Use of Analytical Models in Prospect Evaluation of Gas Hydrate Reservoirs

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Hart Conference – Commercialization of Gas Hydrates

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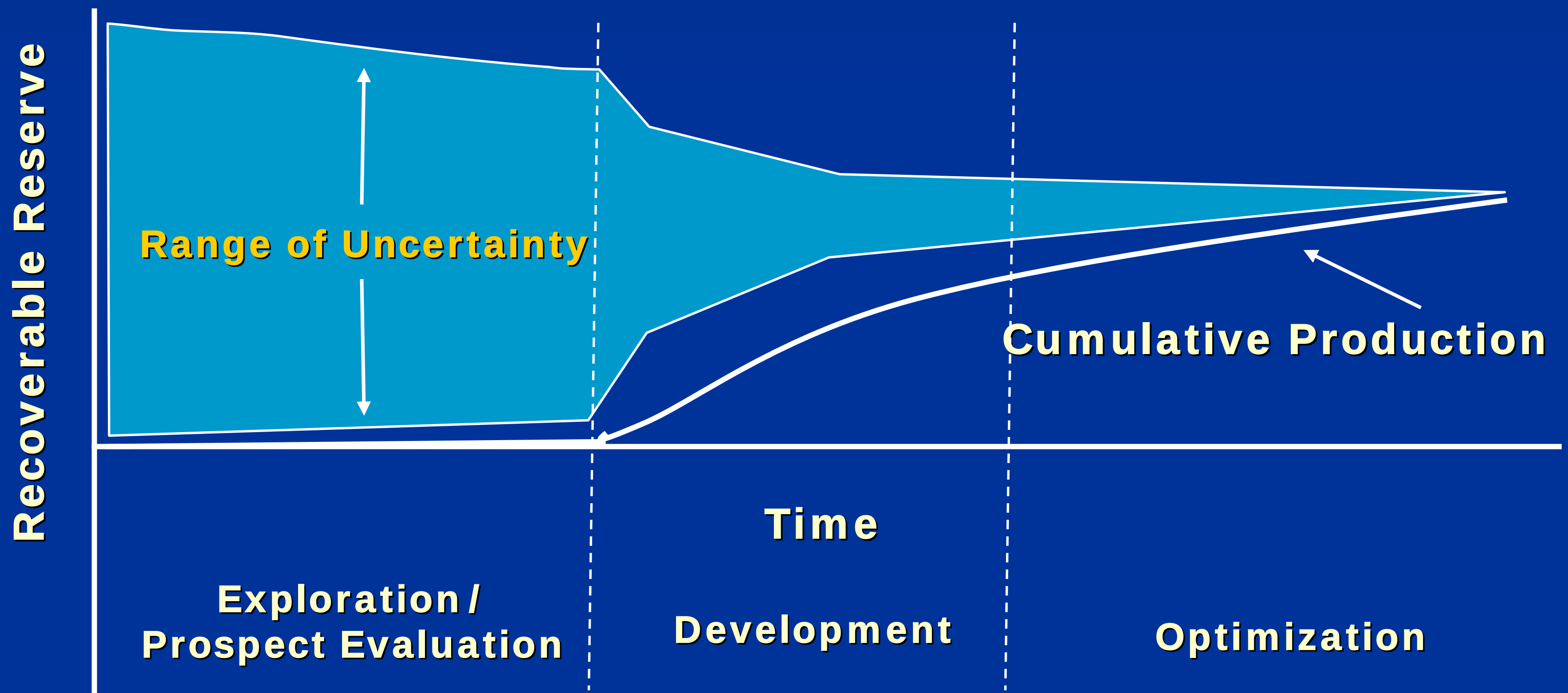
Prospect Evaluation: Realm of High Uncertainty

Limited Data

Need for large number of runs and risk analysis → Analytical Models



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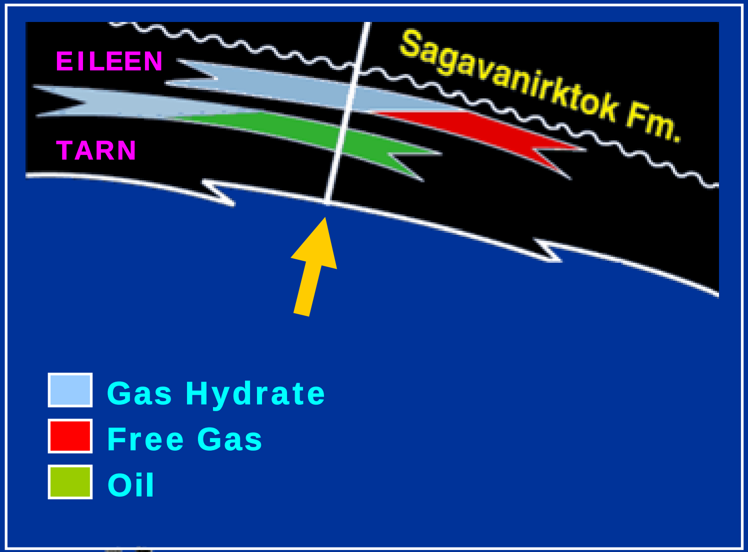
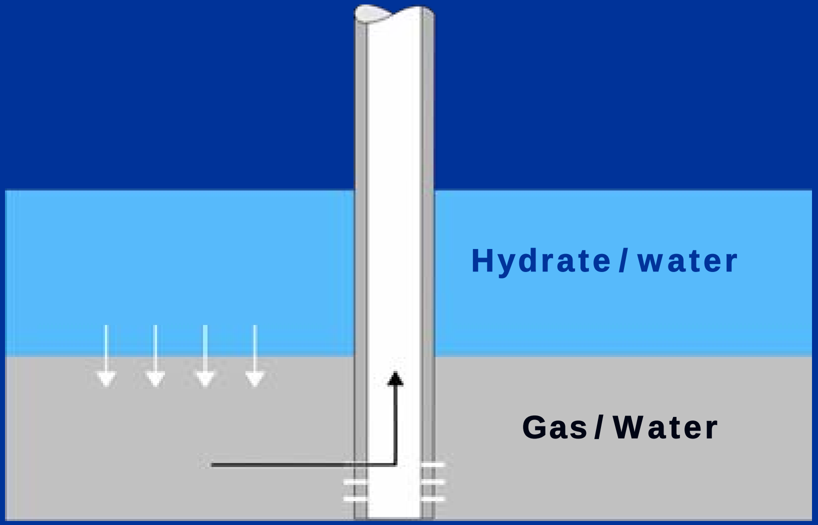
Objectives

- For a hydrate reservoir with underlying free gas
  - Develop, validate and use analytical models for quantifying of
    - The upside in gas recovery associated with the hydrates (forward model)
    - Hydrate reserve (backward model)





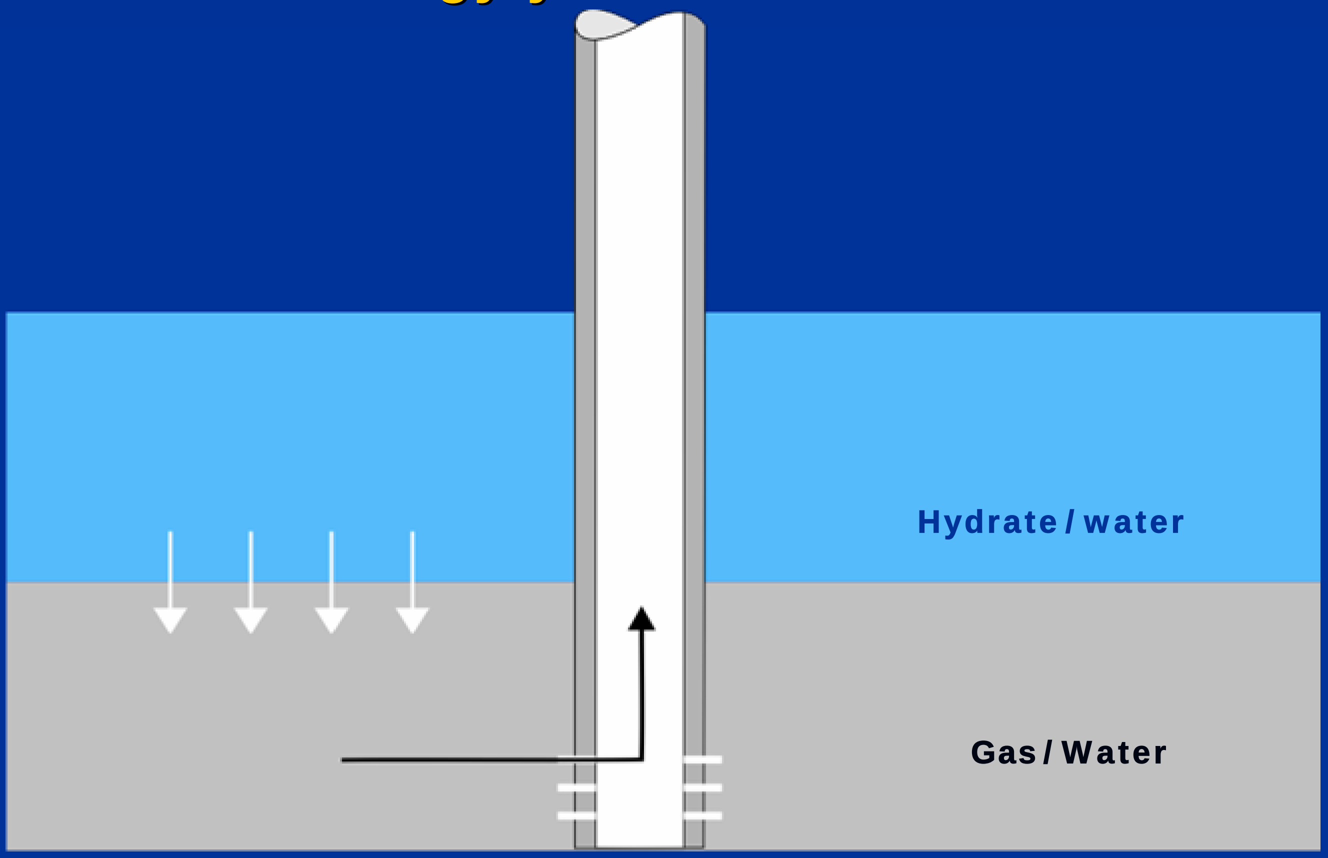
Production by Depressurization

Simplest: Produce from the gas

Least energy intensive: No external heating agent

Examples: Messoyakha, Alaska, Mackenzie Delta

Not a proven technology yet: Use mathematical models!!



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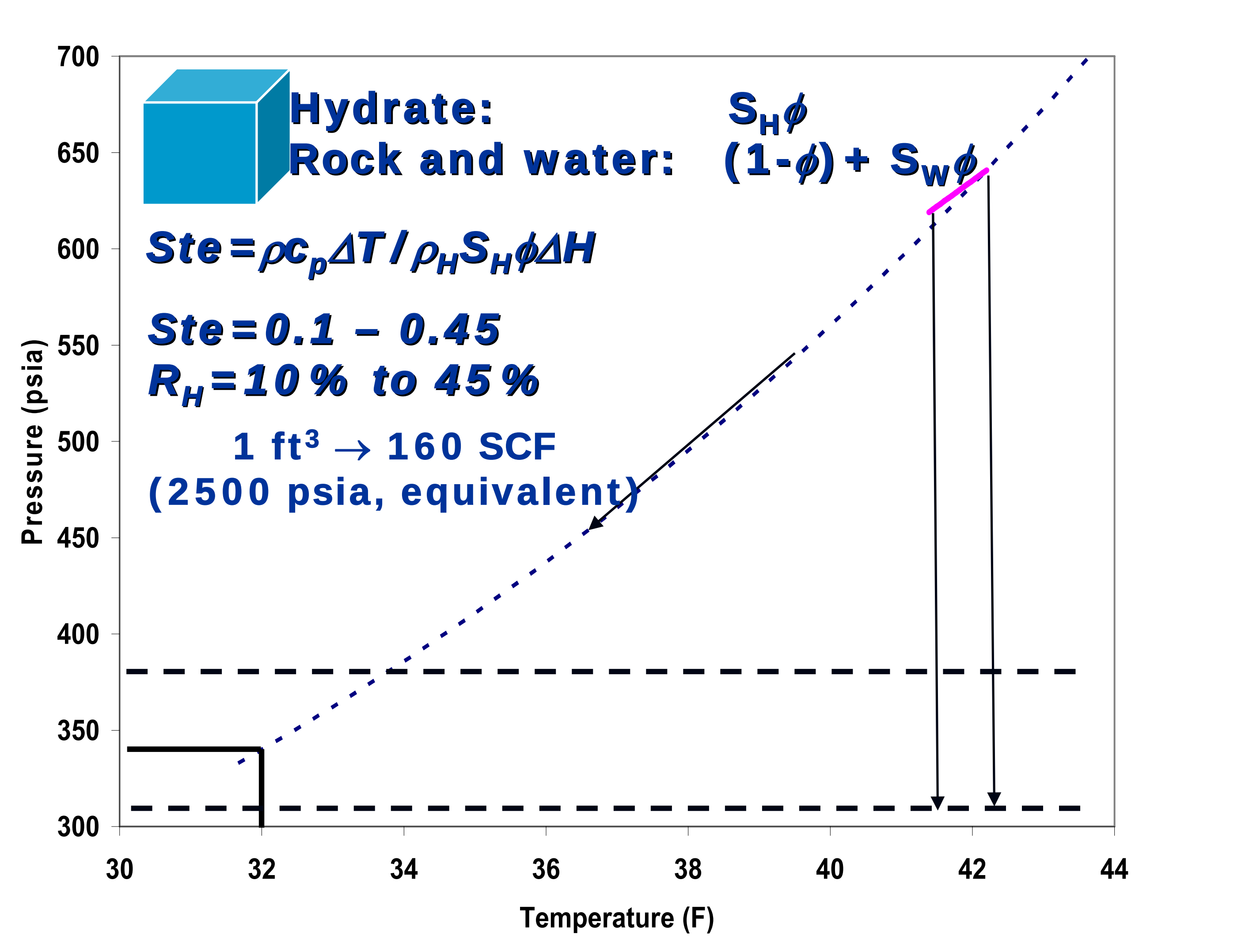
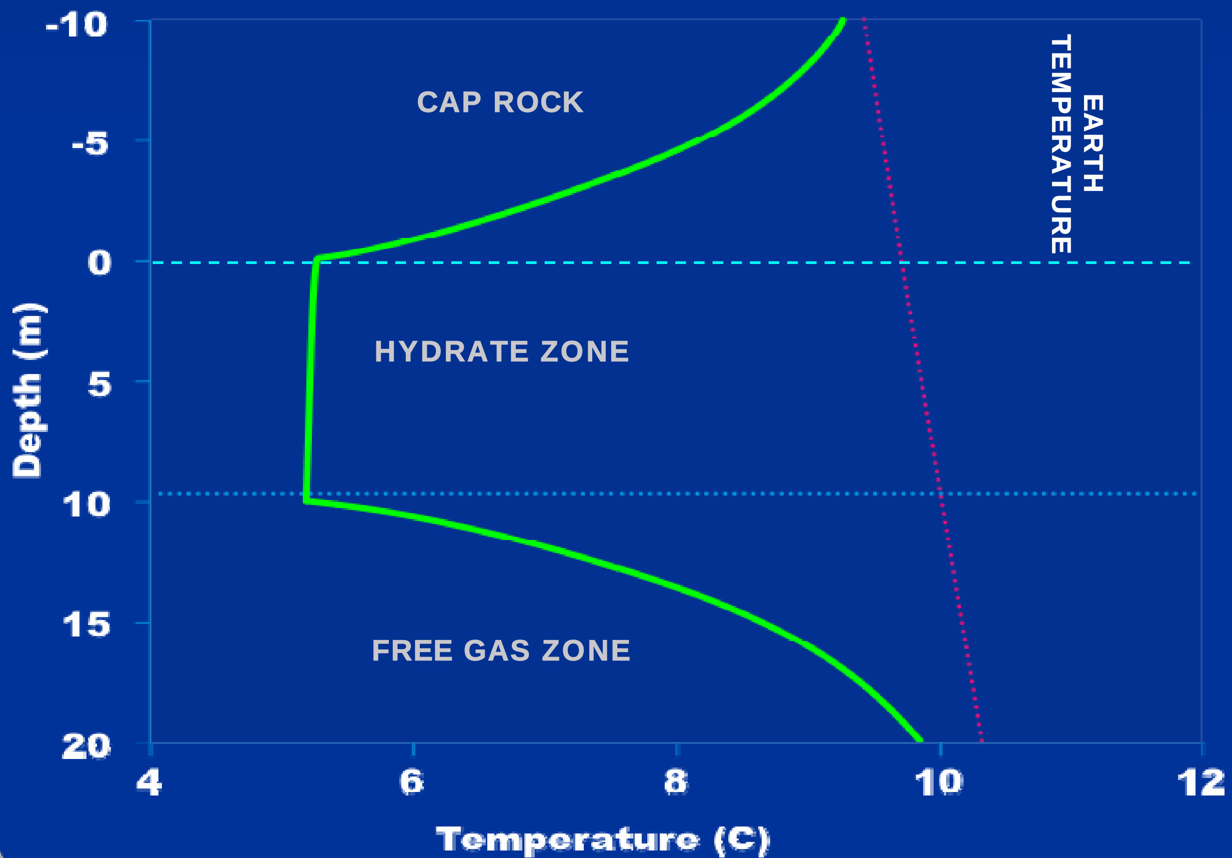
Depressurization Mechanisms

- **Decomposition rate is controlled by our ability to**
  1. Provide heat of decomposition: 11,000 BTU/ft^3 hydrate



Depressurization Mechanisms

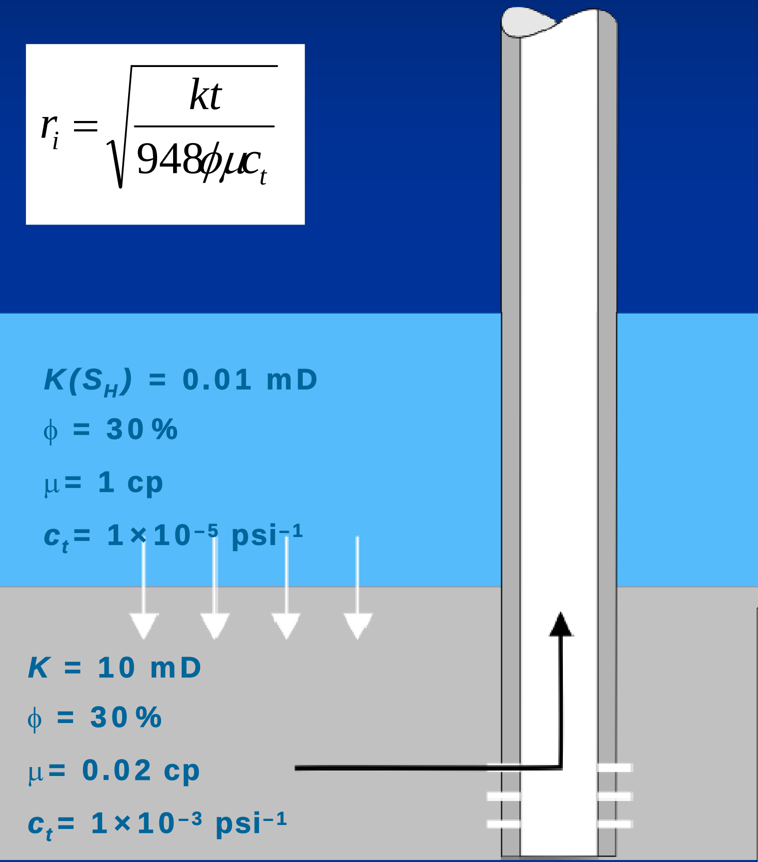
- **Decomposition rate is controlled by our ability to**
  - Provide heat of decomposition: 11,000 BTU/ft³ hydrate
  - From surrounding rock

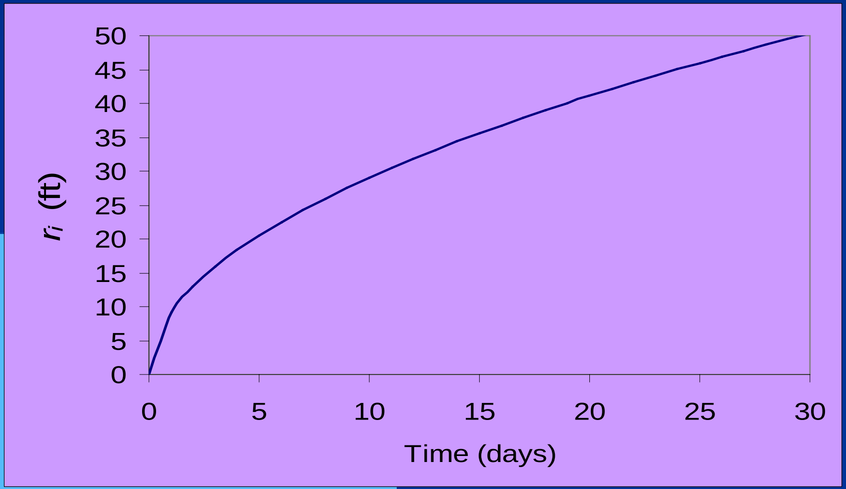


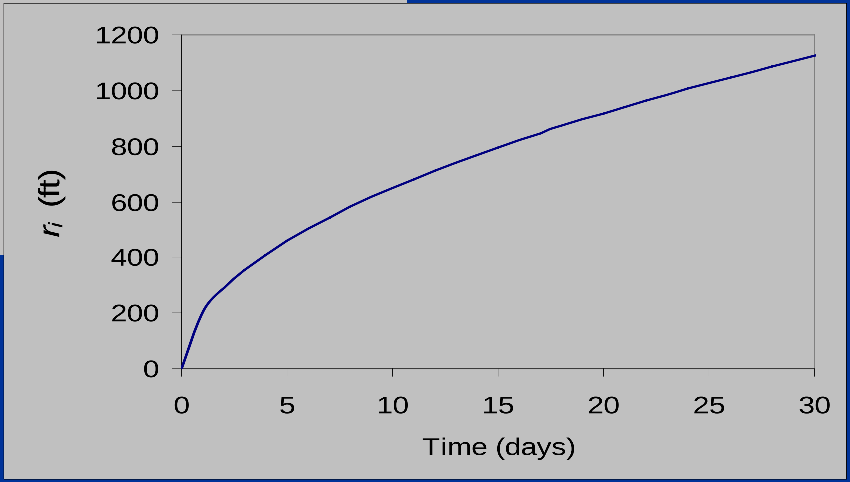
Depressurization Mechanisms

- **Decomposition rate is controlled by our ability to**
  2. Reduce the pressure within the hydrate zone

$$r_i = \sqrt{\frac{kt}{948\phi\mu c_t}}$$







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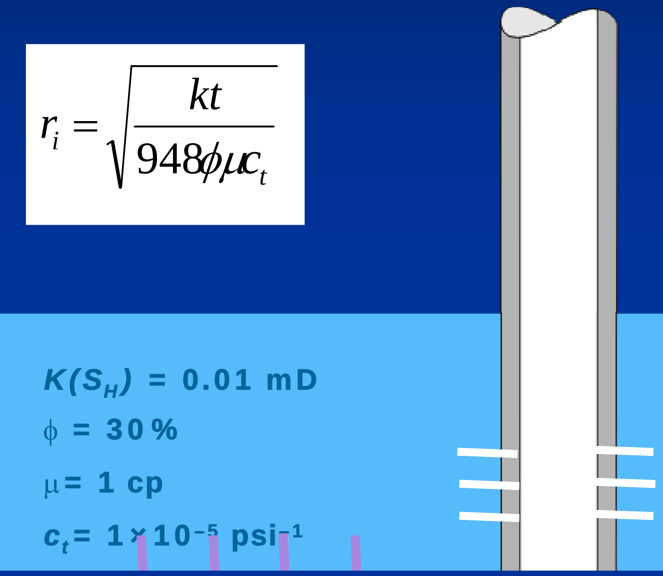

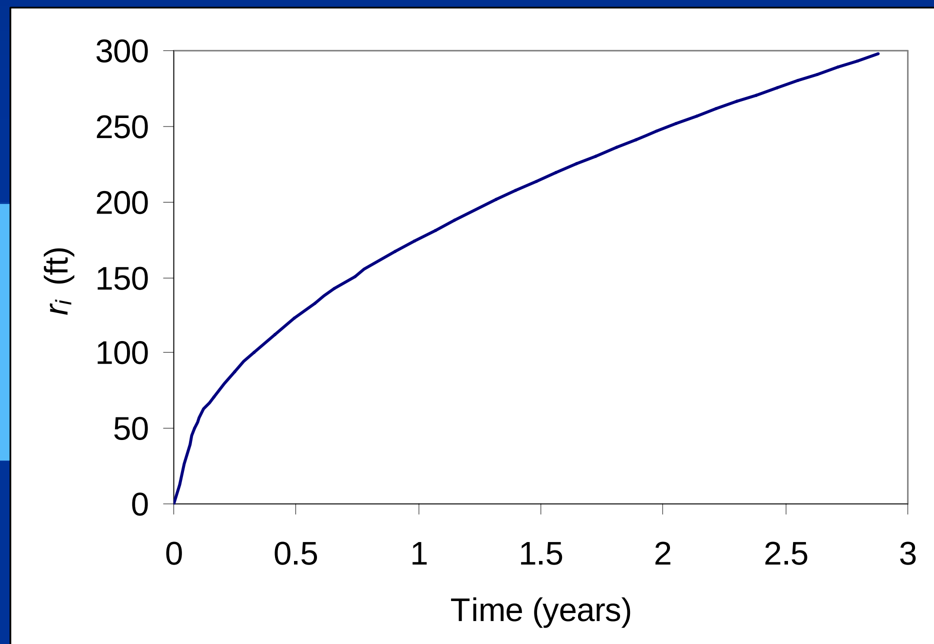

Development of Analytical Model

- **Assumptions**
  - Deep decomposition
    - No vertical gradient (time-scale of one month)
  - Tank-type model (zero-dimensional modeling)
    - No radial gradient (time-scale of one month)
  - Equilibrium decomposition
  - Complete contact between the gas and the hydrate
  - No water flow
  - Constant gas production rate

A Material (& Energy) Balance Equation

- **Material Balance**
  - $G_p = q.t$
  - G_H = Gas generated from the hydrates
  - $G_p - G_H$ = Net gas produced

$$\frac{p}{Z} = \frac{p_i}{Z_i}\left(1 - \frac{G_p - G_H}{G}\right)$$

- **Heat equation:**

  Heat from cap and base + sensible heat =

  Heat available for decomposition (G_H)

- **Equilibrium relation**

$$p = \exp\left(a + \frac{c}{T}\right)$$

- The three unknowns, p, T, and G_H are found

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Solutions (CIPC 2006-018)

$$q_g(t) = \frac{B_H A H \rho c_p}{\rho_H \Delta H} b(t) \left(\frac{4\rho_r c_{pr}}{\sqrt{\pi}\rho c_p} \frac{\sqrt{\alpha_r}}{H} \sqrt{t} + 1 \right)$$

$$b(t) = \frac{q_p}{\left[\frac{1 - (p_{oe} Z_i)/(p_i Z_{oe})}{T_i - T_{oe}} G_f + \frac{B_H A H \rho c_p}{\rho_H \Delta H} \left(\frac{8}{3H\rho c_p \sqrt{\pi}} \sqrt{k_{cr} \rho_r C_{pr}} t + 1 \right) \right]}$$

$$p = \exp\left(a + \frac{c}{T} \right) \qquad T = T_i - b(t)t$$

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Solutions (SPE 102234)

$$\psi_{wf} = \overline{\psi} - \frac{q_w p_{sc} T}{\pi T_{sc} k h_t} \left[\ln\left(\frac{r_e}{r_w}\right) - \frac{3}{4} + S \right]$$

$$Ste = \frac{\rho c_p \Delta T}{\rho_H \phi S_H \Delta H} \qquad N_p = \frac{q_p / G_f}{\alpha / H^2} \qquad N_b = \frac{b / \Delta T}{\alpha / H^2}$$

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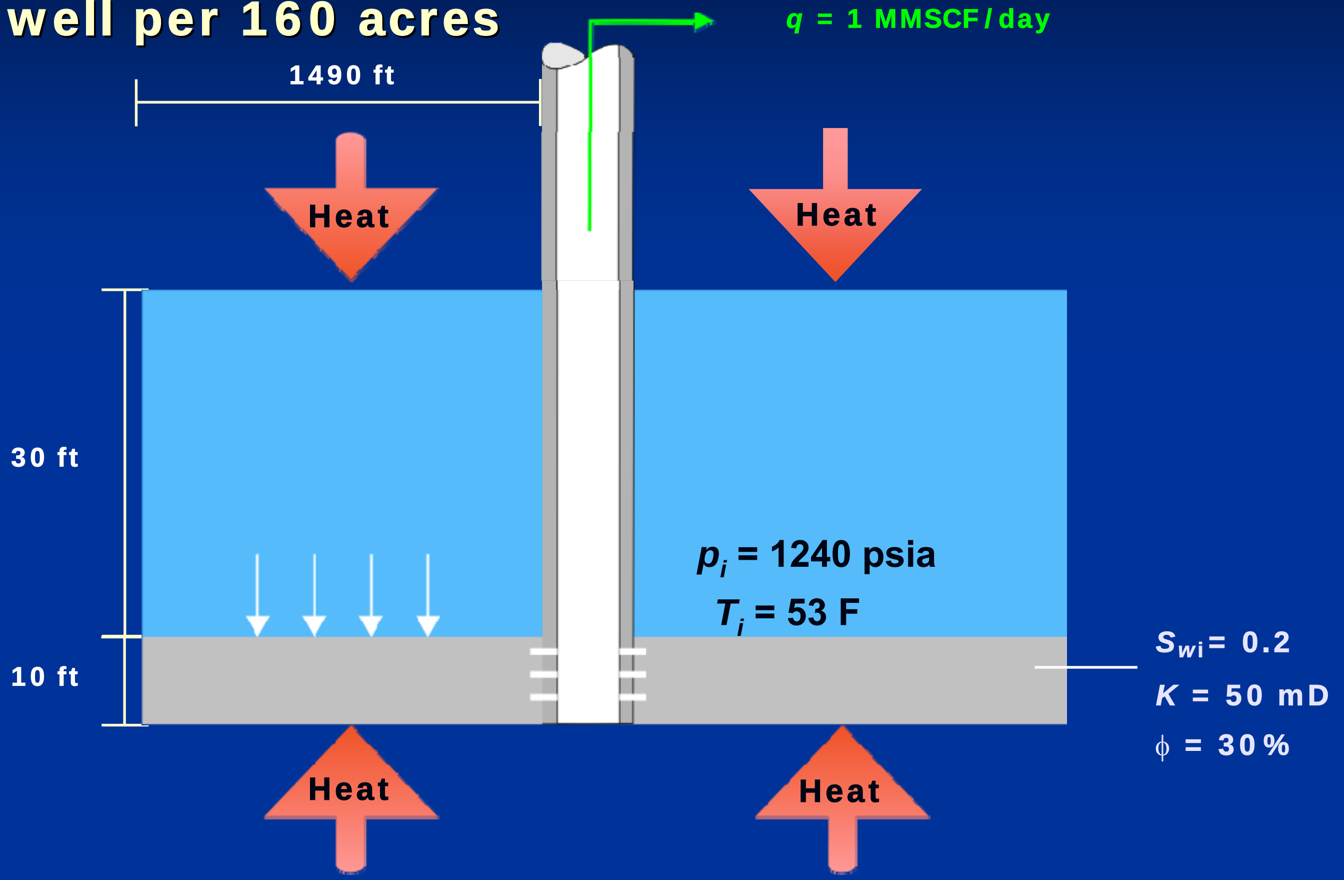
Validation against Numerical Simulator (Hydrsim)

- Heat flow
  - Conduction and convection
  - Decomposition heat of hydrate
  - Heat input from the cap/base rock
  - Heat output by the producing fluids
- Fluid flow
  - Multi-phase flow through porous media
  - Generation of fluids due to decomposition
  - Gravity, capillary and viscous forces
- Intrinsic Kinetics of decomposition
  - The Kim-Bishnoi model
- No geomechanical changes

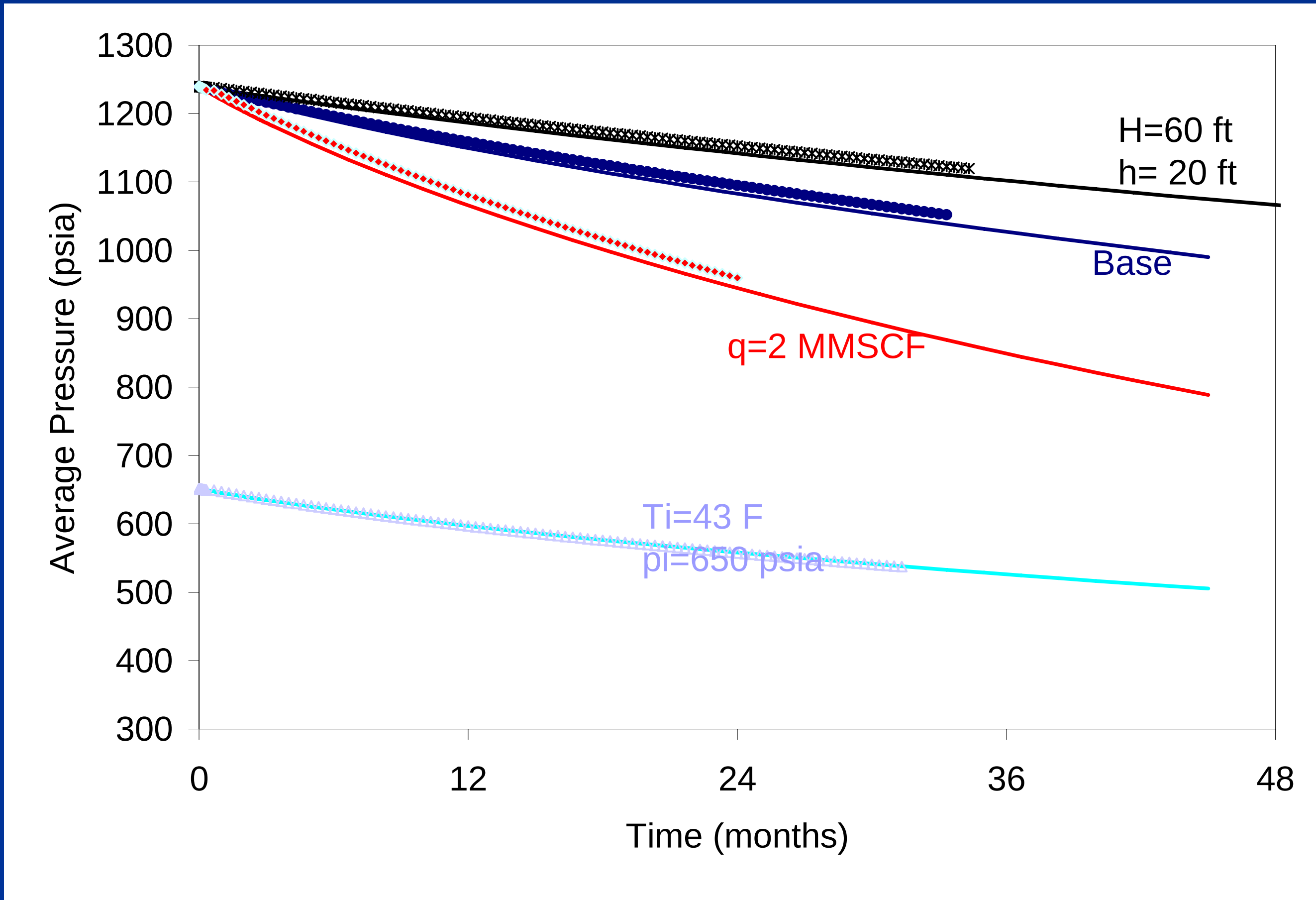
Base Case

One well per 160 acres

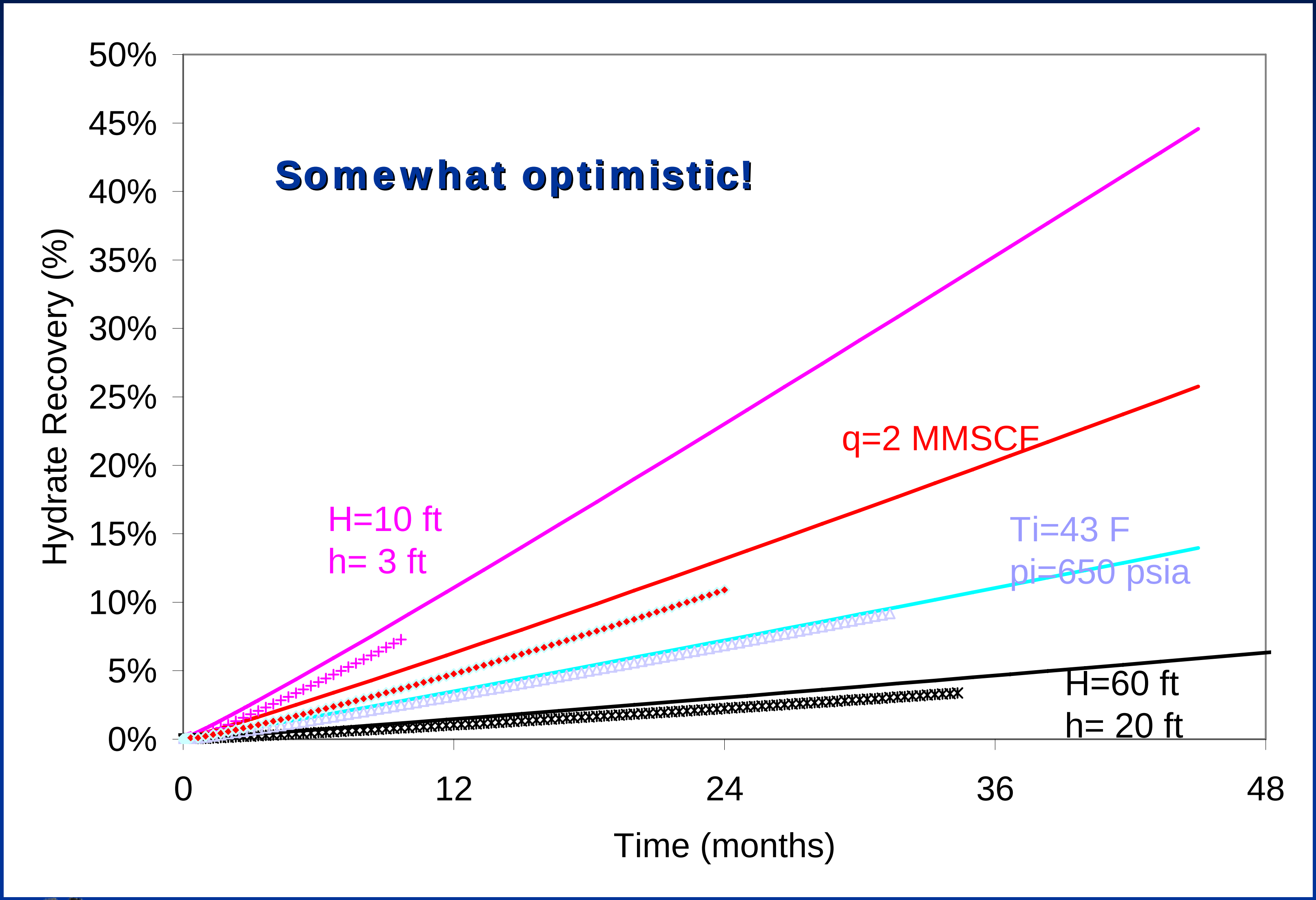


Validation – Average Pressure

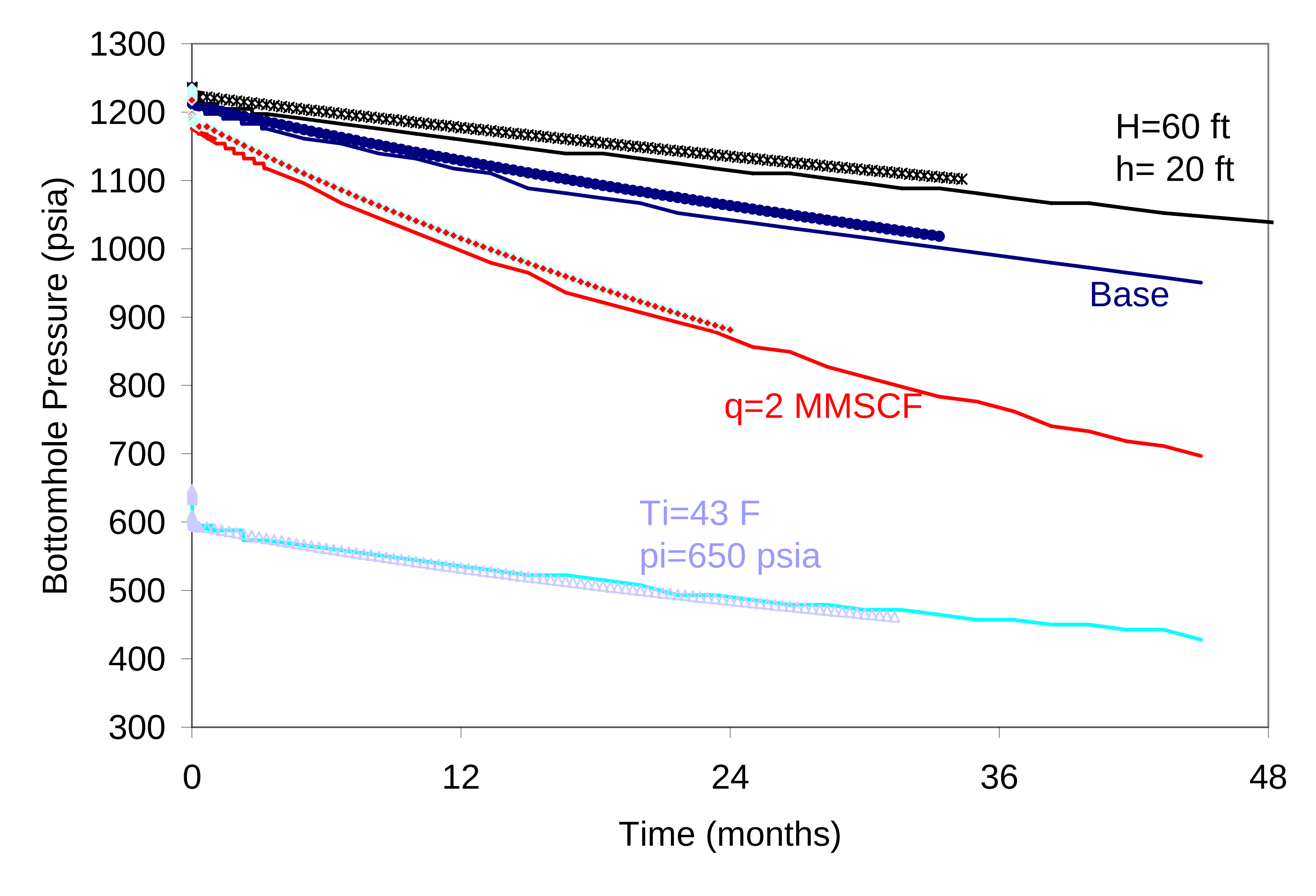
- **Various Cases**
  - Porosity
  - Thermal conductivity
  - Production rate
  - Net pay
  - Drainage area
  - Initial Pressure
  - Permeability



Validation – Hydrate Recovery



Validation – Flowing BHP



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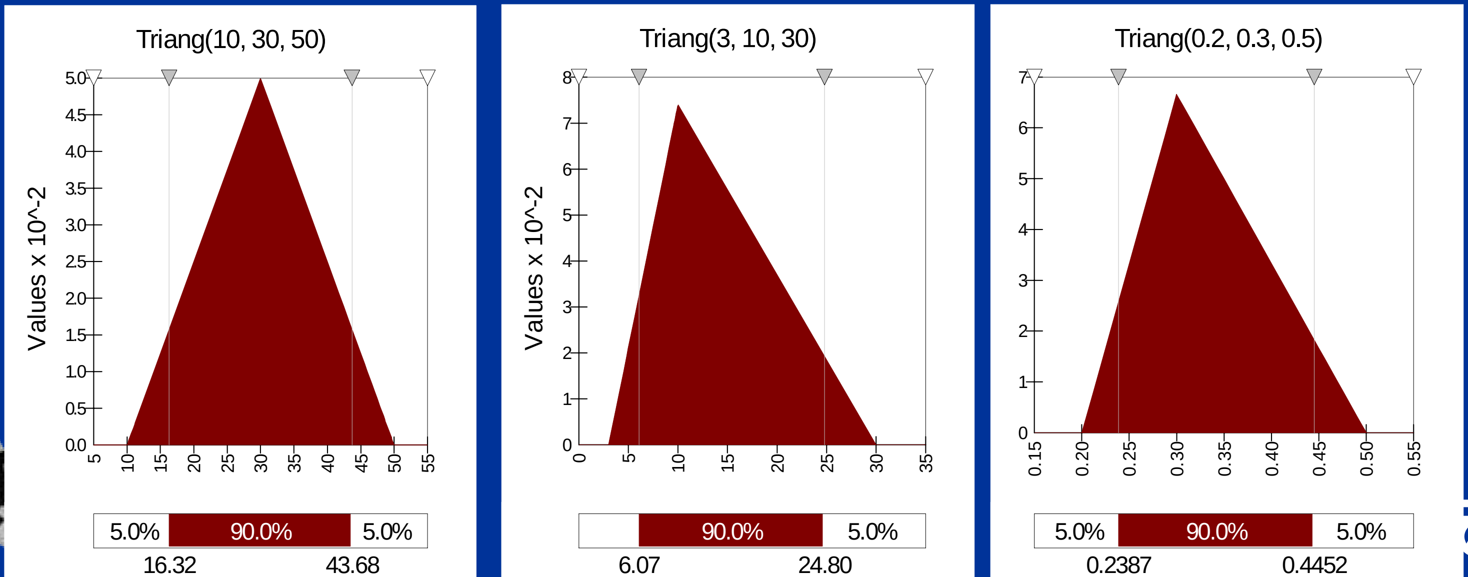
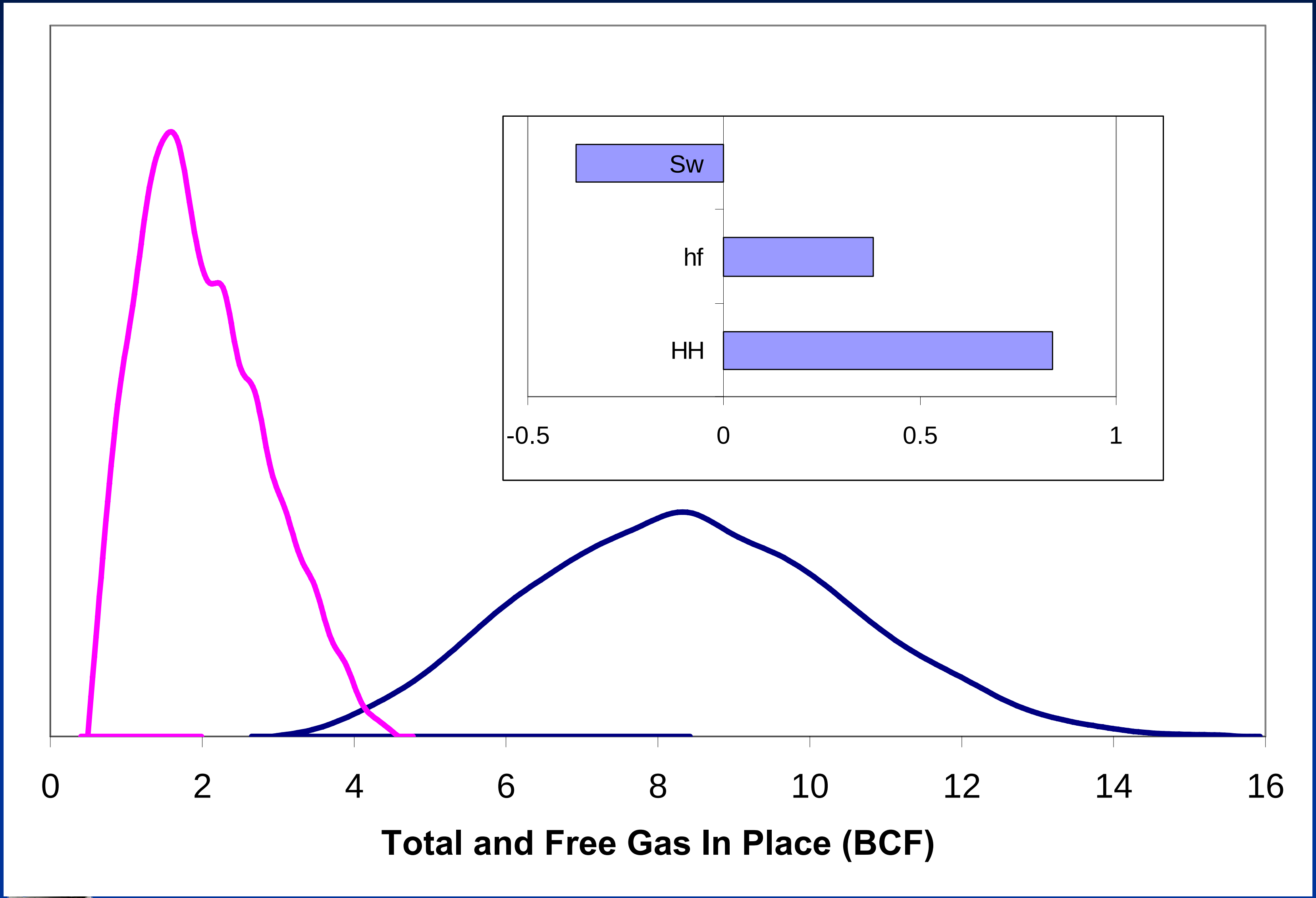
Prospect Evaluation Uncertain Input Parameters

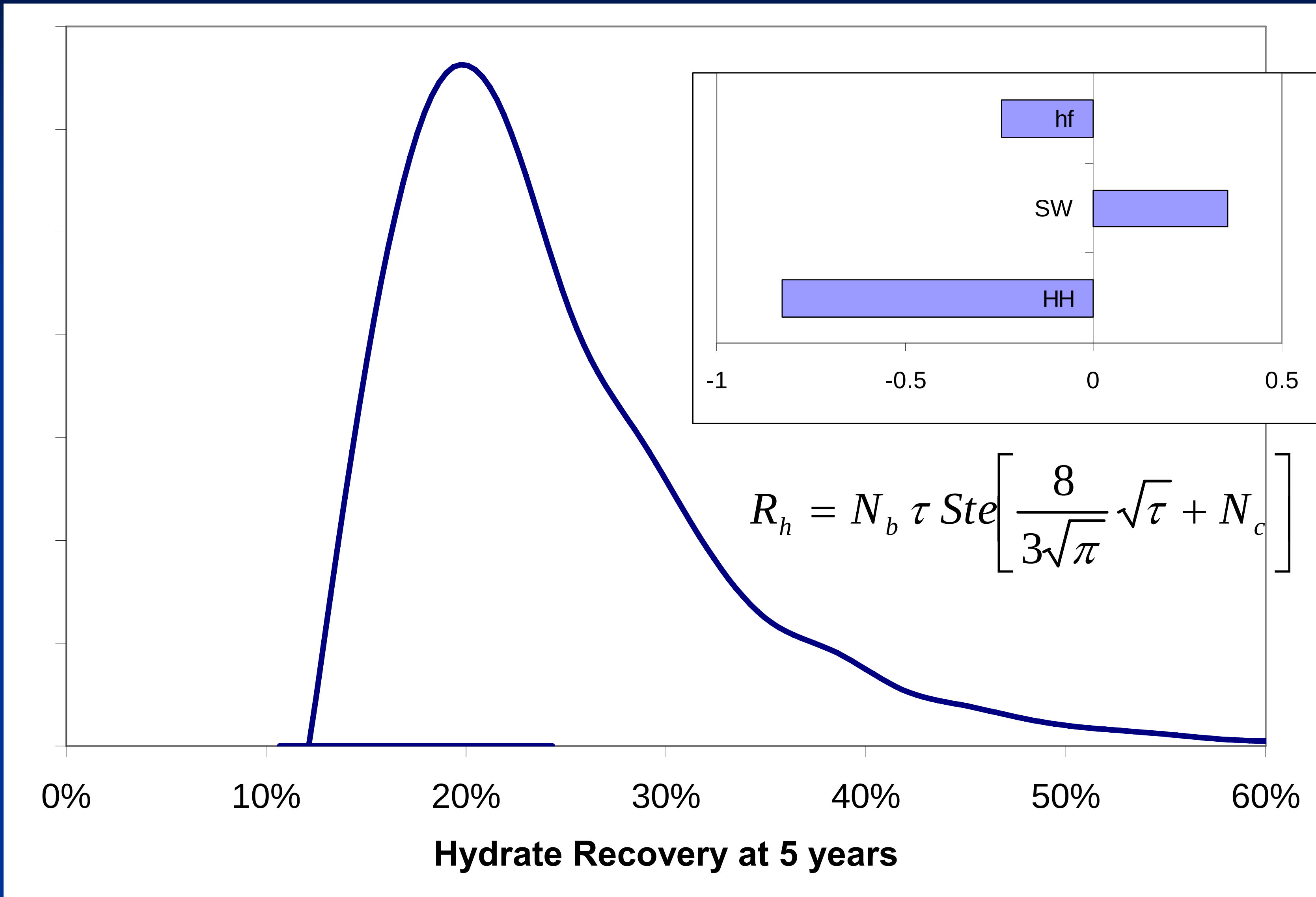
- Thickness of the hydrate layer (10, 30, 50 ft)
- Thickness of the free gas zone (3, 10, 30 ft)
- Hydrate Saturation (0.5, 0.6, 0.8)
- Porosity
- Drainage Area
- Equilibrium relation



Total vs. Free Gas In Place

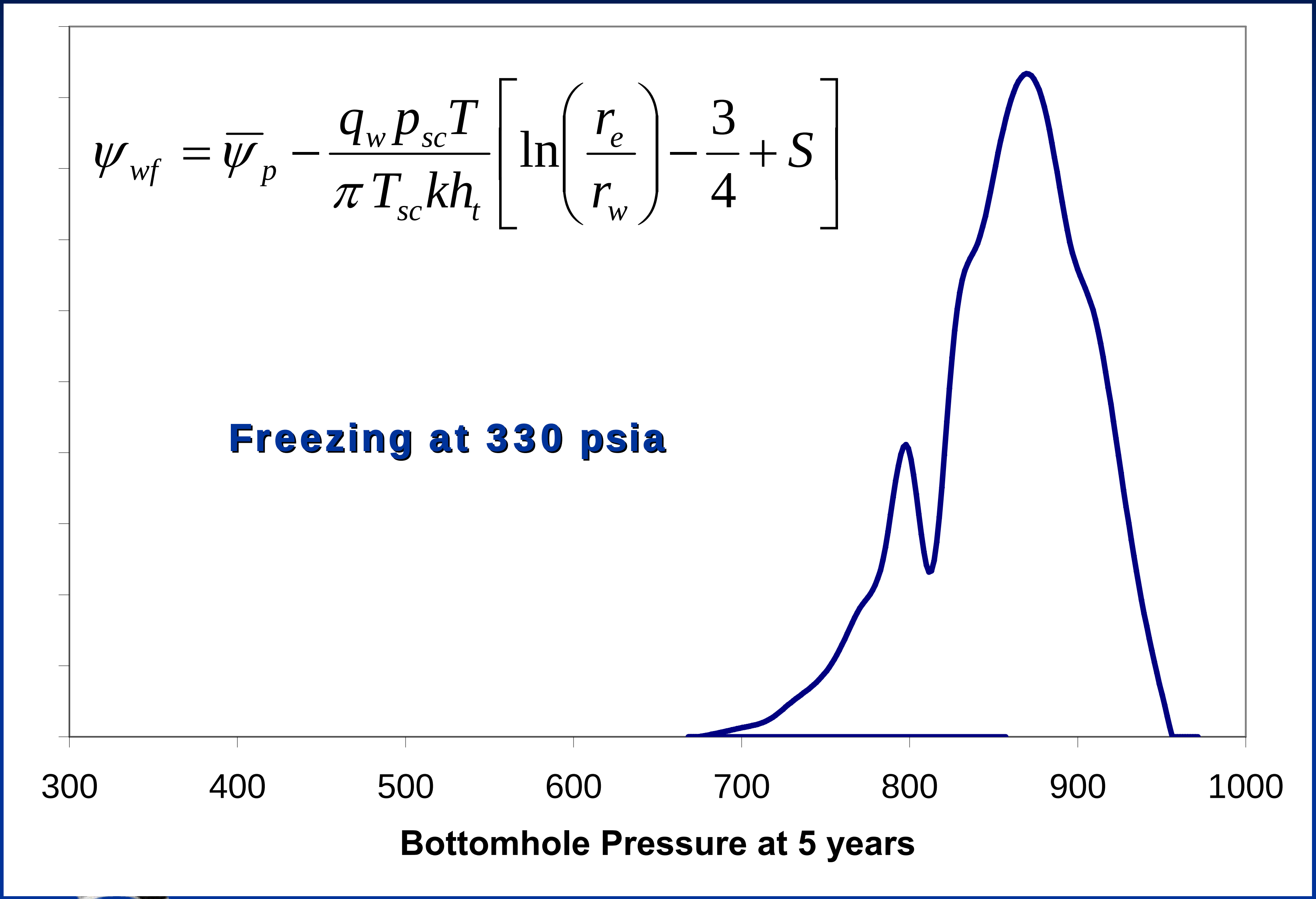


Hydrate Recovery

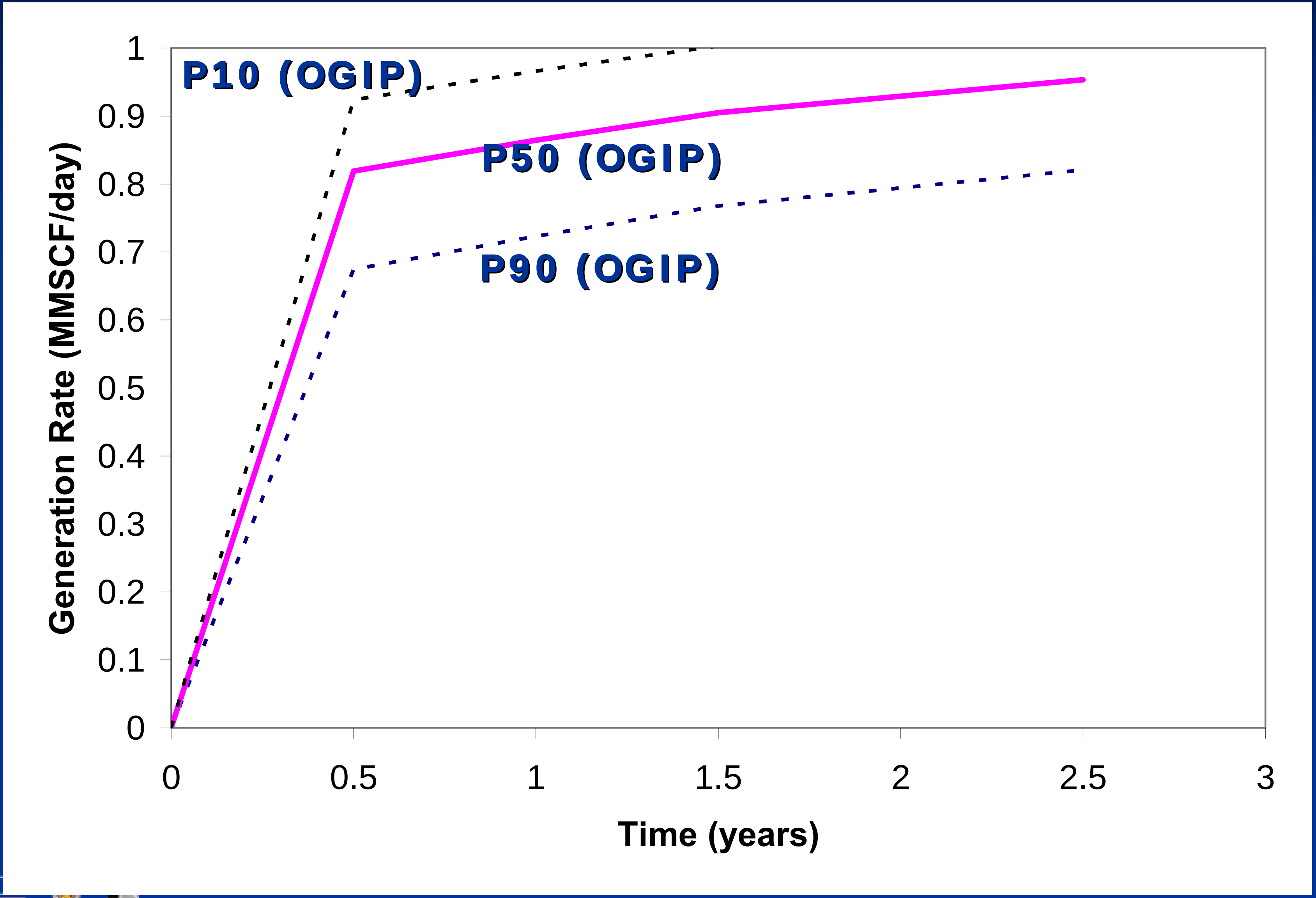


$$R_h = N_b \, \tau \, Ste\left[\frac{8}{3\sqrt{\pi}}\sqrt{\tau} + N_c\right]$$

Bottomhole Pressure



Hydrate Contribution in Rate



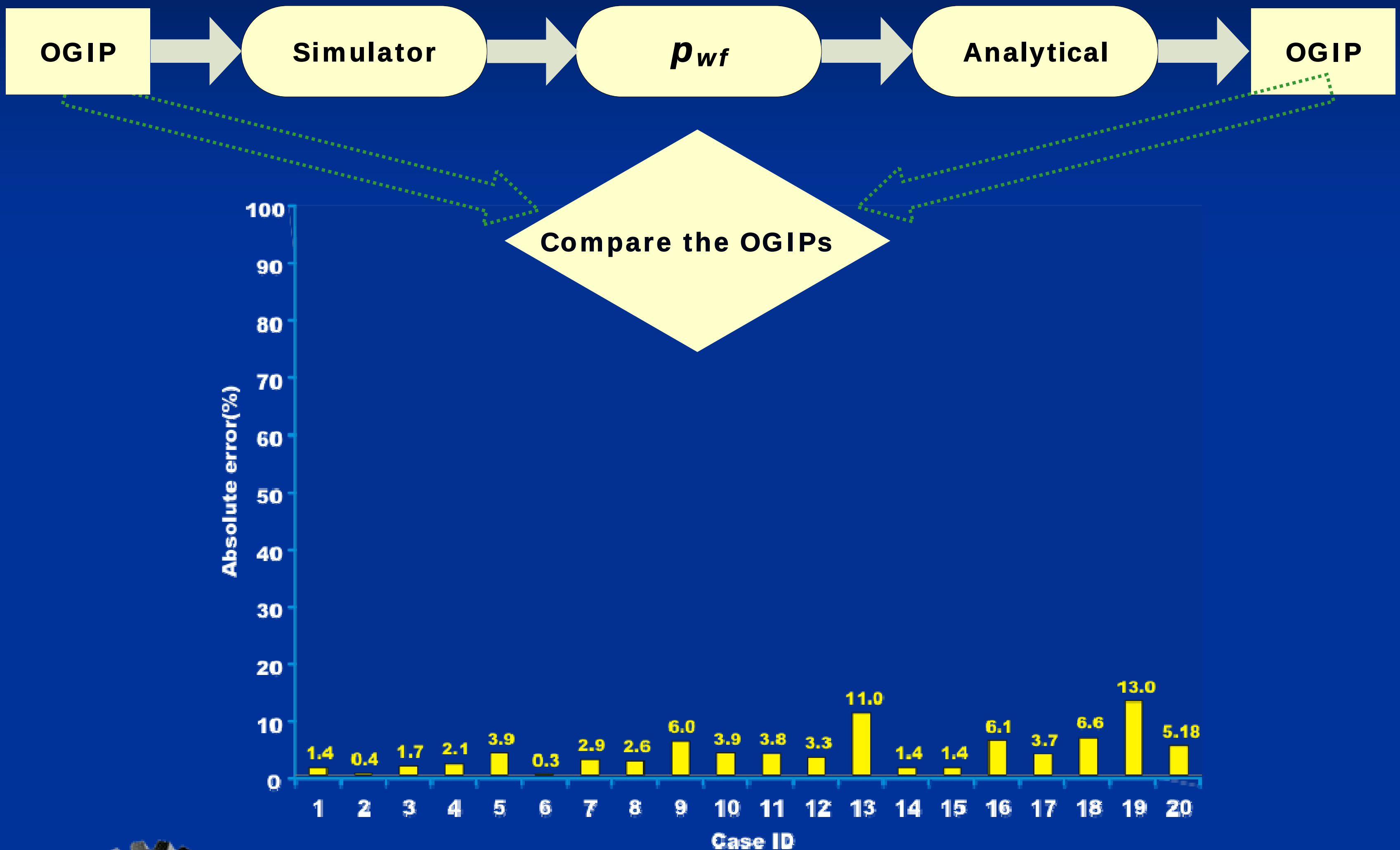
Why Analytical?

- **Limited data requires risk analysis (hundred's of runs)**

- **Speed-up factor**
  - One simulation run: 10 hours
  - 10,000 analytical runs: 2 minutes
  - Speed-up factor: 3×10^6

- **Availability and ease of use**

Reserve Estimation



Conclusions

- For the cases studied
  - Hydrate contribution to gas production was significant
- A “simple” material (and energy) balance equation was developed
- The simple model allows prospect evaluation and large number of runs required in risk analysis
    - Evaluate the upside due to contribution of hydrates
    - Etc.
- In an inverse mode, the model can be used for reserve estimation

Acknowledgments

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Thank you!

Questions?