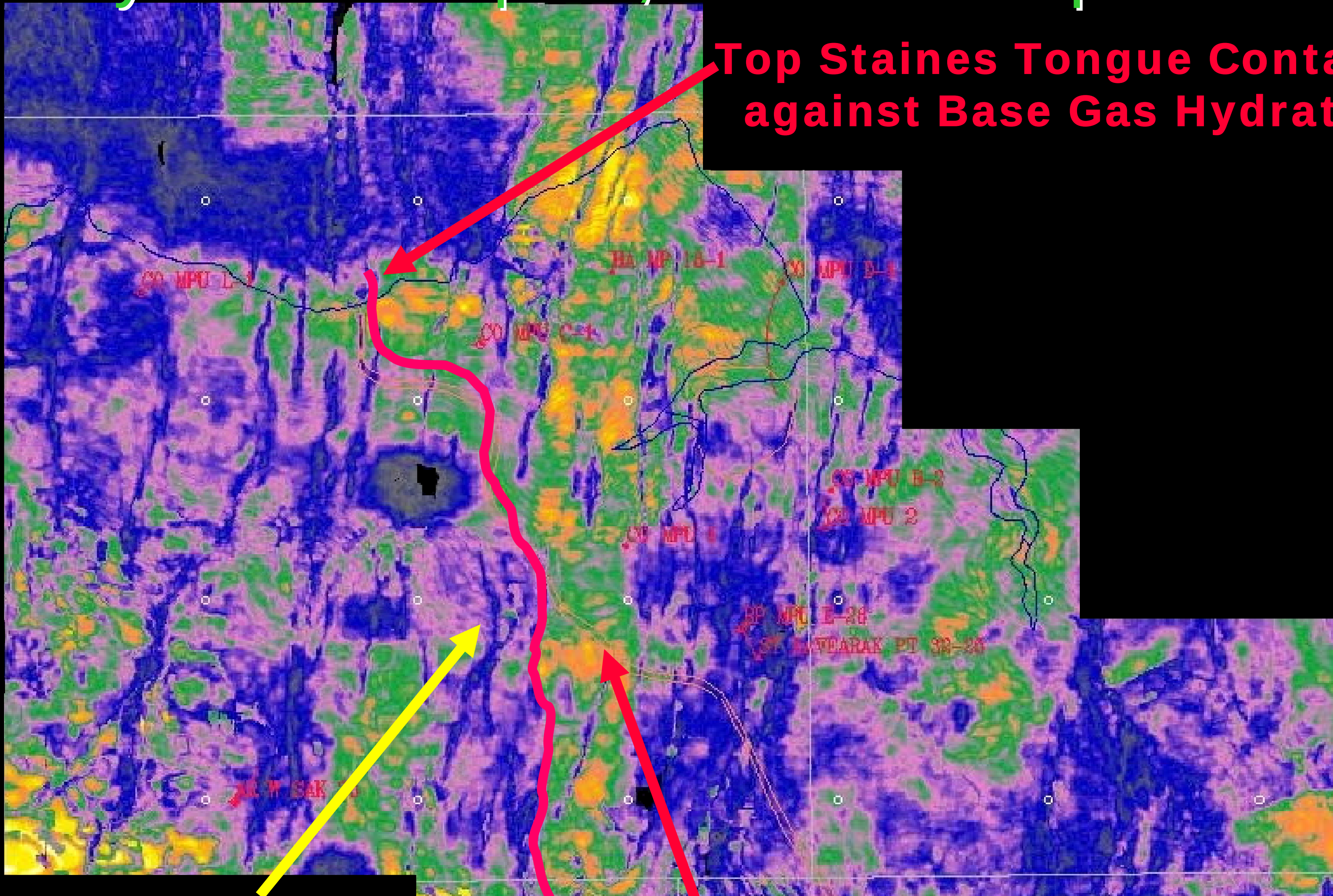
Mt. Elbert Gas Hydrate Prospect
Seismic Amplitude

3-way Fault-bounded Trap, Gas Hydrate-bearing Reservoir



USGS science for a changing world

Gas Hydrate Prospect, Seismic Amplitude



USGS
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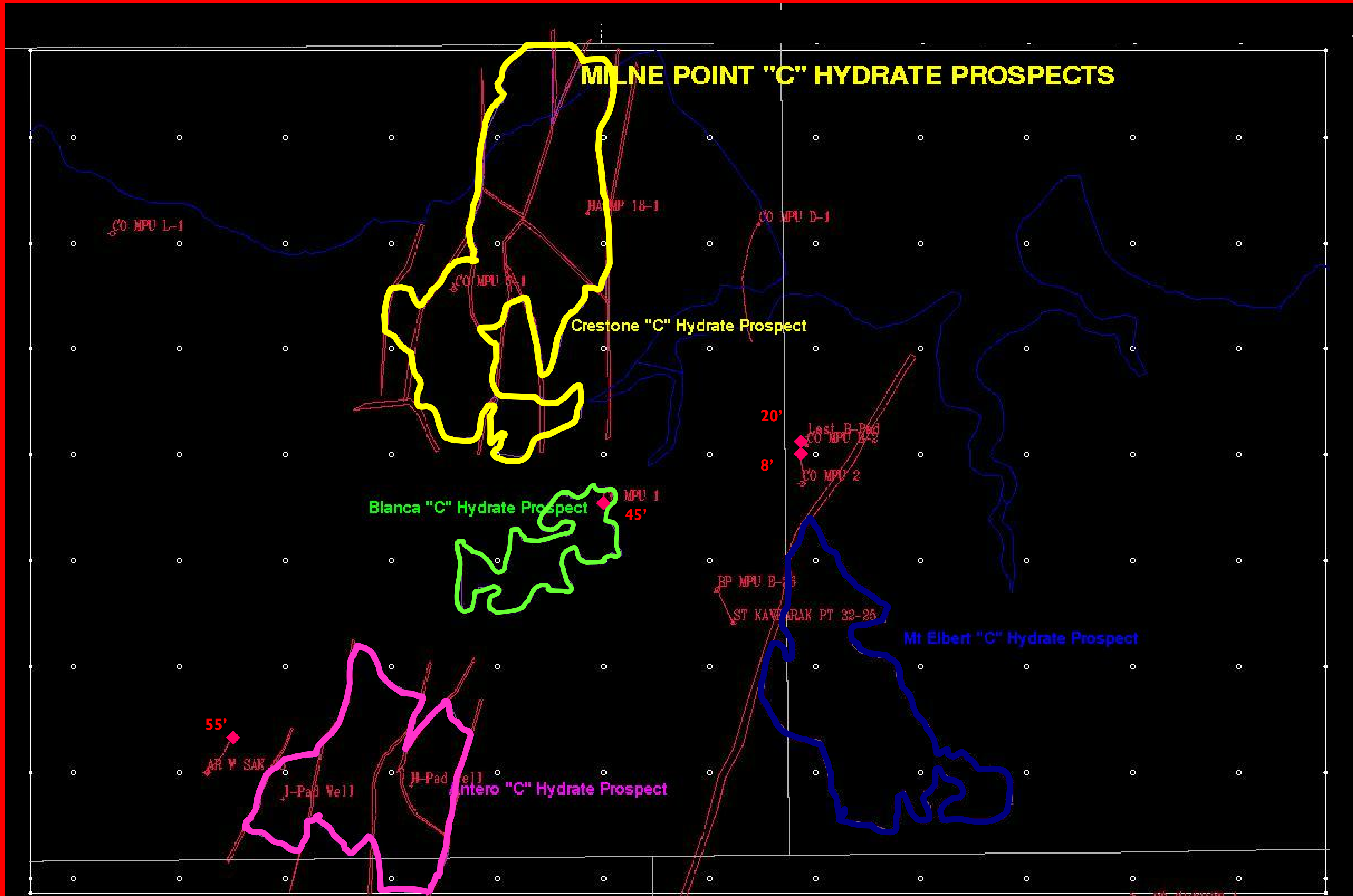
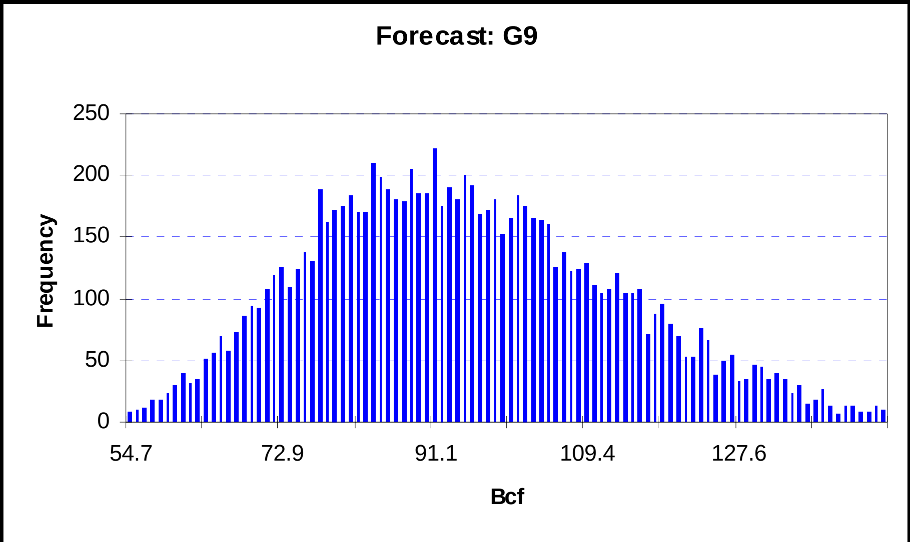
Gas Hydrate Prospects, USGS C Horizon



Wells with “C” Hydrate, 1993 Study (AAPG), T. Collett

Gas Hydrate Prospect Uncertainty Analyses



Crystal Ball Report
Simulation started on 8/30/04 at 12:02:55
Simulation stopped on 8/30/04 at 12:04:37

Forecast: G9 **Cell: G9**

Summary:
- Display Range is from 54.3 to 145.3 Bcf
- Entire Range is from 50.3 to 168.2 Bcf
- After 10,000 Trials, the Std. Error of the Mean is 0.2

Statistics:	Value
Trials	10000
Mean	94.9
Median	93.3
Mode	---
Standard Deviation	18.4
Variance	338.7
Skewness	0.40
Kurtosis	2.88
Coeff. of Variability	0.19
Range Minimum	50.3
Range Maximum	168.2
Range Width	117.9
Mean Std. Error	0.18

BULK ROCK VOLUME

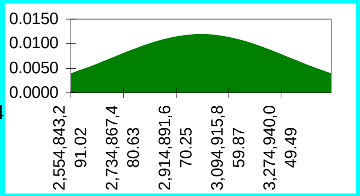
Assumptions

Assumption: Elbert C **Cell: G2**

Normal distribution with parameters:

Mean	3,000,403,160.32
Standard Dev.	300,040,316.03

Selected range is from 2,550,342,686.27 to 3,450,4



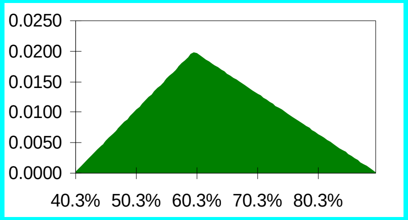
SATURATION

Assumption: G5 **Cell: G**

Triangular distribution with parameters:

Minimum	40.0%
Likeliest	59.7%
Maximum	90.0%

Selected range is from 40.0% to 90.0%



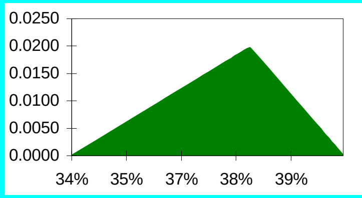
POROSITY

Assumption: G3 **Cell: G3**

Triangular distribution with parameters:

Minimum	34%
Likeliest	38%
Maximum	40%

Selected range is from 34% to 40%



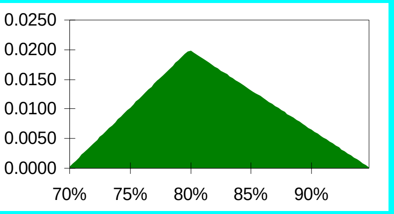
NET-TO-GROSS

Assumption: G4 **Cell: G**

Triangular distribution with parameters:

Minimum	70%
Likeliest	80%
Maximum	95%

Selected range is from 70% to 95%



MPU HYDRATE PROSPECTS VOLUMETRICS

	Antero C	Bierstadt D	Bierstadt E	Blanca C	Crestone C	Elbert C	Elbert D	Grays Peak B
GRV (cu ft)	2350045580	1119622596	1232193097	740796681	6349463797	3000403160	1761367545	203815727
Porosity	38%	38%	38%	38%	38%	38%	38%	38%
Net-to-Gross	80%	80%	80%	80%	80%	80%	80%	80%
Gas Saturation	66.1%	49.8%	66.9%	55.1%	49.8%	59.7%	52.6%	47.2%
1/Bg	164	164	164	164	164	164	164	164
Volume in Place cu ft)	**77.4**	**27.8**	**41.1**	**20.4**	**157.6**	**89.3**	**46.2**	**4.8**

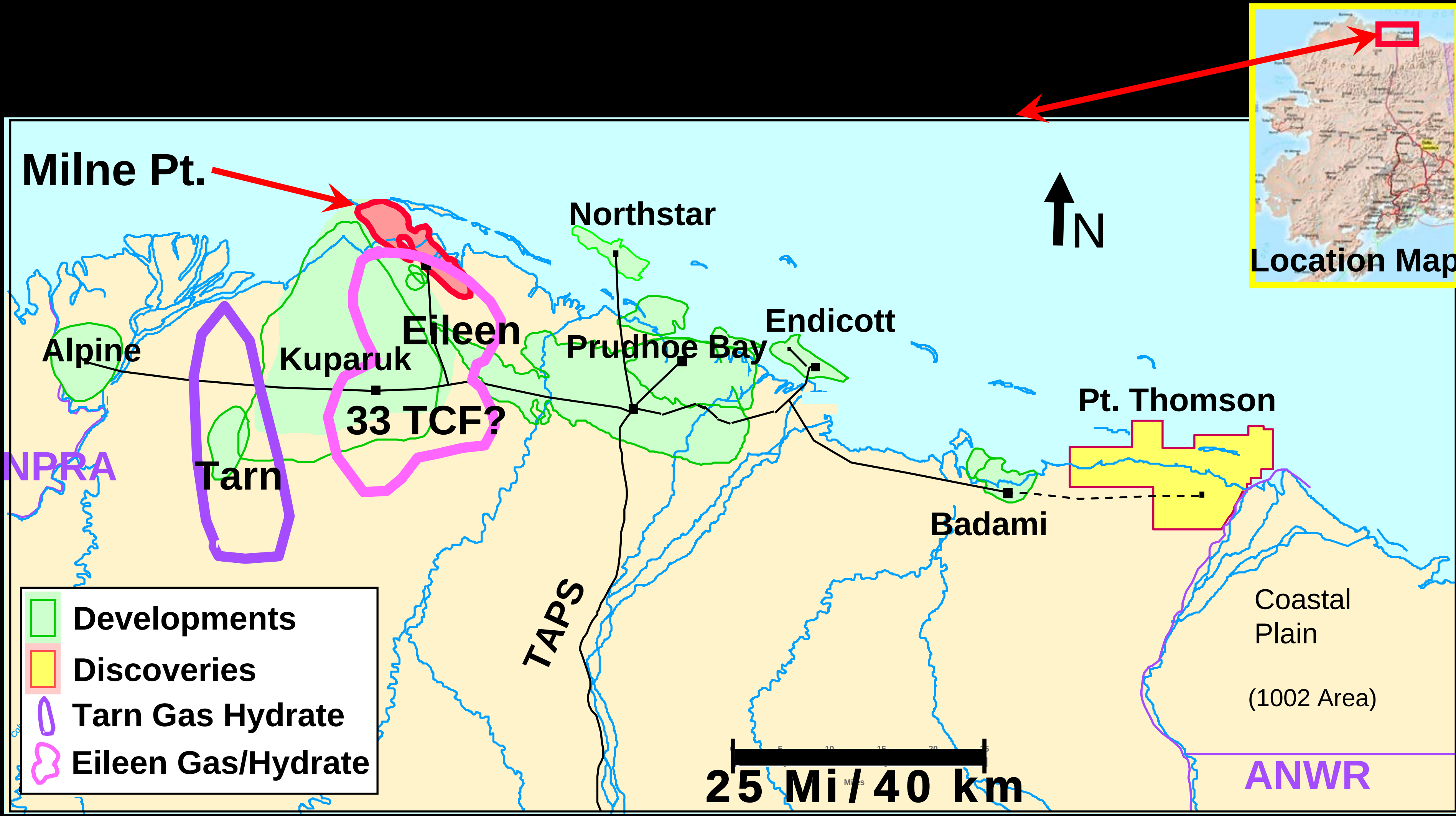
	Maroon Peak A	Mt Princeton D	Pikes Peak B	Red Cloud B	Sneffels D	Uncompaghre Peak D
	927428988.1	1291844038	397708421.7	585518227.8	1516746825	390458860.9
	38%	38%	38%	38%	38%	38%
	80%	80%	80%	80%	80%	80%
	81.2%	53.2%	68.8%	58.1%	57.6%	49.3%
	164	164	164	164	164	164
	37.5	**34.3**	**13.6**	**17.0**	**43.6**	**9.6**

14 "Intra-Hydrate" Prospects

620 BCF Median Estimated Gas in Place

A Volumes (Bcf)	37.5
B Volumes (Bcf)	35.4
C Volumes (Bcf)	344.7
D Volumes (Bcf)	161.4
E Volumes (Bcf)	41.1
Volume	620.2

MPU Location within Eileen Trend



MPU Associated Free Gas VOLUMETRICS

	Long's Peak Middle	Mt Yale Upper	Kit Carson Upper	Maroon Peak Middle	Mt Shavano Middle	Mt Holy Cross Middle	Mt Holy Cross Upper
Area (acres)	796	400	576	380	255	1012	391
Gross Thickness (ft)	25	25	25	25	25	25	25
Porosity	36%	36%	36%	36%	36%	36%	36%
Net-to-Gross	80%	80%	80%	80%	80%	80%	80%
Gas Saturation	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%
1/Bg	108	108	108	108	108	108	108
Volume in Place Gas (billion cu ft)	**18.9**	**9.5**	**13.7**	**9.0**	**6.0**	**24.0**	**9.3**

Upper Volumes (Bcf)	**32.4**
Middle Volumes (Bcf)	**57.9**
Total Hydrate Volume	**90.3**

7 Prospects Totaling 90.3 BCF
Median Estimated Gas In Place

- Based on these prospect analyses and proximity to infrastructure, locations to acquire data would be chosen in collaboration with the resource owner

- We have developed a workflow that can be used for gas hydrate prospecting in other areas of the North Slope

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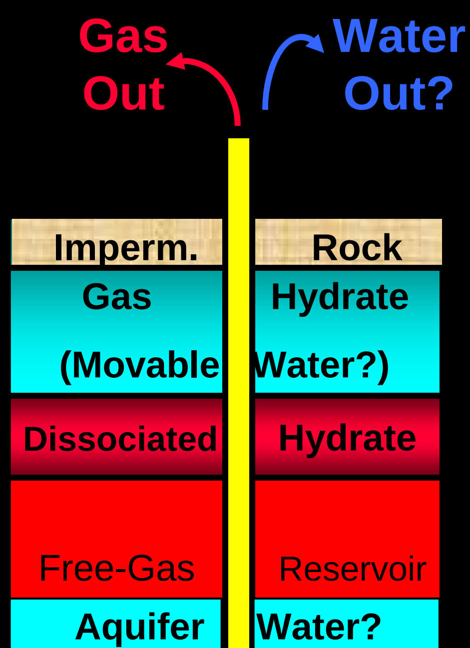
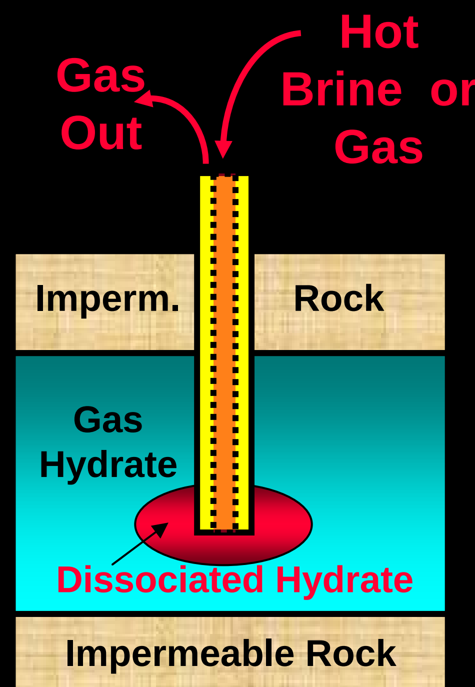
Productivity/Development Challenges
Gas Hydrate Production Methods

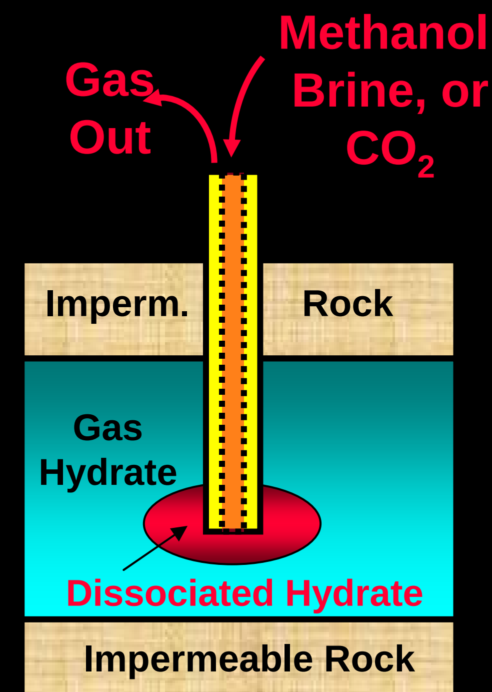
PRESSURE



TEMPERATURE



CHEMICAL



Modified
After Collett, 2000

- Endothermic Heat of Gas Dissociation
- Temperature Recovery Lag Time
- Hydrate Self-Preservation

- Large energy in
- Heat Host Rock
- In-situ combustion?
- In-situ Electromag?

- Methanol High cost
- PNNL Lab Tests CO_2
- Not Field-Tested
- Potassium Formate?

Proof-of-Principle CH4 → CO2

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

UAF UNIVERSITY OF ALASKA FAIRBANKS

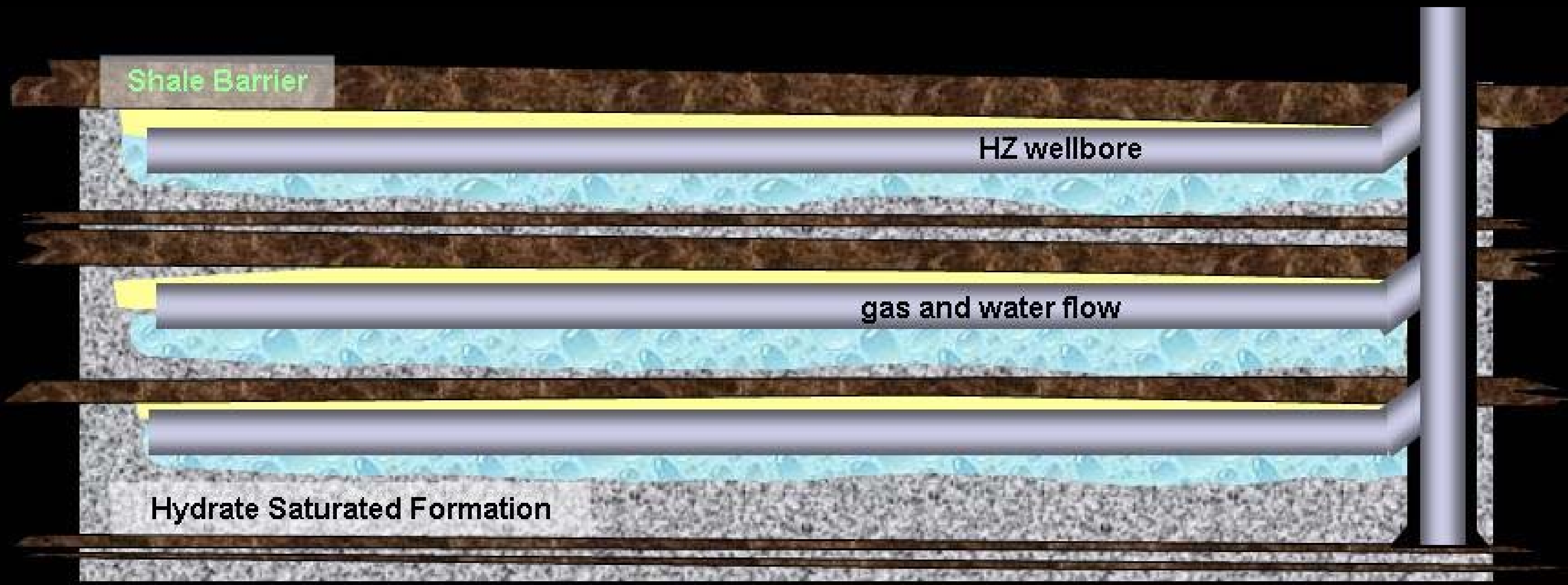
Theory: Inject CO_2 to Recover CH_4 from Gas Hydrate

- Thermodynamically Favorable
- Offsetting Dissociation Enthalpy: CO_2 Hydrate Formation Heat ~20% > CH_4 hydrate dissociation
- Sediment Mechanical Stabilization

Results: CH4 from Gas Hydrate by Injecting CO2

- Liquid- CO_2 Emulsion Best Method
- Temperature Reading Immediately Spiked from -2.5°C to 8°C
- Only Methane Gas Output
- Lab bench ------→ vs... Field Trial

Productivity/Development Challenges
Gas Hydrate Production Methods



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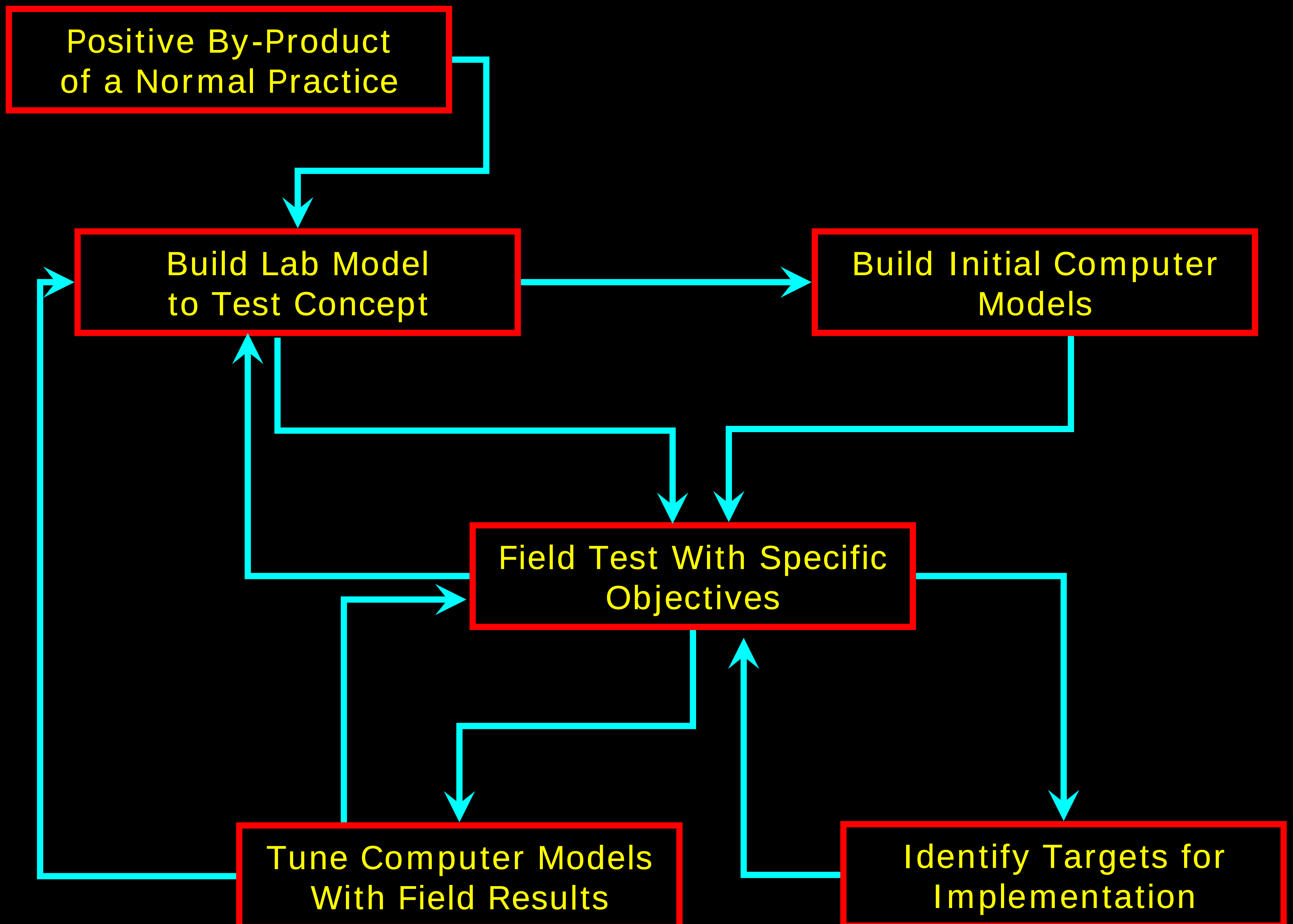
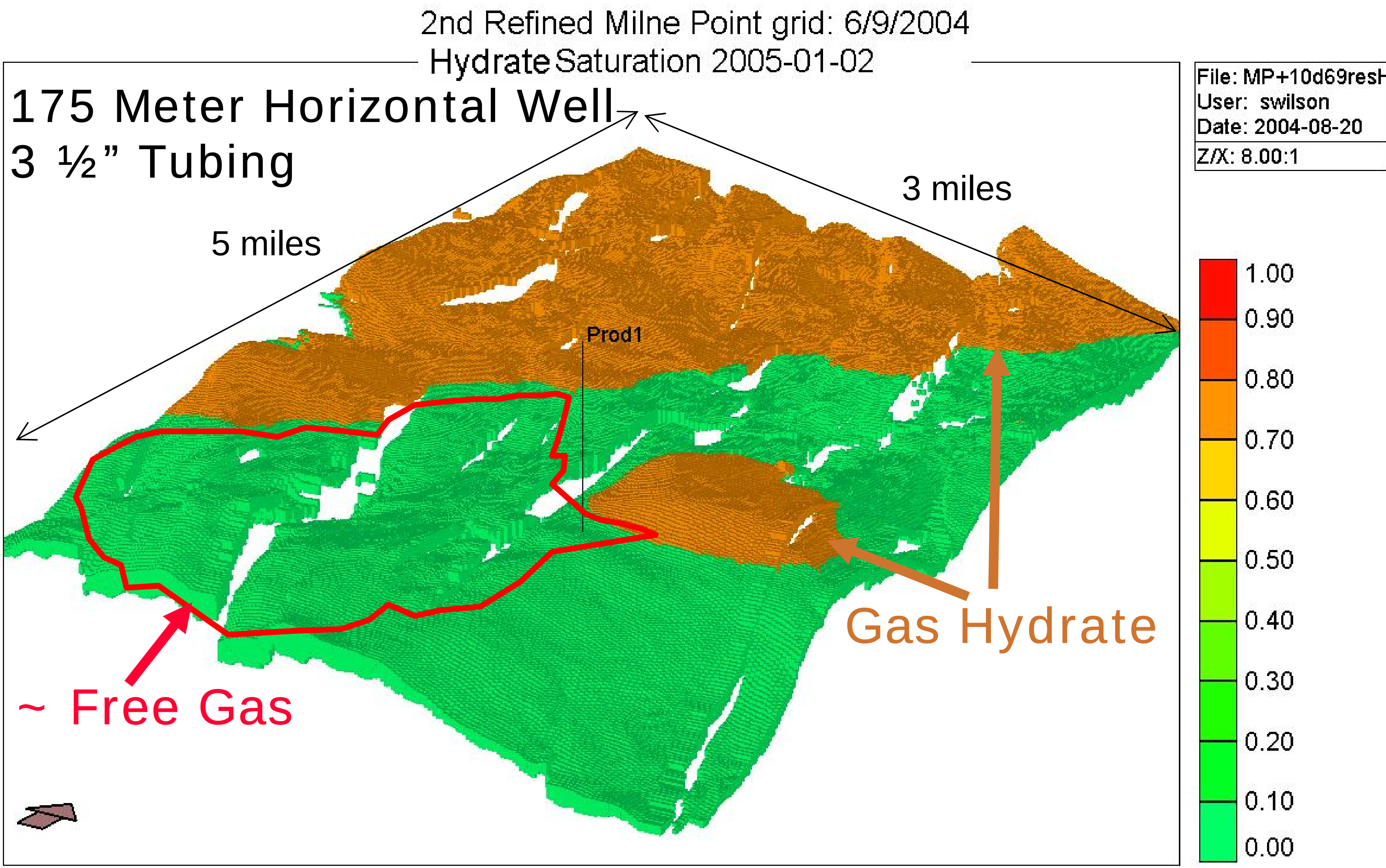
Reservoir Modeling Historical Perspective



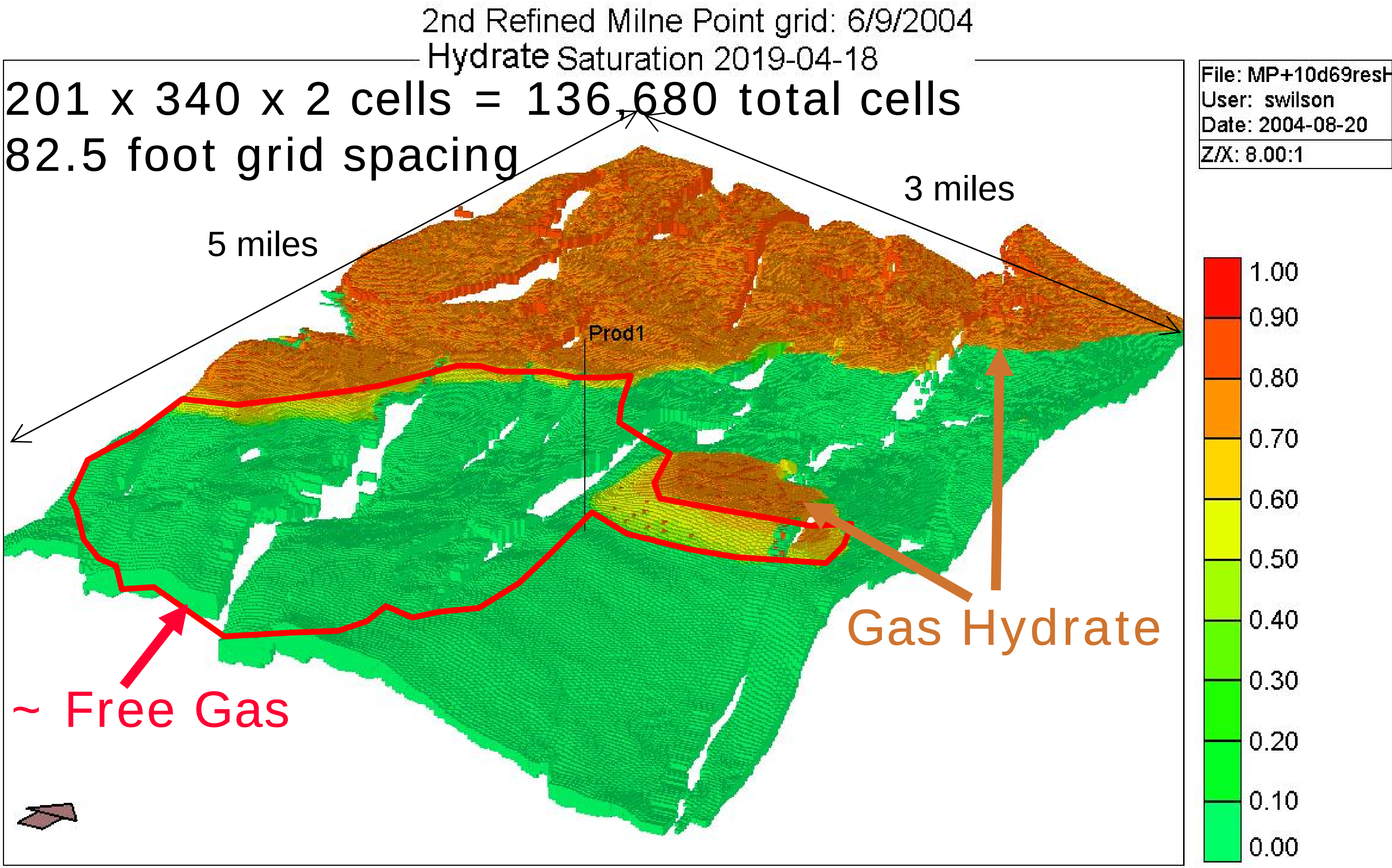
Reservoir Modeling

- Adapted Industry-Standard Reservoir Models to Gas Hydrate Phase-behavior
  - Used CMG-STARS and special inputs
  - Enabled Well/Field-scale modeling
- Developed Type-Well Cases/Ranges
  - Studied Pressure Response Variables
  - Evaluated Coalbed Methane Analog
  - Expanded to Full-Field Development

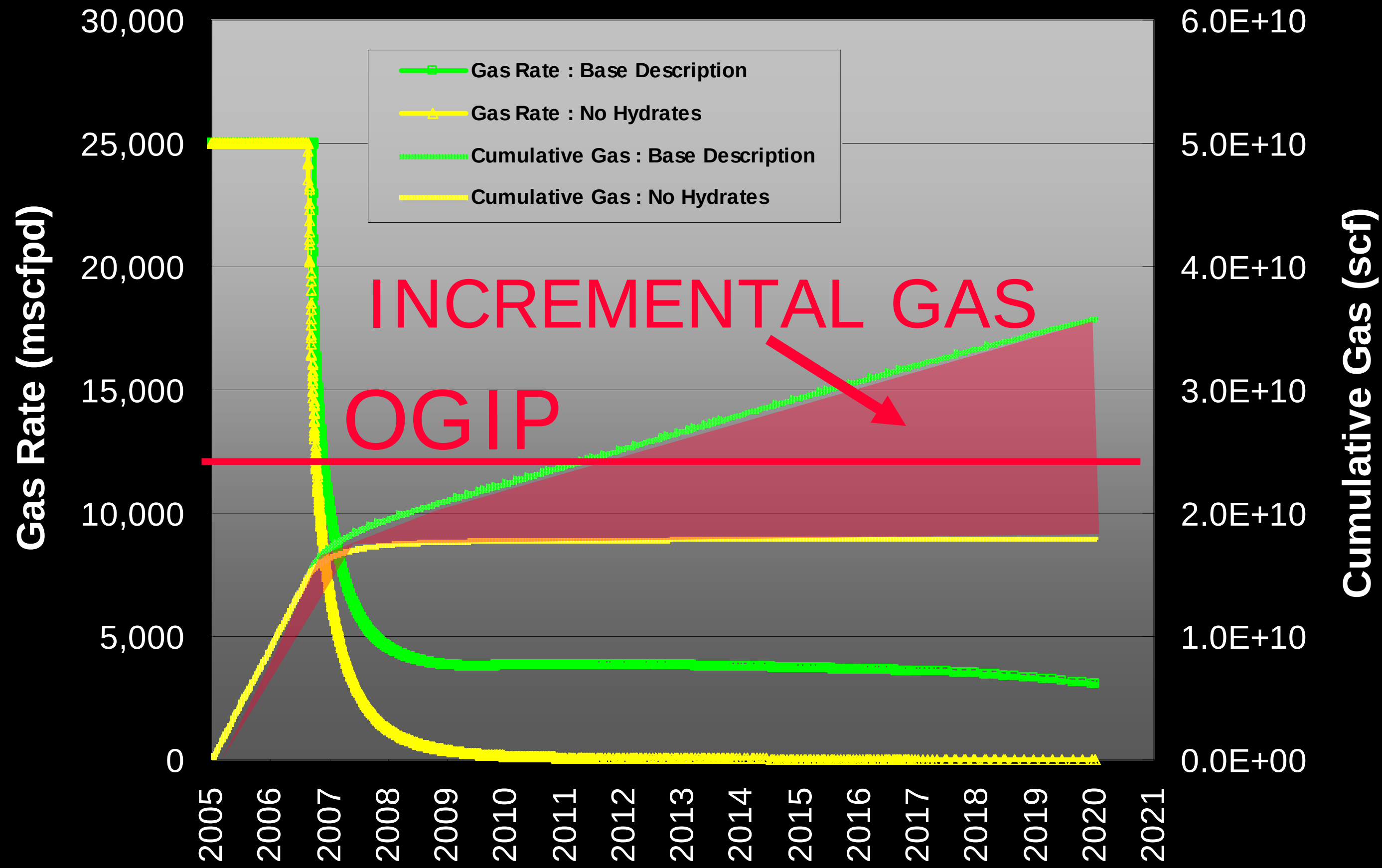
CMG STARS Reservoir Model Results
Gas Production & Gas Hydrate Dissociation



CMG STARS Reservoir Model Results
Gas Hydrate Dissociation after 15 years



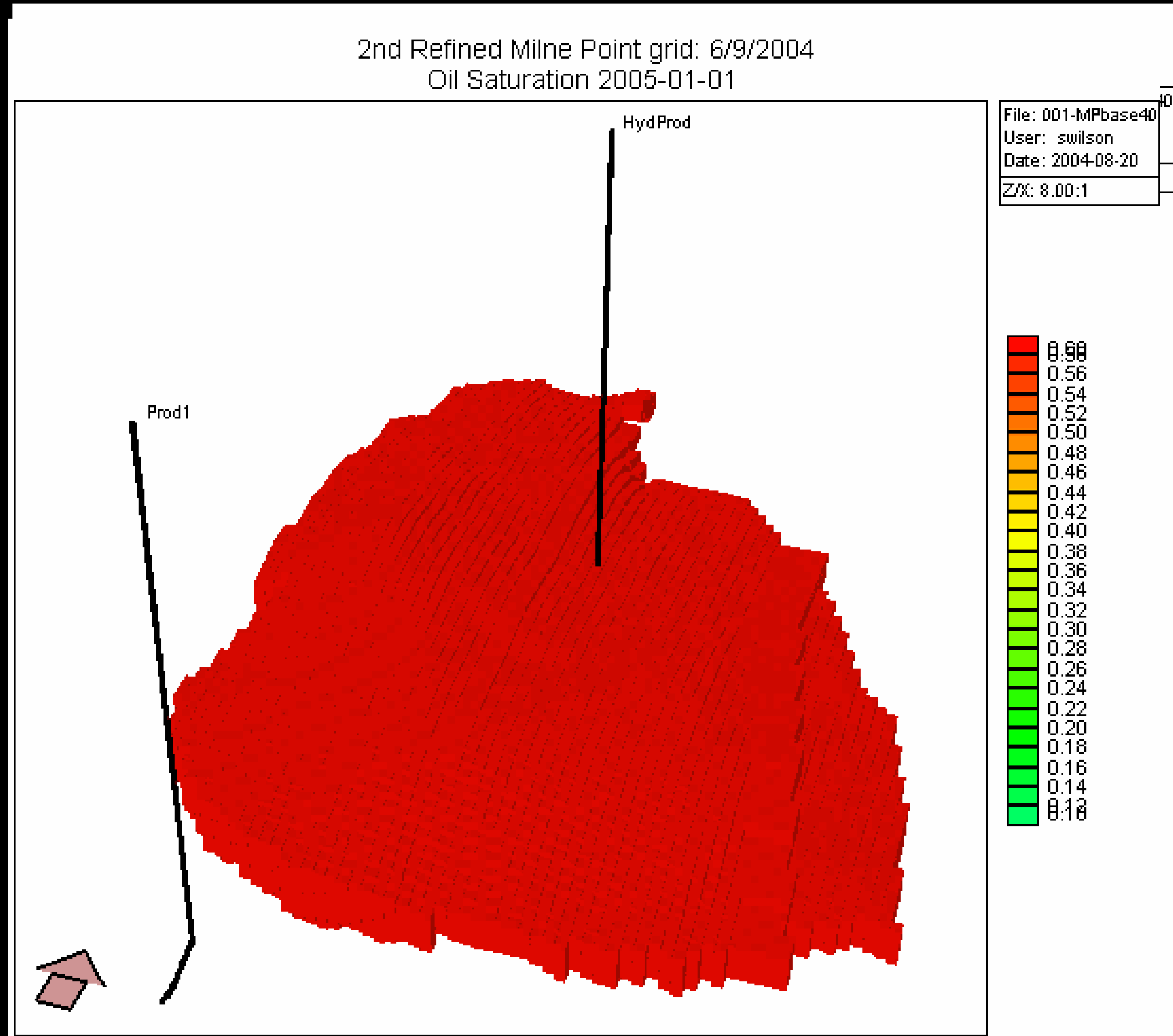
Reservoir Model: Depressurization Production Profile Comparison



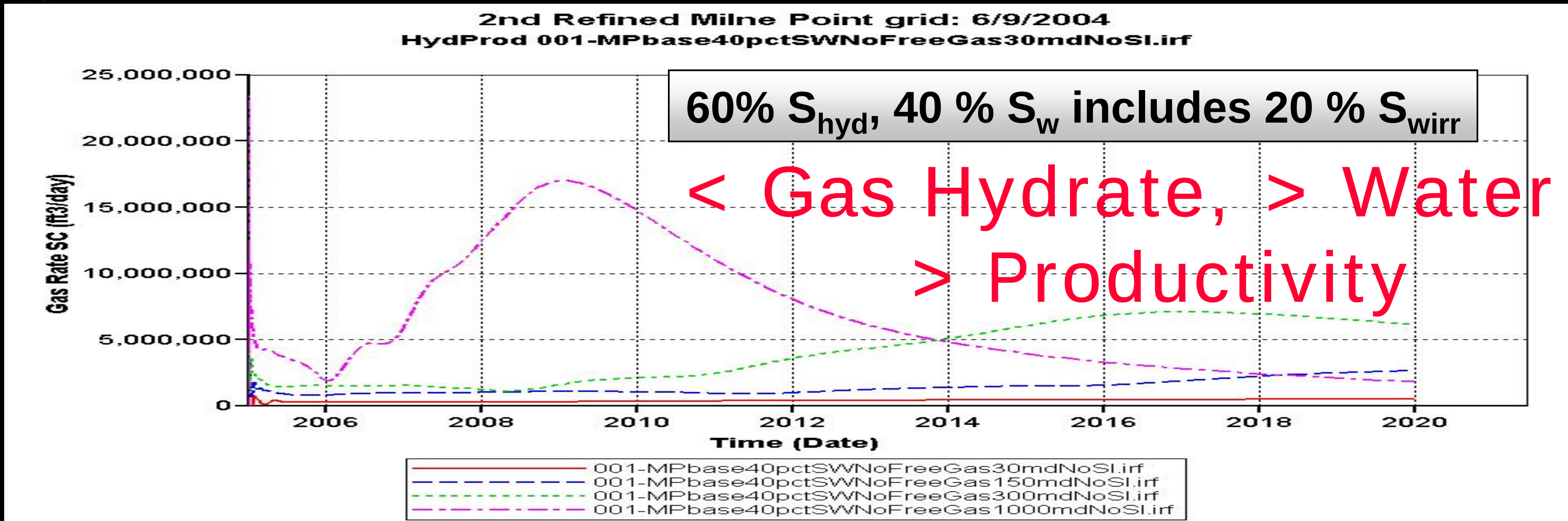
- Significant Production Increase (~2X) due to Free Gas Dissociation from Gas Hydrate
- Significant Uncertainties Remain

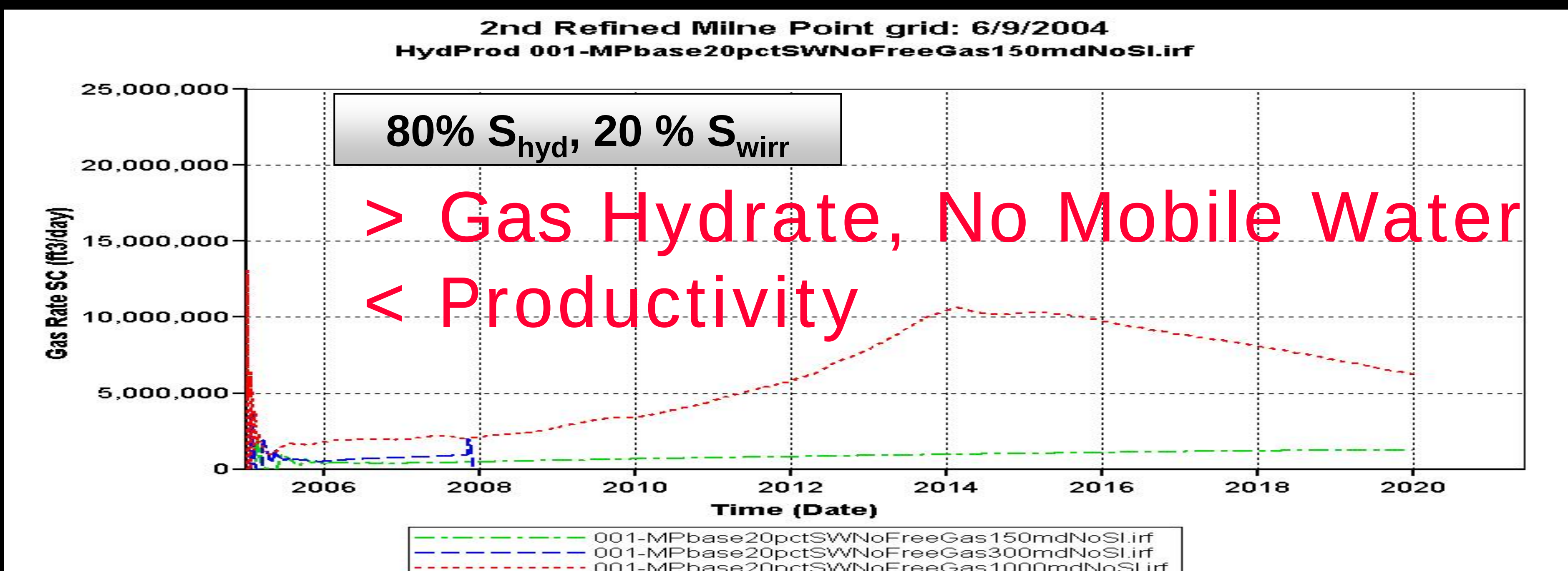
Intra-Hydrate Production Scenarios

- 40% initial S_w
- Well Placement in Hydrate zone
- Initial $S_w > S_{wirr}$

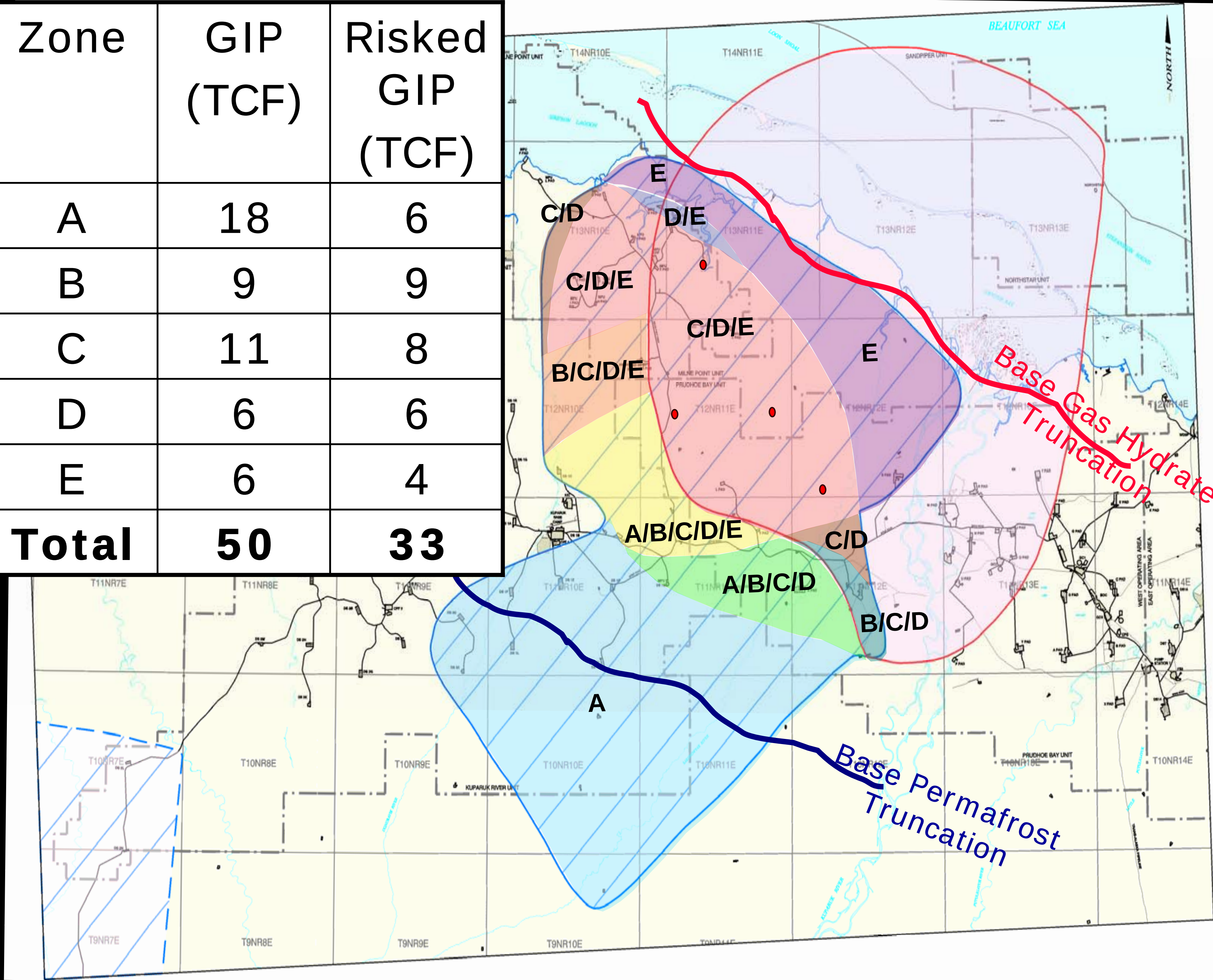


Intra-Hydrate Production Scenarios



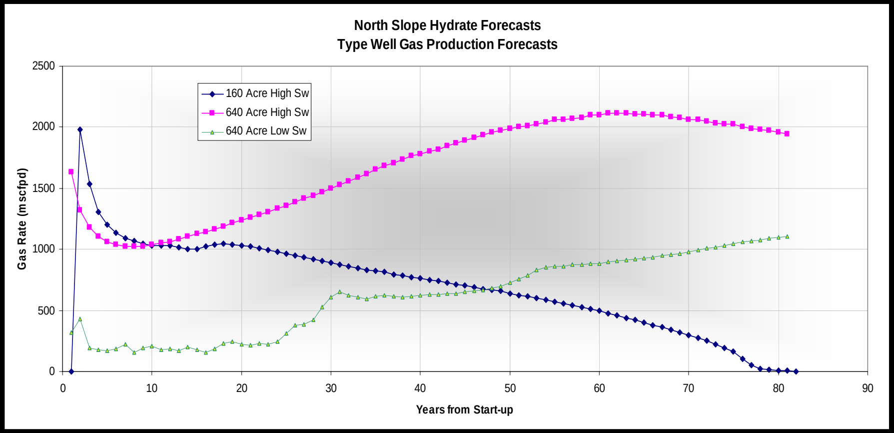


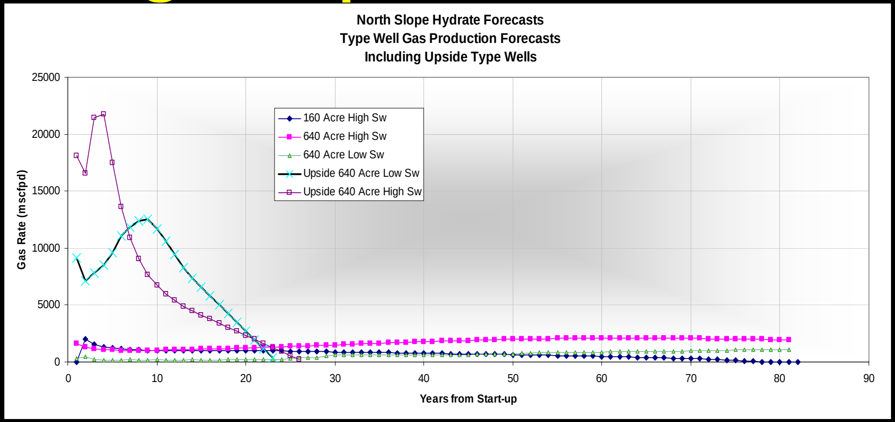
Zone	GIP (TCF)	Risked GIP (TCF)
A	18	6
B	9	9
C	11	8
D	6	6
E	6	4
Total	**50**	**33**

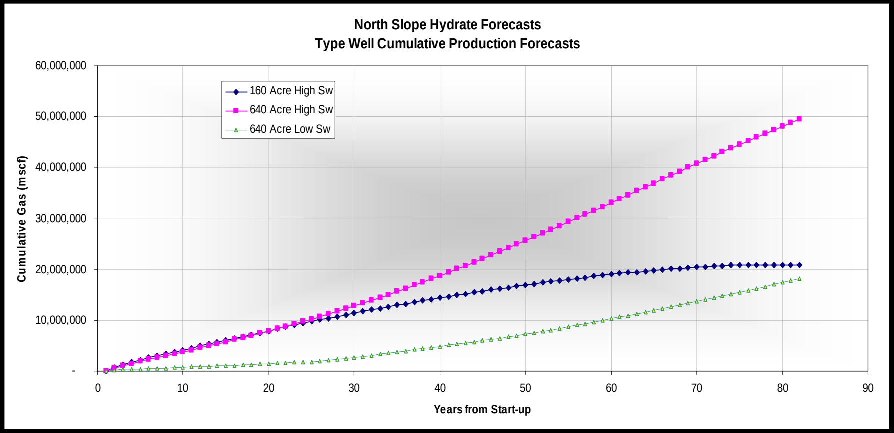


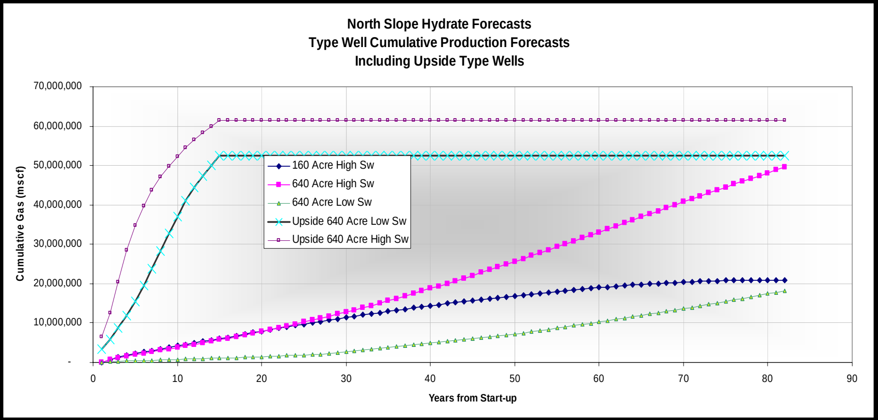
Type Wells

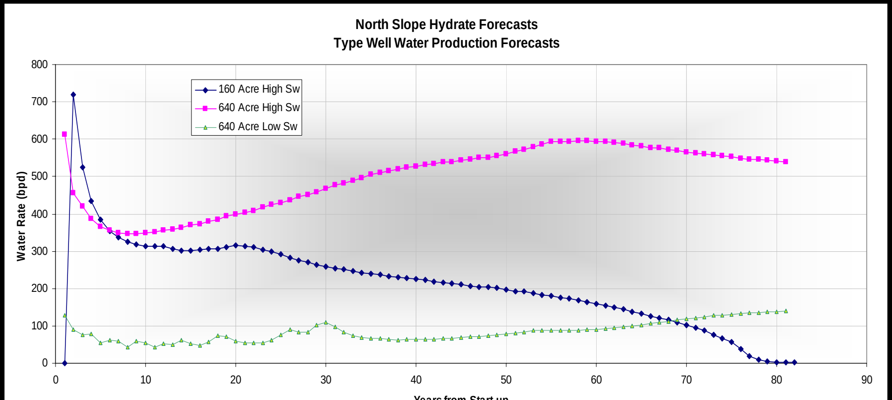
Reference Case | High Upside Case

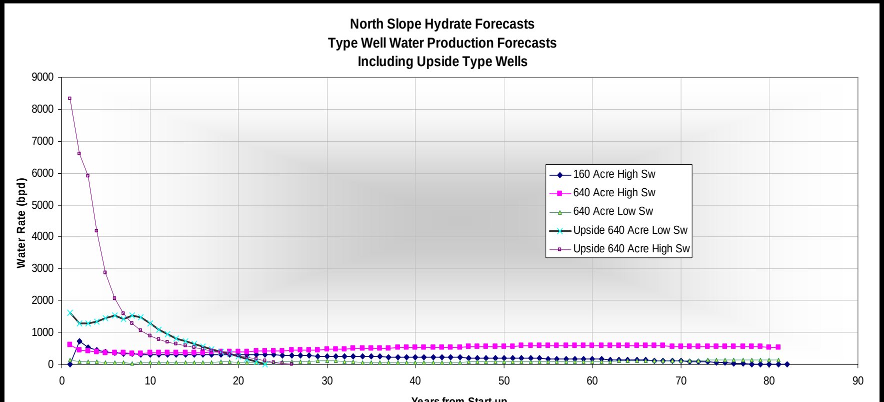




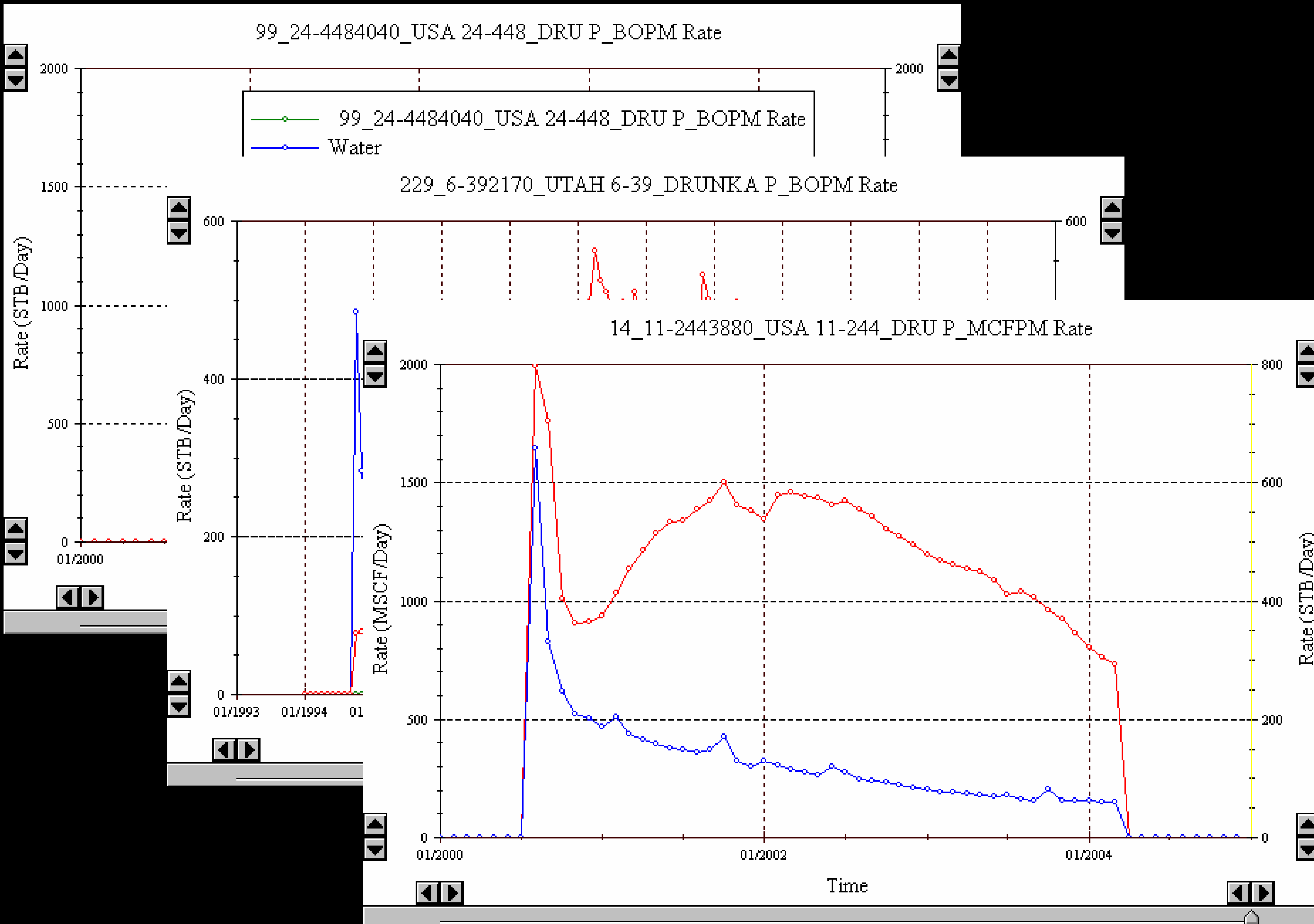








Coal Bed Methane Analog?



Development Modeling

- Predicted to follow historical patterns
- Initial positive results expanded to full-field

Stage 1: Initial Pilot Testing and Data Acquisition

Stage 2: Multi-well Pilot Testing and Calibration

Stage 3: Limited Initial Development

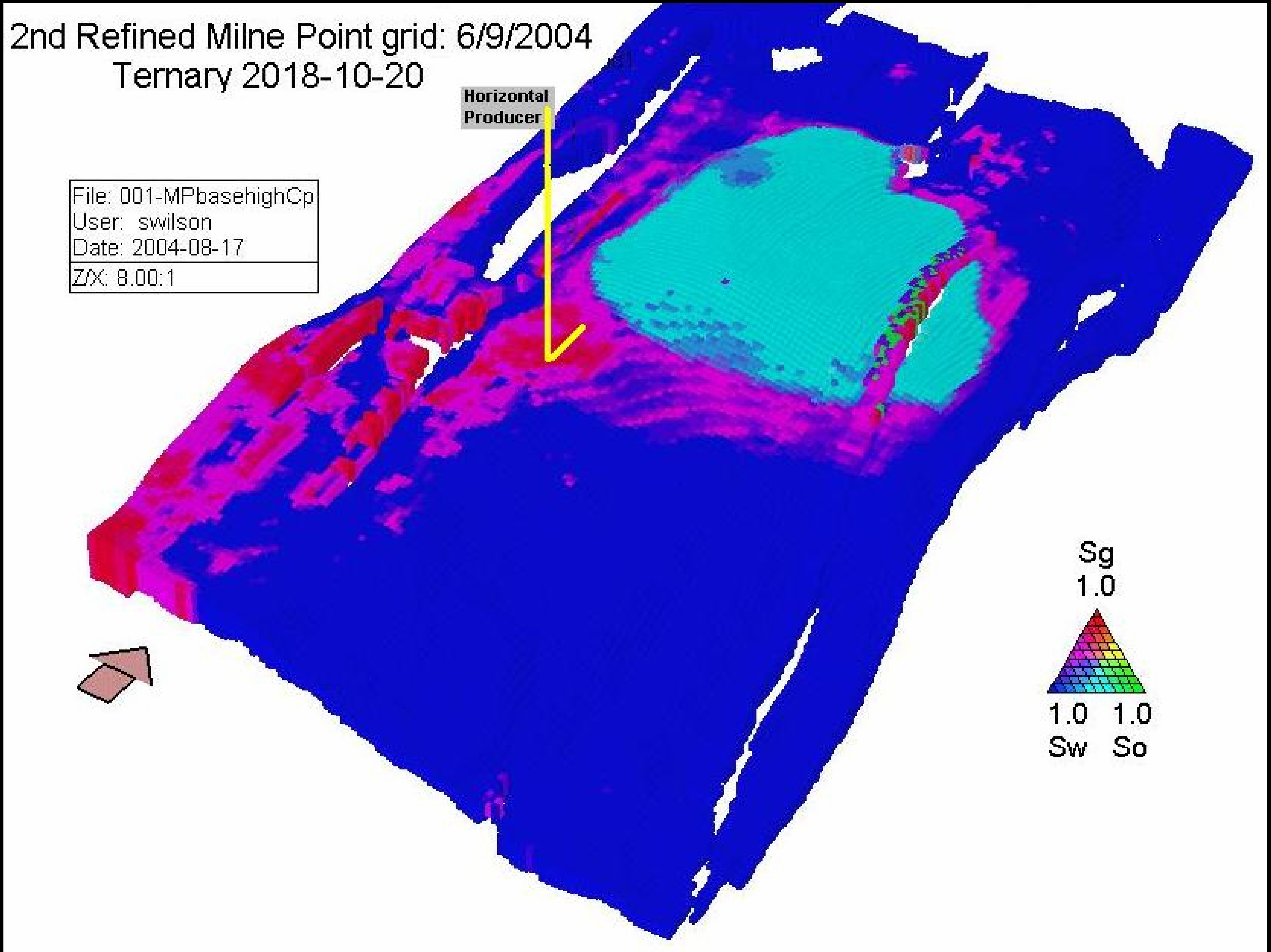
Stage 4: Full-Field Development

Stage 5: Resource Harvesting and Optimization

Stage 6: Manage and Expand Resource

Stage 7: New Technology / Infill Drilling

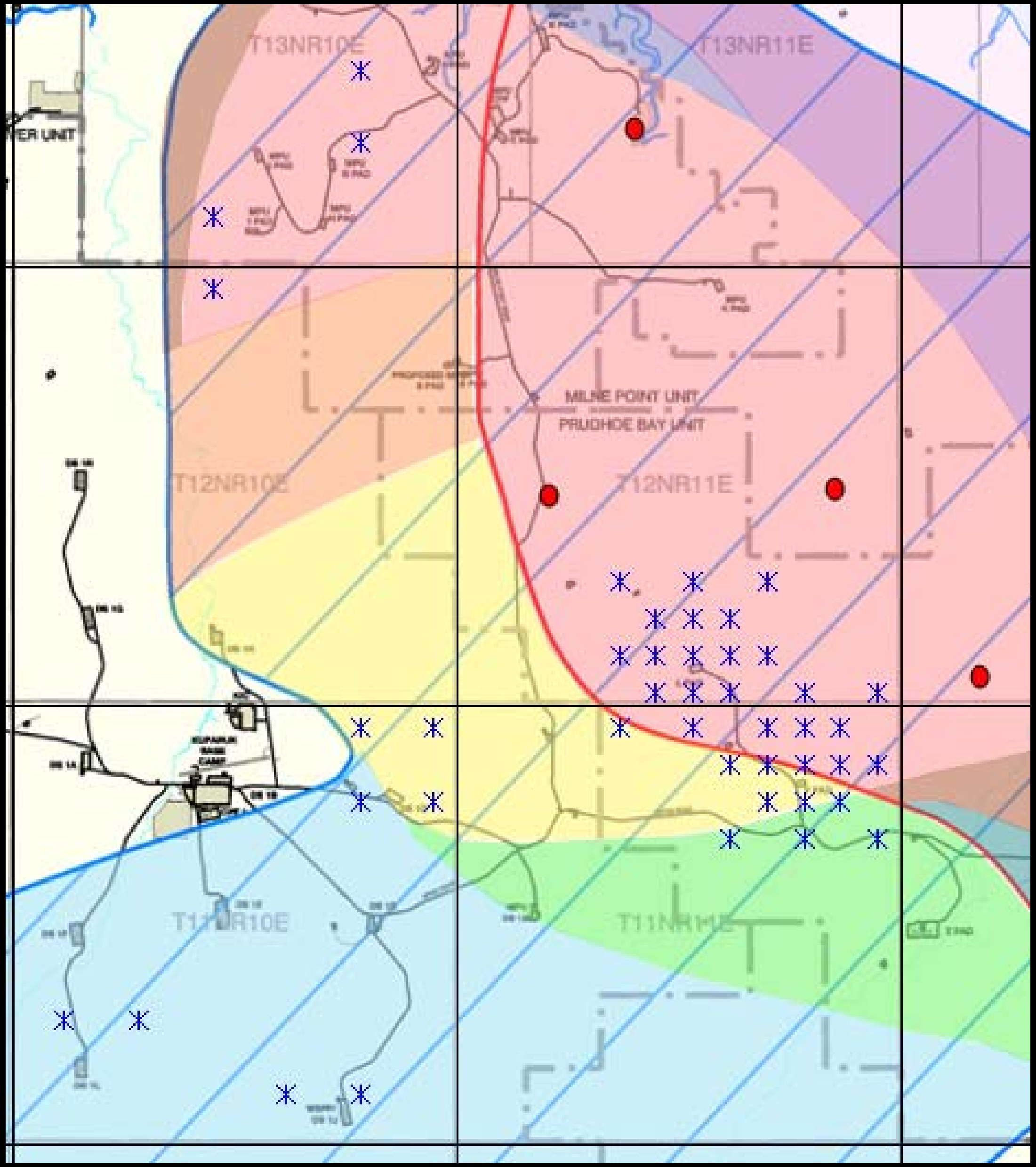
Stage 1: Single Well Pilot Testing



Stage 2: Multi-well testing/calibration

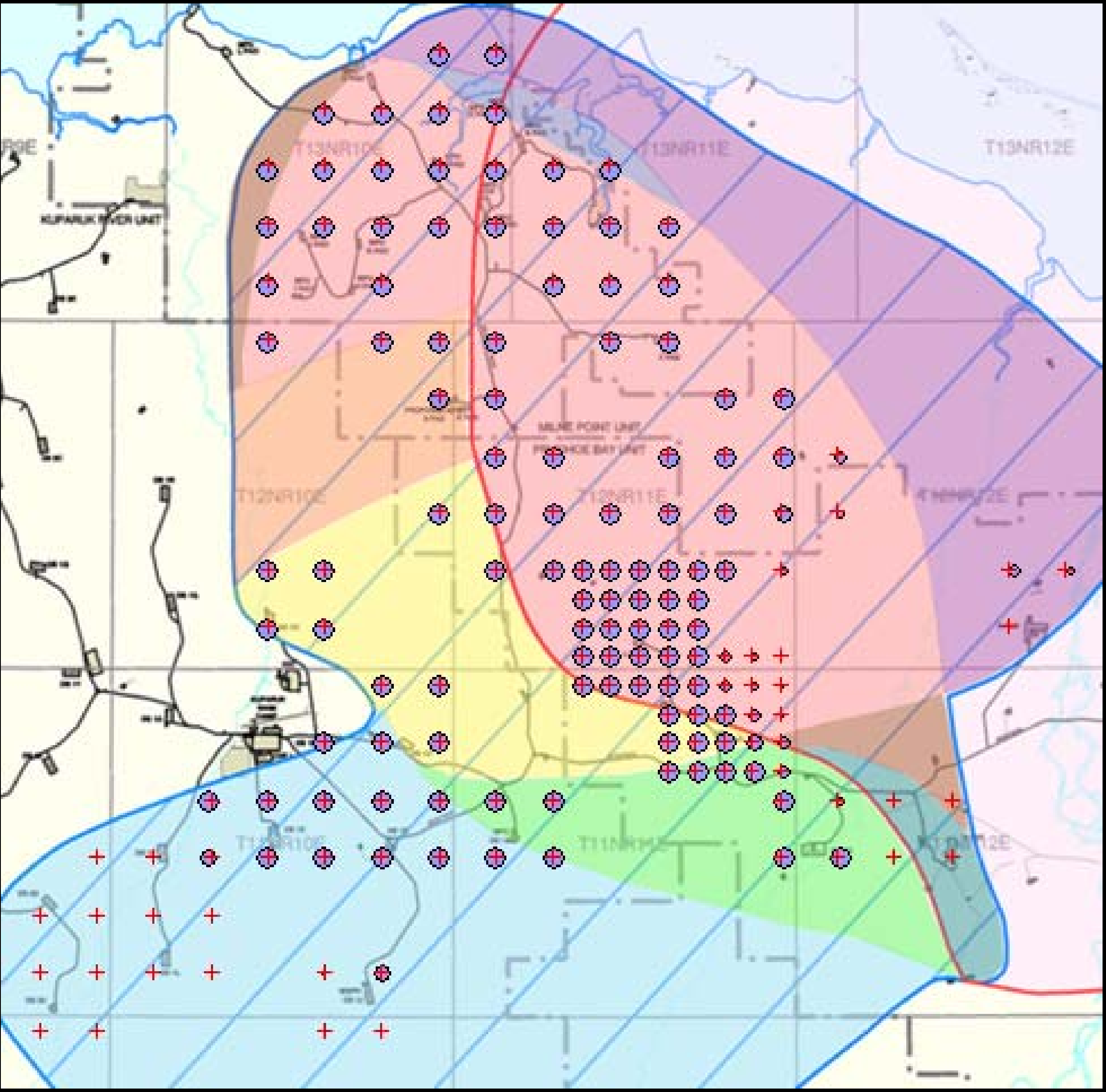
- Well locations schematic-only
- Multi-well 160 Acre Pilot

Stage 3: Limited Initial Development



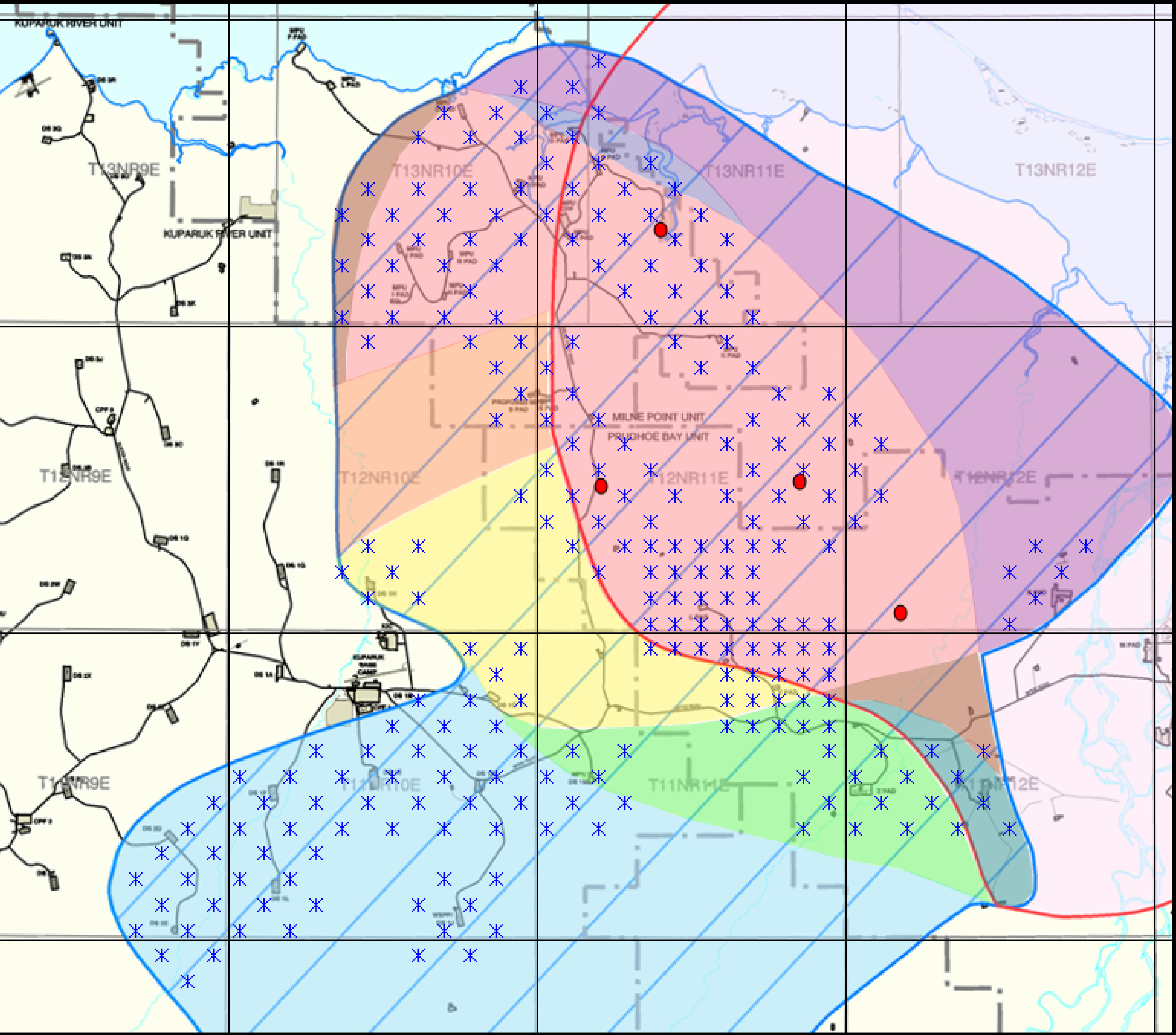
- Well locations schematic-only
- Fully Dependent upon successful Stage 1-2
- Conceptually Similar to WSak 1J pilot in KRU viscous oil
- Additional area tests
- First Major Capex
- First Reserve Booking

Stage 4: Full-field development



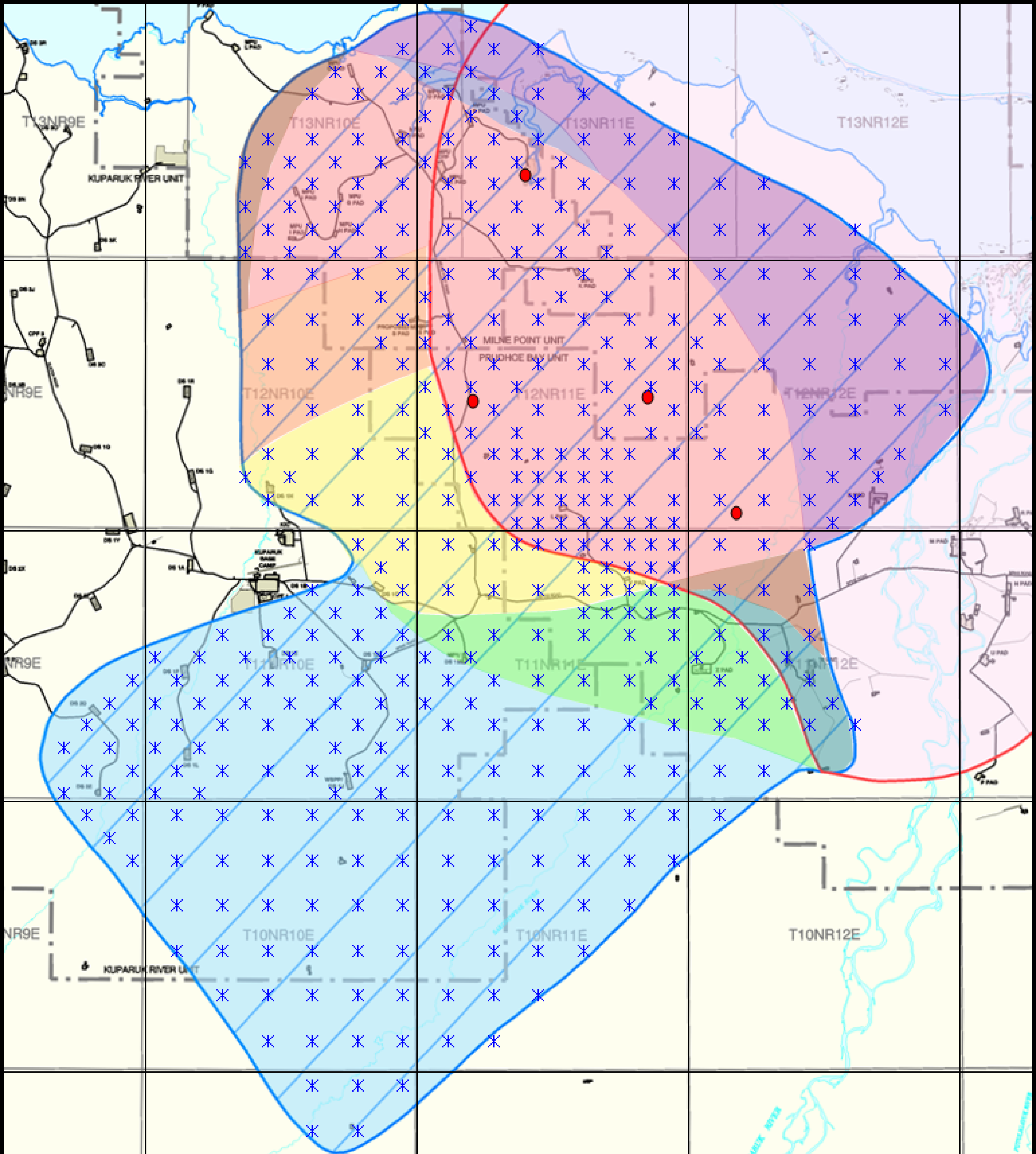
- Well locations schematic-only
- Latter stage development
- Major Capex Required
- Filters applied to reduce well count to ~148 at 640 Ac. in C/D sands > 0’
- Infilling as-needed

Stage 5: Resource Harvesting



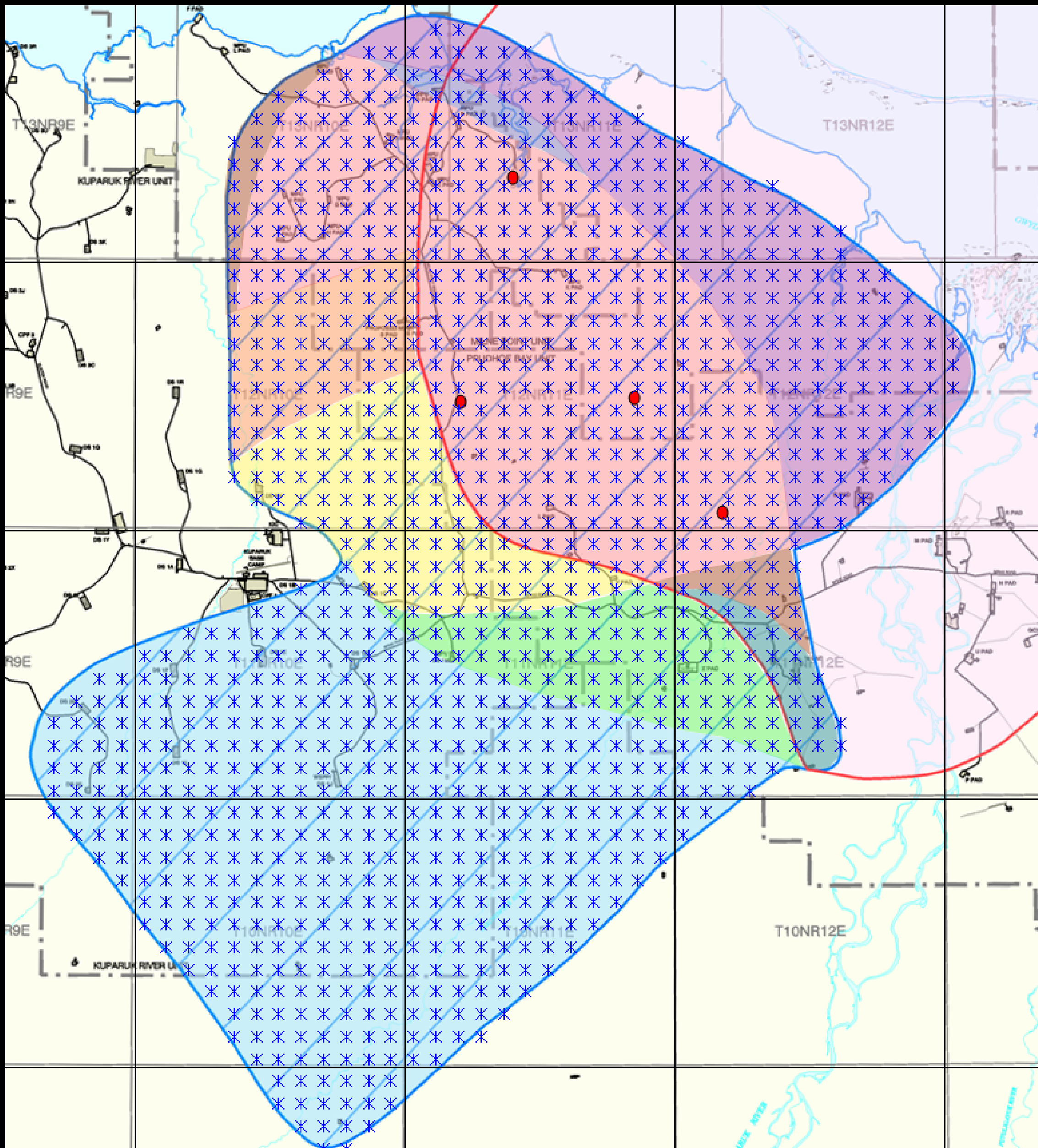
- Well locations schematic-only
- Latter stage development
- 640 to 320 Acre Spacing
- Infilling to tighter spacing
- Major Capex Required
- Optimization
- Possible new pad extensions

Stage 6: Manage/Expand Resource



- Well locations schematic-only
- Very Late-stage development
- 640 to 320 Acre Spacing
- Infilling to tighter spacing and extension
- Major Capex Required
- Optimization
- Possible multi-laterals
- Possible new pad extensions
- Resource on-decline
- New Technology?

Stage 7: New Technology/Infilling



- Well locations schematic-only
- Latest stage conceptual full-field development
- 160 Acre spacing
- Major Capex Required
- Optimization
- Improved technology?

Fieldwide Production Forecasts

Production trends predicted using the type wells and development timing. Four cases:

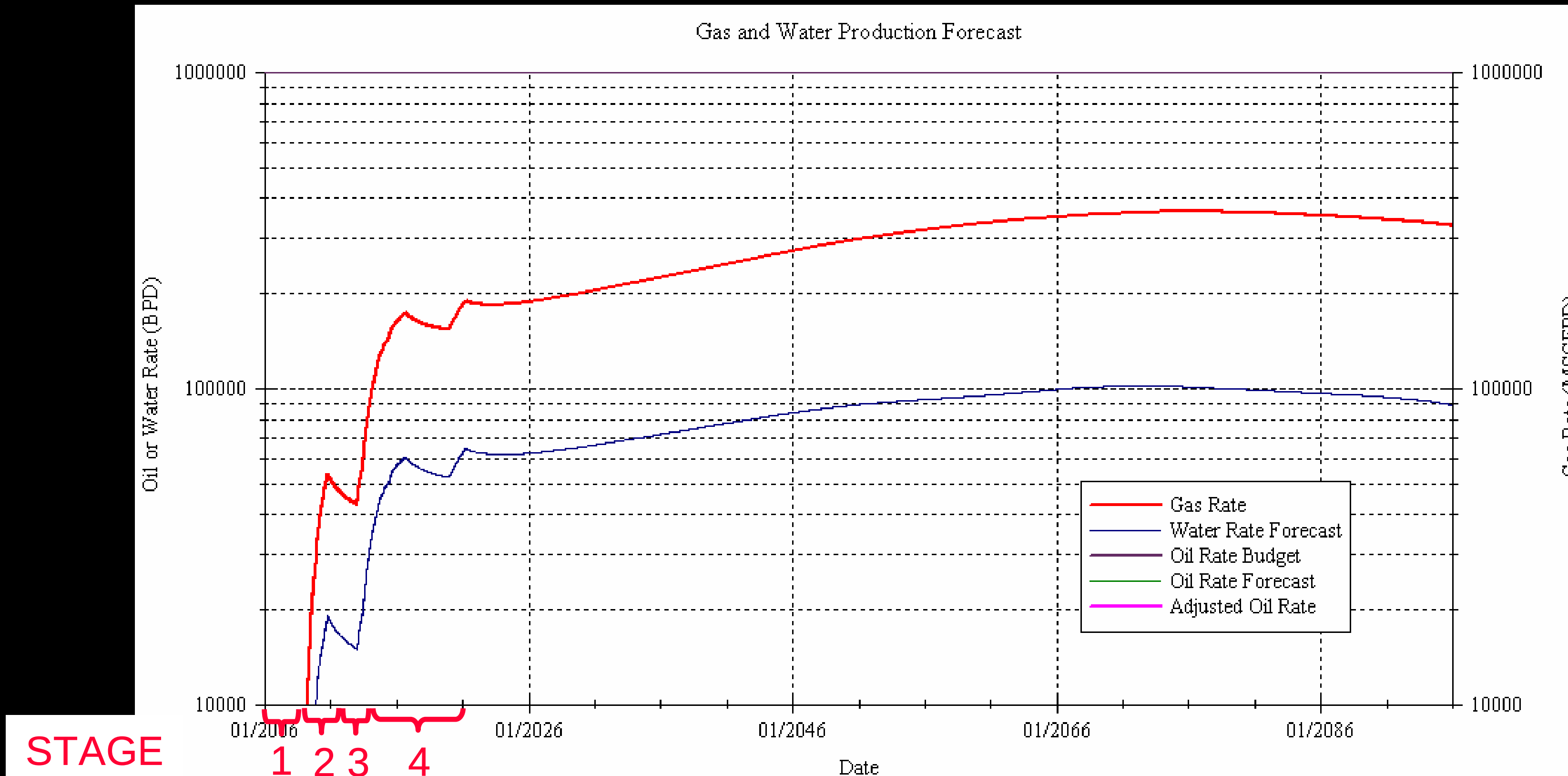
1. **Downside case:** Poor Pilot test, additional testing and ultimate project economic failure, technical resource evaluation success.
   1-4 wells, 0 TCF Recovered

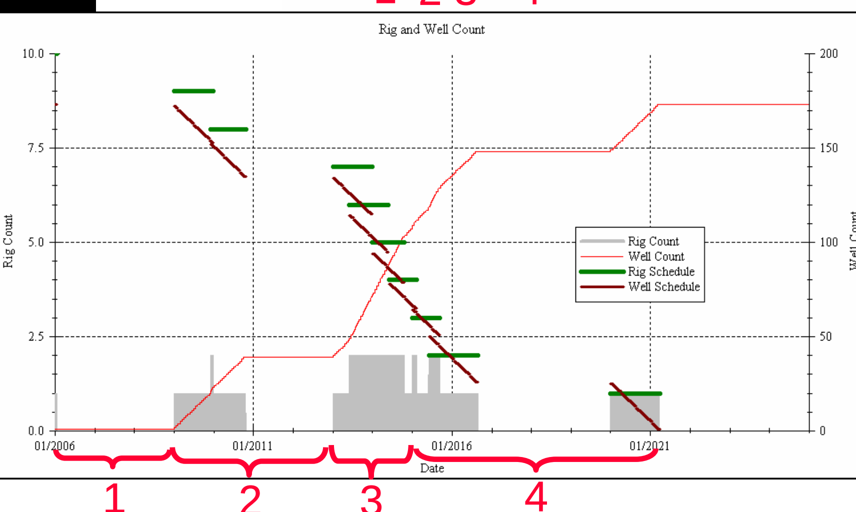
2. **Reference case:** Encouraging pilot results and Stage 2 (18 well) pilot development transition into large scale development.
   172 wells, 2.5-9.6 TCF

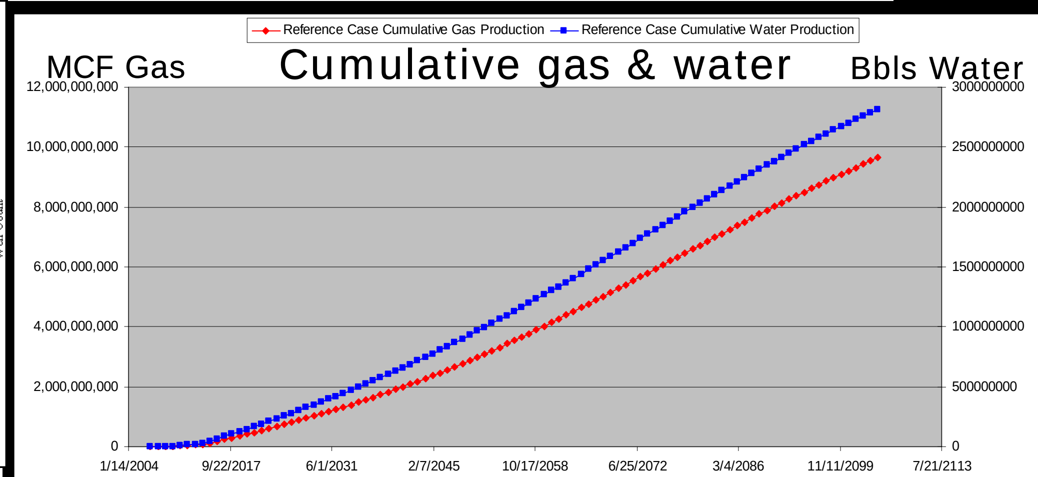
3. **Upside case:** Good pilot and Stage 2 results transition into 320 acre development with heat or chemical assisted production.
   283 wells, 3.6-11.8 TCF

4. **Extreme upside case:** Outstanding pilot/Stage 2 confirms resource; development moves forward rapidly on 640 acre spacing.
   141 wells, 8.8-9.3 TCF
   Potential case analog in the lower-48 Coal Bed Methane (CBM)

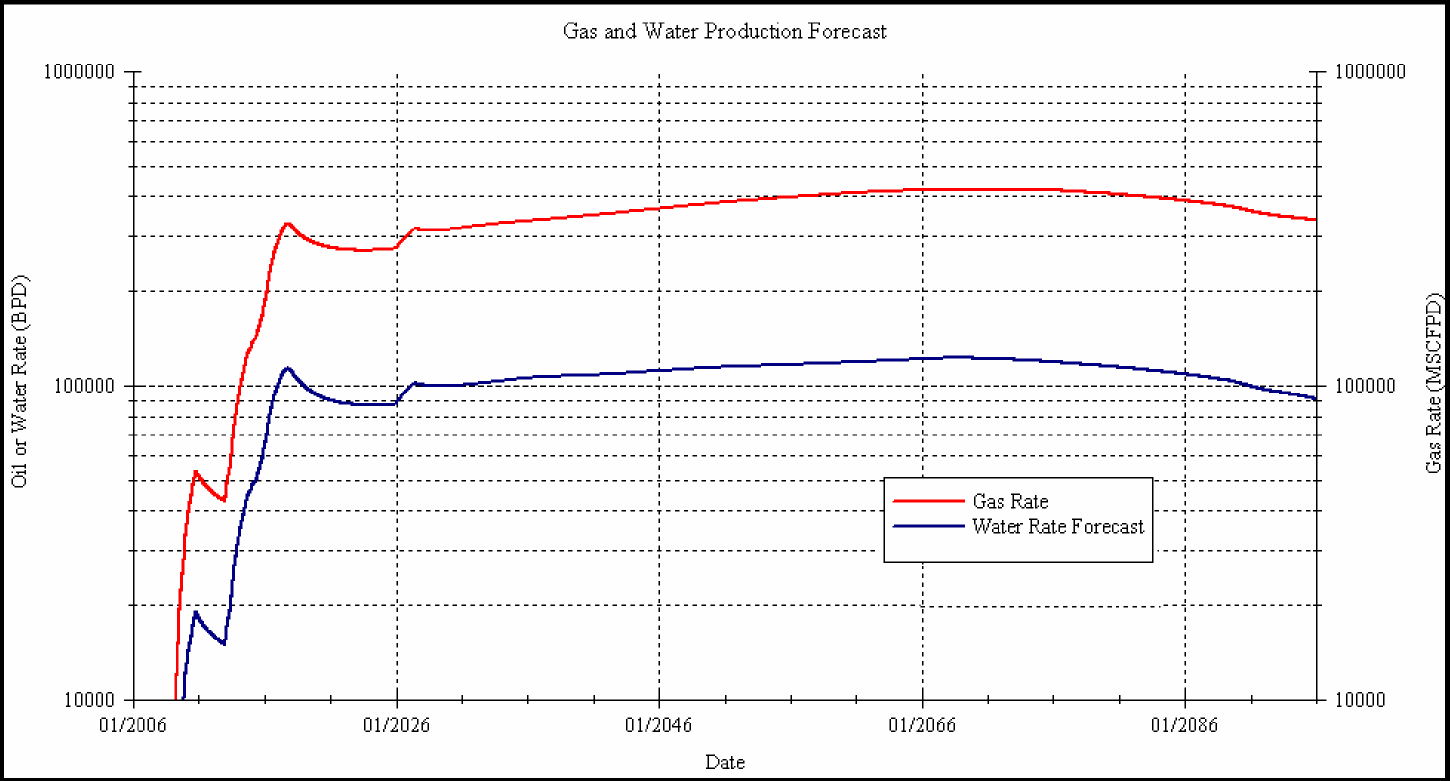
Reference Case



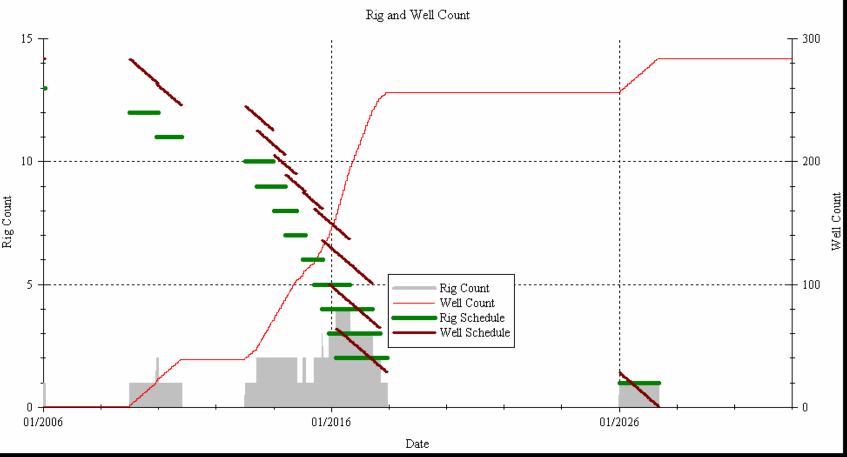




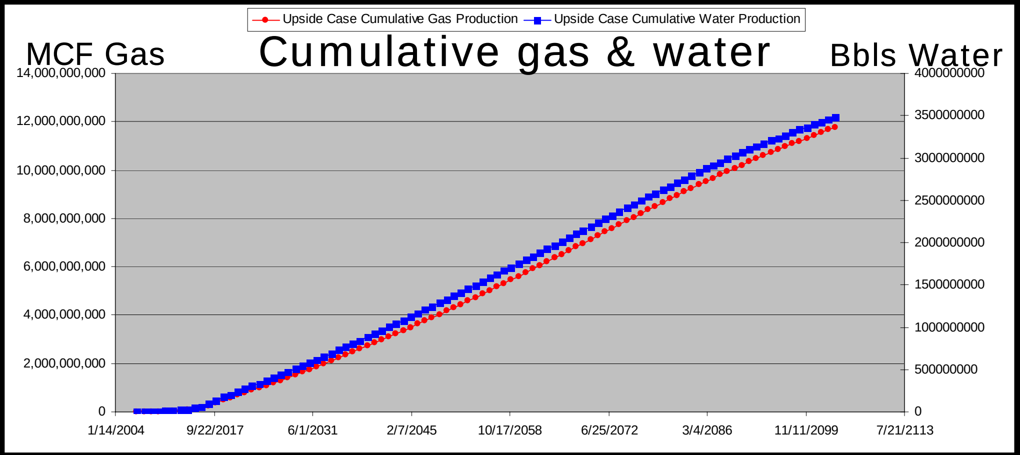
Upside Case



Gas and Water Production Forecast
1000000
100000
10000
Oil or Water Rate (BPD)
Gas Rate (MSCFPD)
01/2006
01/2026
01/2046
01/2066
01/2086
Date
Gas Rate
Water Rate Forecast

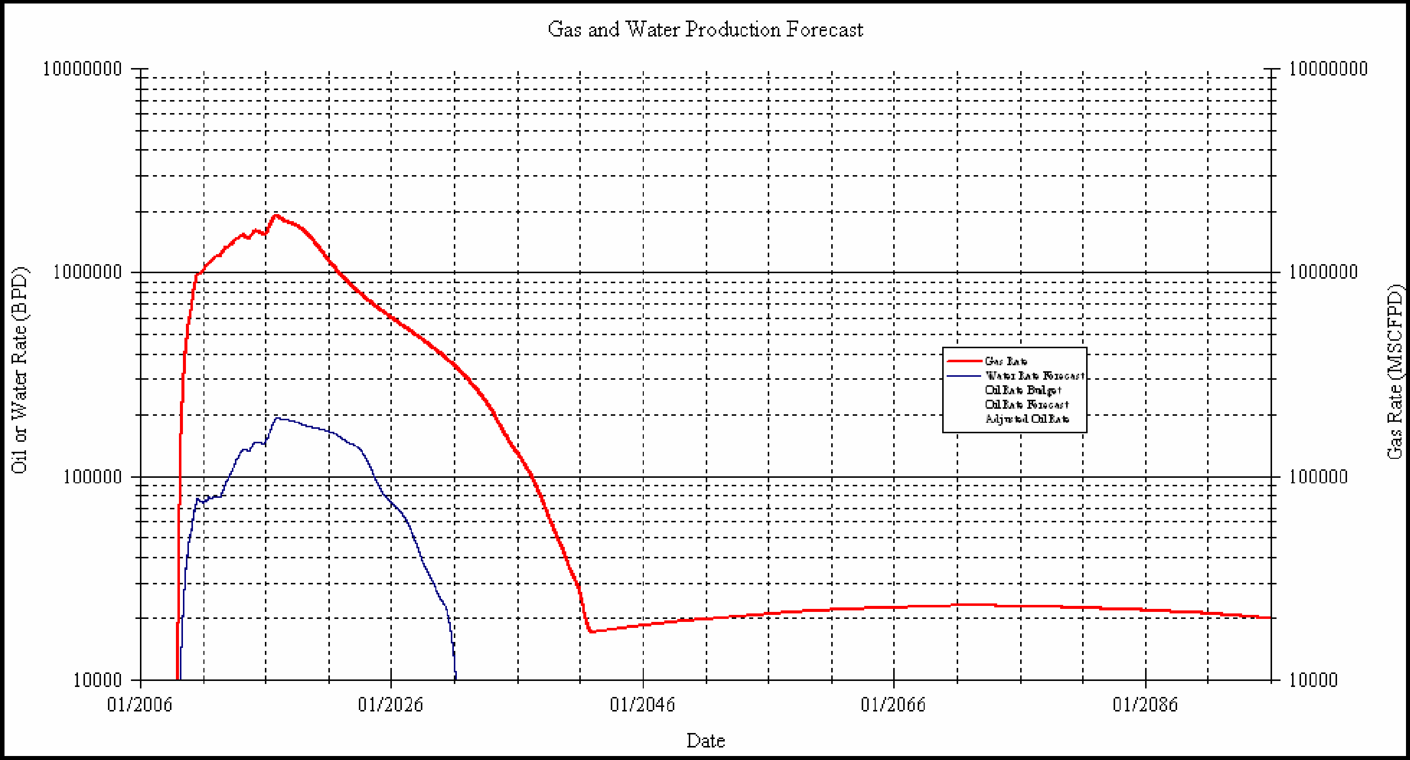


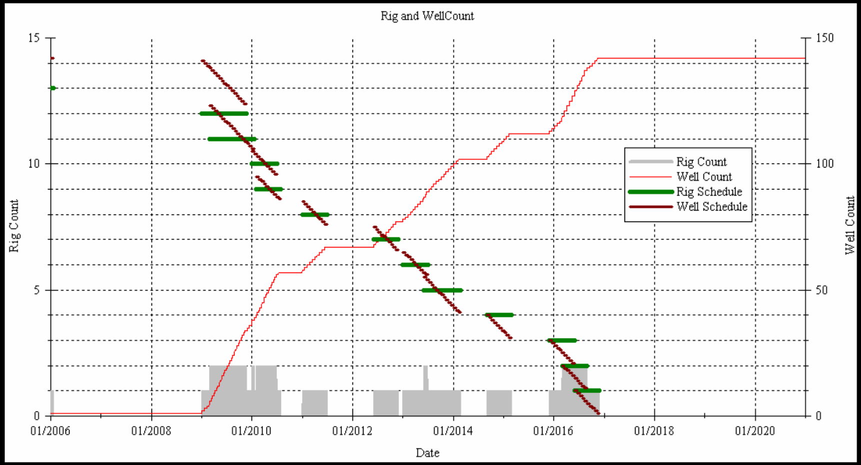
Rig and Well Count
Rig Count
Well Count
Rig Schedule
Well Schedule
01/2006
01/2016
01/2026
Date

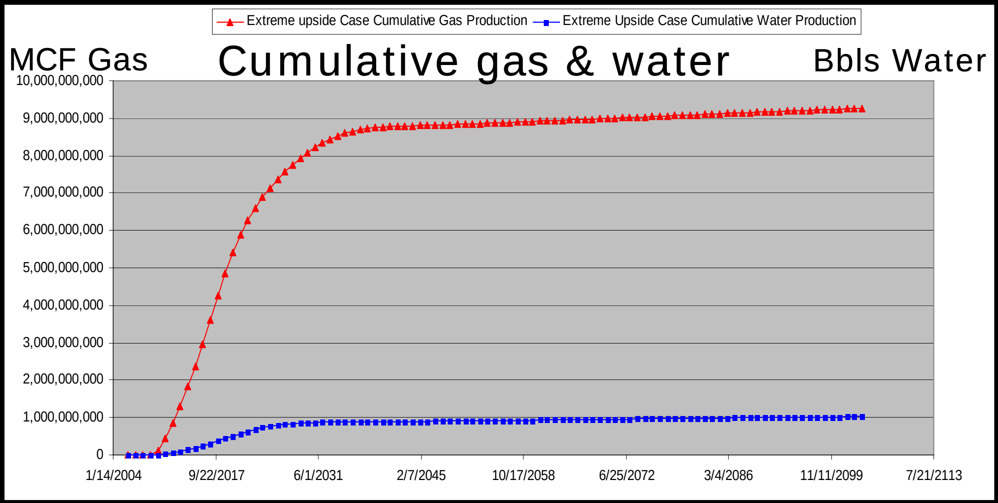


Upside Case Cumulative Gas Production
Upside Case Cumulative Water Production
MCF Gas
Cumulative gas & water
Bbls Water
1/14/2004
9/22/2017
6/1/2031
2/7/2045
10/17/2058
6/25/2072
3/4/2086
11/11/2099
7/21/2113

Extreme Upside Case







Production Uncertainties

- Dissociation & gas production character/rate
- Associated water production rate
- Endothermic effects of production
- Initial and dissociating permeabilities
- Gas hydrate saturations
- Production technologies

Uncertainty Mitigations

- Prospect delineation of seismic-prospects
- Production testing (short & long-term)
- Thermal enhancement understanding
- Sand control, Artificial Lift, In-situ combustion?

Presentation Outline

- ✓ Introduction / Collaboration
- ✓ Gas Hydrate Resource
- ✓ Resource Characterization
- ✓ Production Technology
- ✓ Reservoir/Development Models
- ➢ Conclusions

Interim Conclusions

- ANS – Gas Hydrate Petroleum System
  - Complex Shallow Structure & Stratigraphy
  - Multiple High-graded MPU Prospects Revealed: 620 BCF
  - Regional Development Scenarios Under Evaluation

- Significant uncertainties remain
  - Regional Resource In-Place may be >33 TCF Eileen Trend
  - Resource Potential Remains Uncertain – 0-12 TCF possible
  - Direct Detection Geophysical Methods Require Delineation
  - Additional Data Acquisition Could Calibrate Resource Potential
  - Type Well Production Rates Modeled at 0.4-2 MMSCF/d
  - Peak Field-wide Forecast Models up to >350 MMSCF/d
  - Modeled Production Character Long with Flat Declines
  - Potentially High Associated Water Volumes

- Technical Project Results Helping to Solve Issues
  - Industry & Government to make more Informed Decisions