SPE 63085

Compositional Grading
Theory and Practice

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SPE International

Society of Petroleum Engineers

“Theory”

Simple 1D Gradient Models

- **Isothermal Gravity/Chemical Equilibrium**
  - **Defining General Characteristics**
    - **Different Fluid Systems (SPE 28000)**
    - **Quantifying Variations**

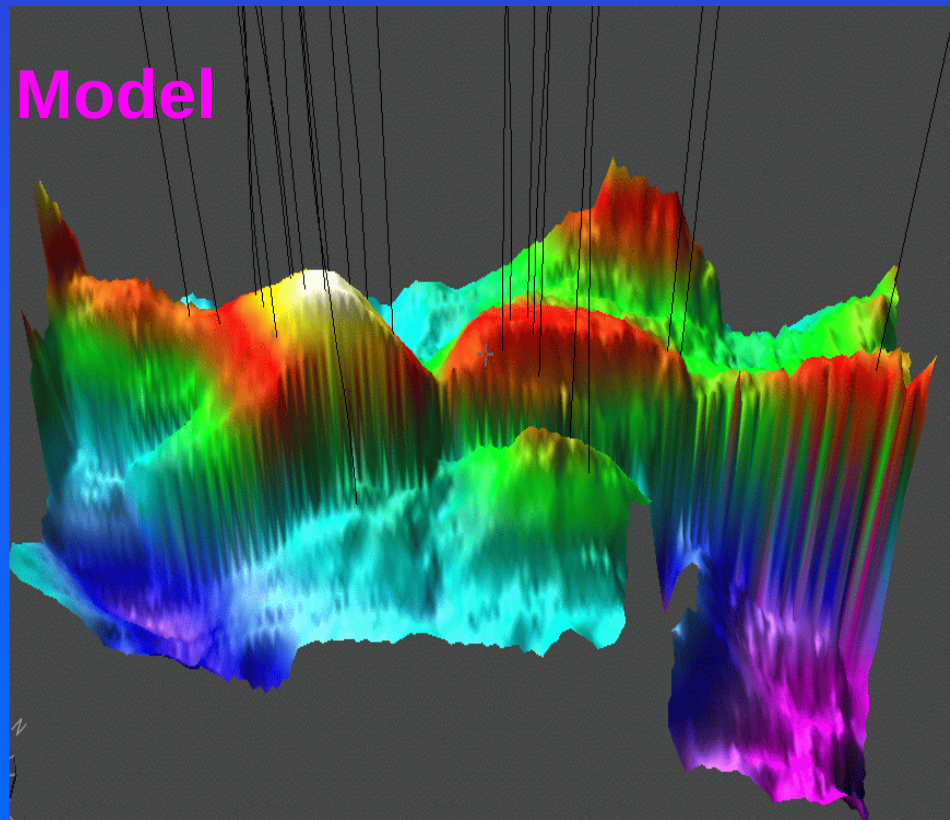
- **Non-Isothermal Models with Thermal Diffusion.**
  - ***Quantitative* Comparisons**
    - ***Different Models***
    - ***Different Fluid Systems***

“Practice”

- Using Samples
- Quantifying Uncertainties

… Develop a Consistent EOS Model

- Defining Trends
- Fluid Communication
- Initializing Reservoir Models
- Predicting a Gas-Oil Contact
- History Matching



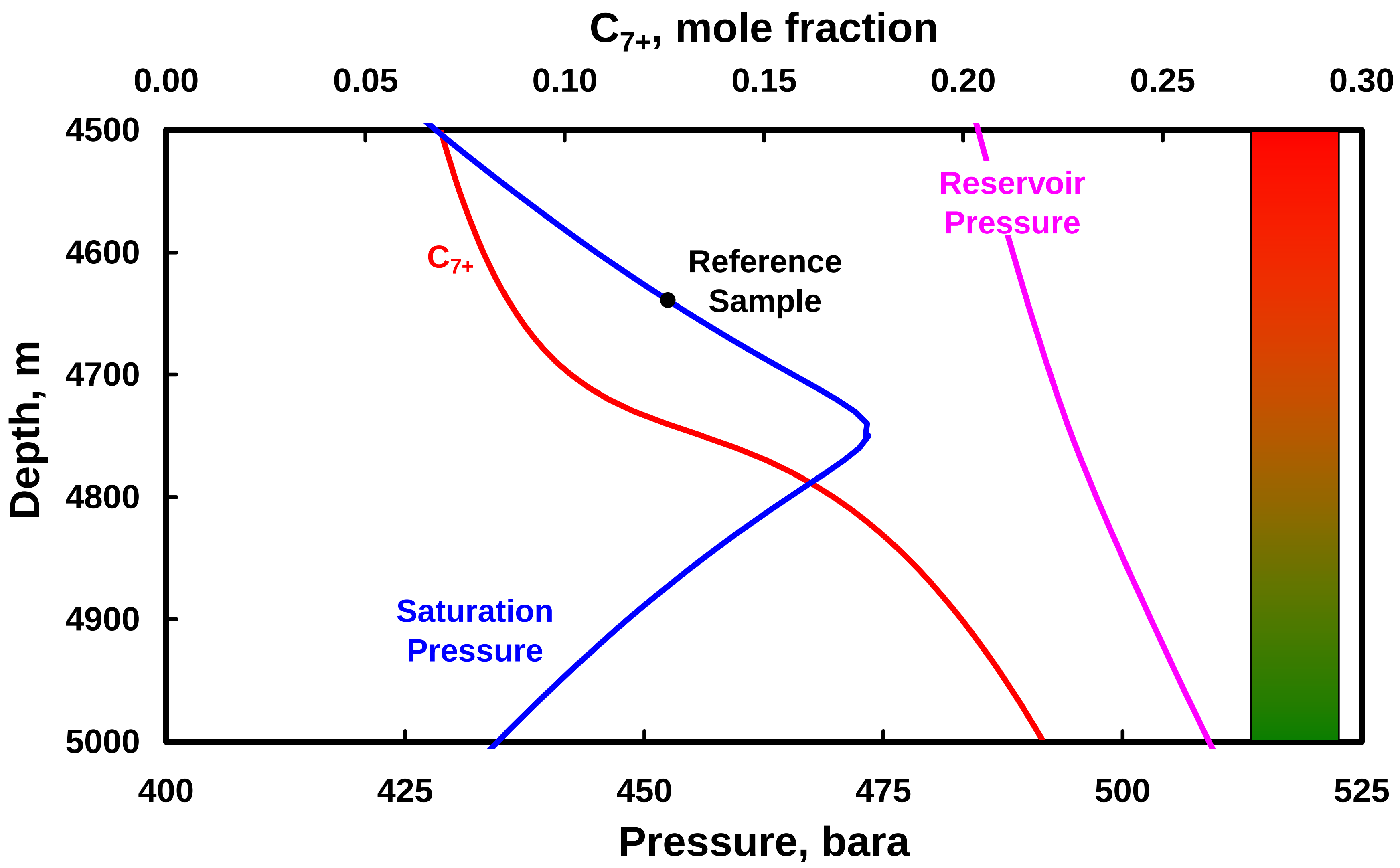
Isothermal Gradient Model

- Balance of chemical and gravity potentials

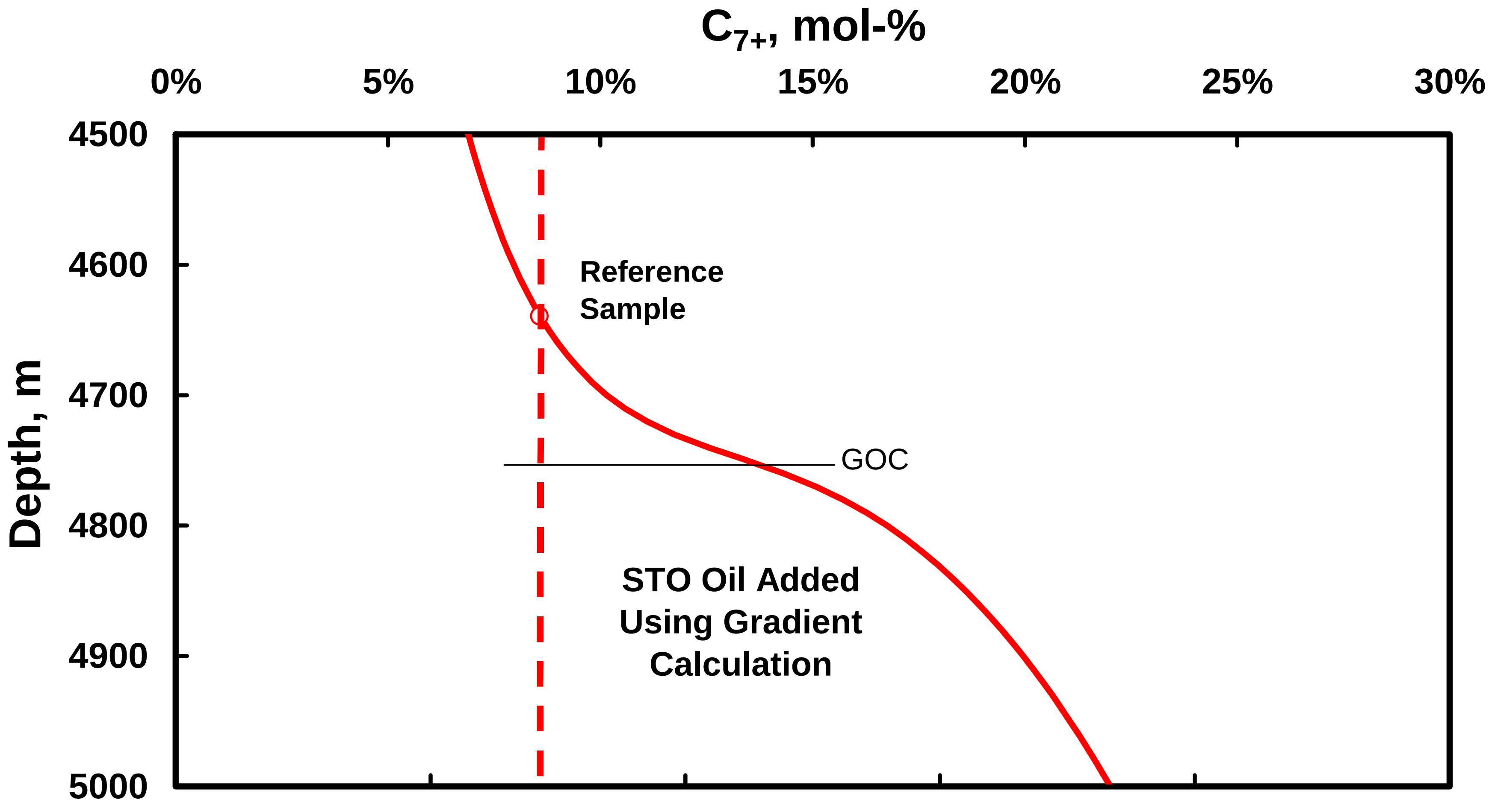
- Given … { H_{ref} , p_{Rref} , T_{ref} , z_{iref} } … calculate
  - $z_i(H)$
  - $p_R(H)$
  - $p_{sat}(H)$

- IOIP(H) ~ $z_{C7+}(H)$

Isothermal Gradient Model



IOIP(H) ~ z_{C7+}(H)



C7+, mol-%
0%
5%
10%
15%
20%
25%
30%
4500
4600
4700
4800
4900
5000
Depth, m
Reference
Sample
GOC
STO Oil Added
Using Gradient
Calculation

Non-Isothermal Gradient Models

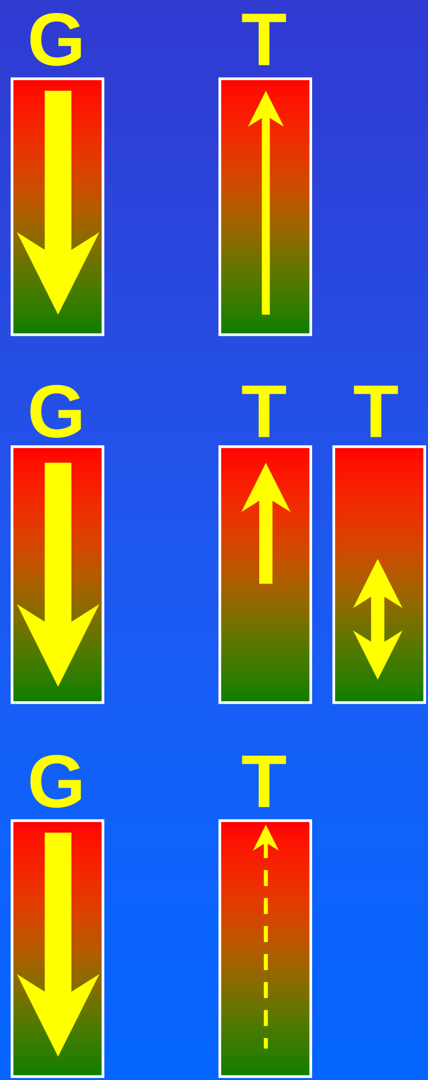
- Component Net Flux = Zero
  - Chemical Energy
  - Gravity
  - *Thermal Diffusion ???*
- Given … { H_{ref} , p_{Rref} , T_{ref} , z_{iref} } … calculate
  - $z_i(H)$
  - $p_R(H)$
  - $p_{sat}(H)$

T(H)

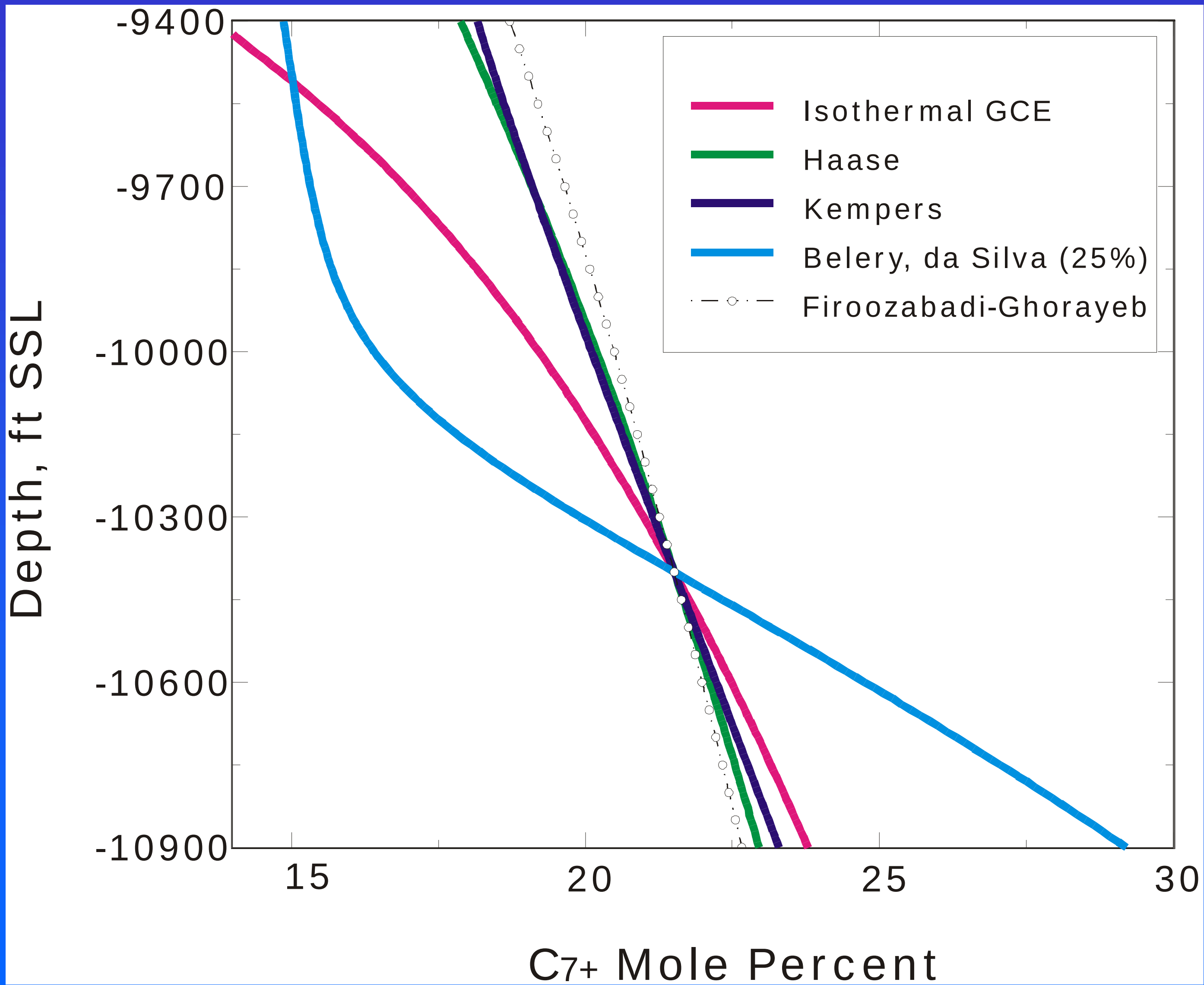
Non-Isothermal Gradients

Thermal Diffusion Models

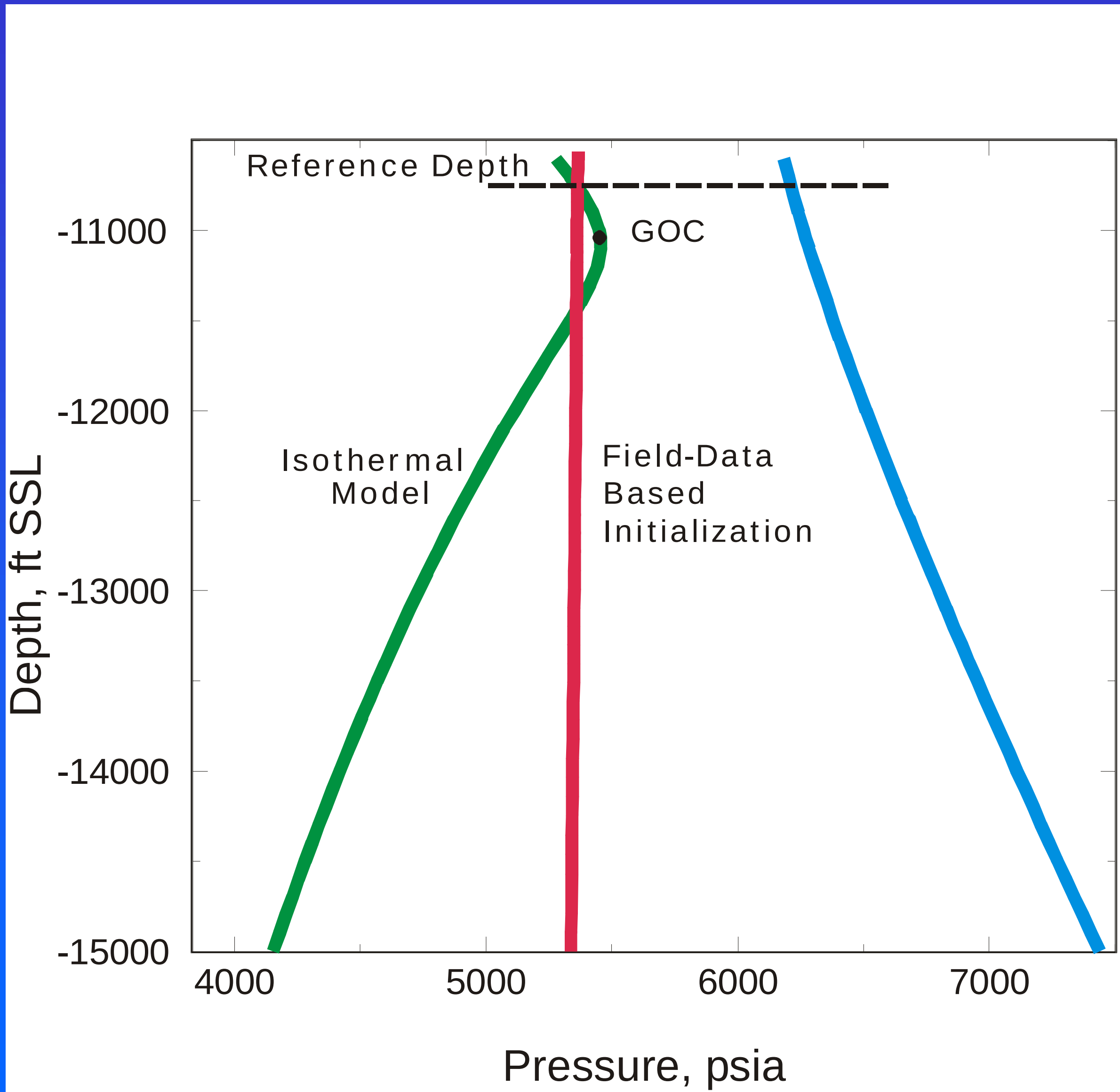
- Thermodynamic
  - Haase
  - Kempers
- Thermodynamic / Viscosity
  - Dougherty-Drickhamer (Belery-da Silva)
  - Firoozabadi-Ghorayeb
- “Passive”
  - Thermal Diffusion = 0 , $\nabla T \neq 0$



Ekofisk Example

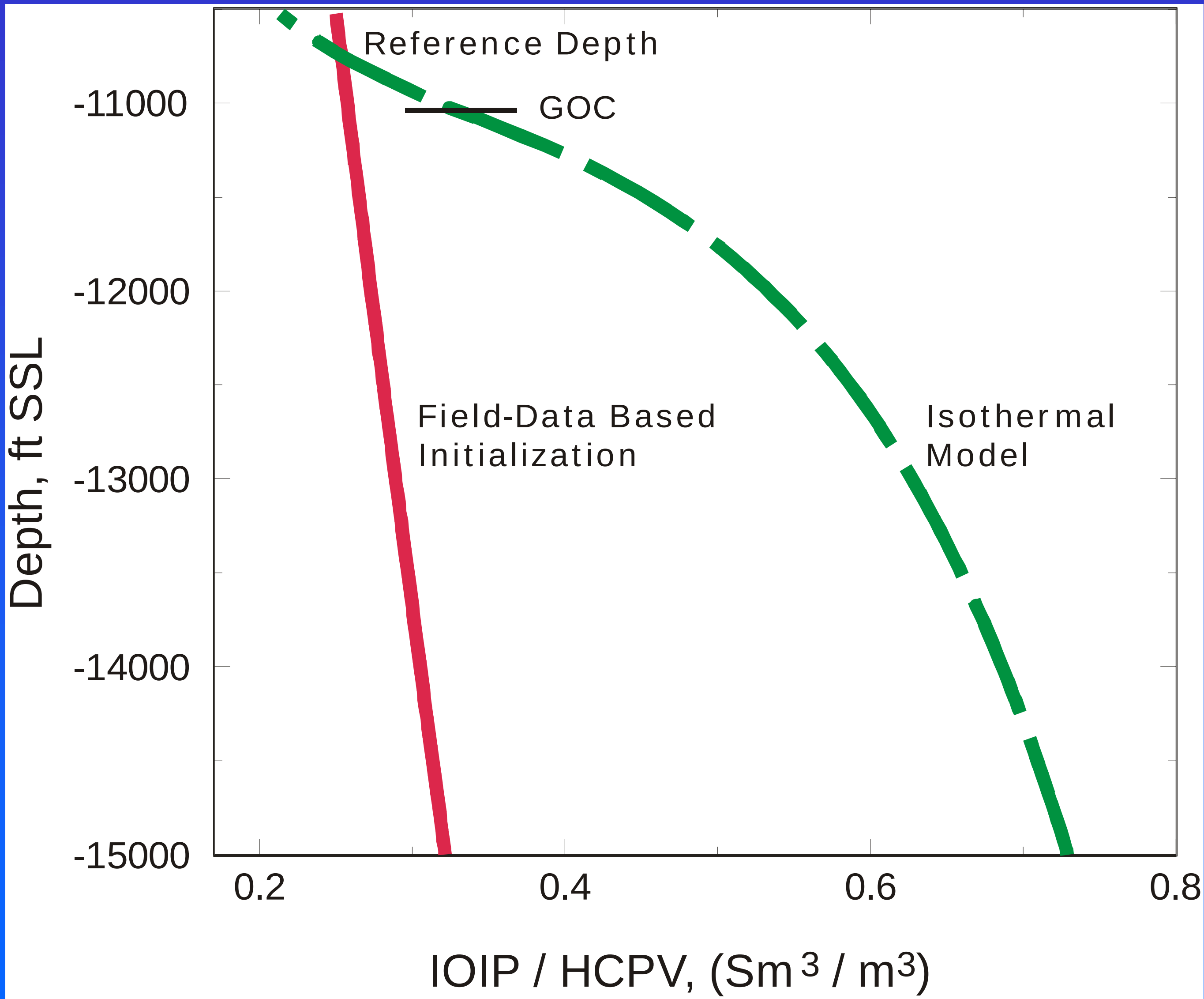


Cupiagua



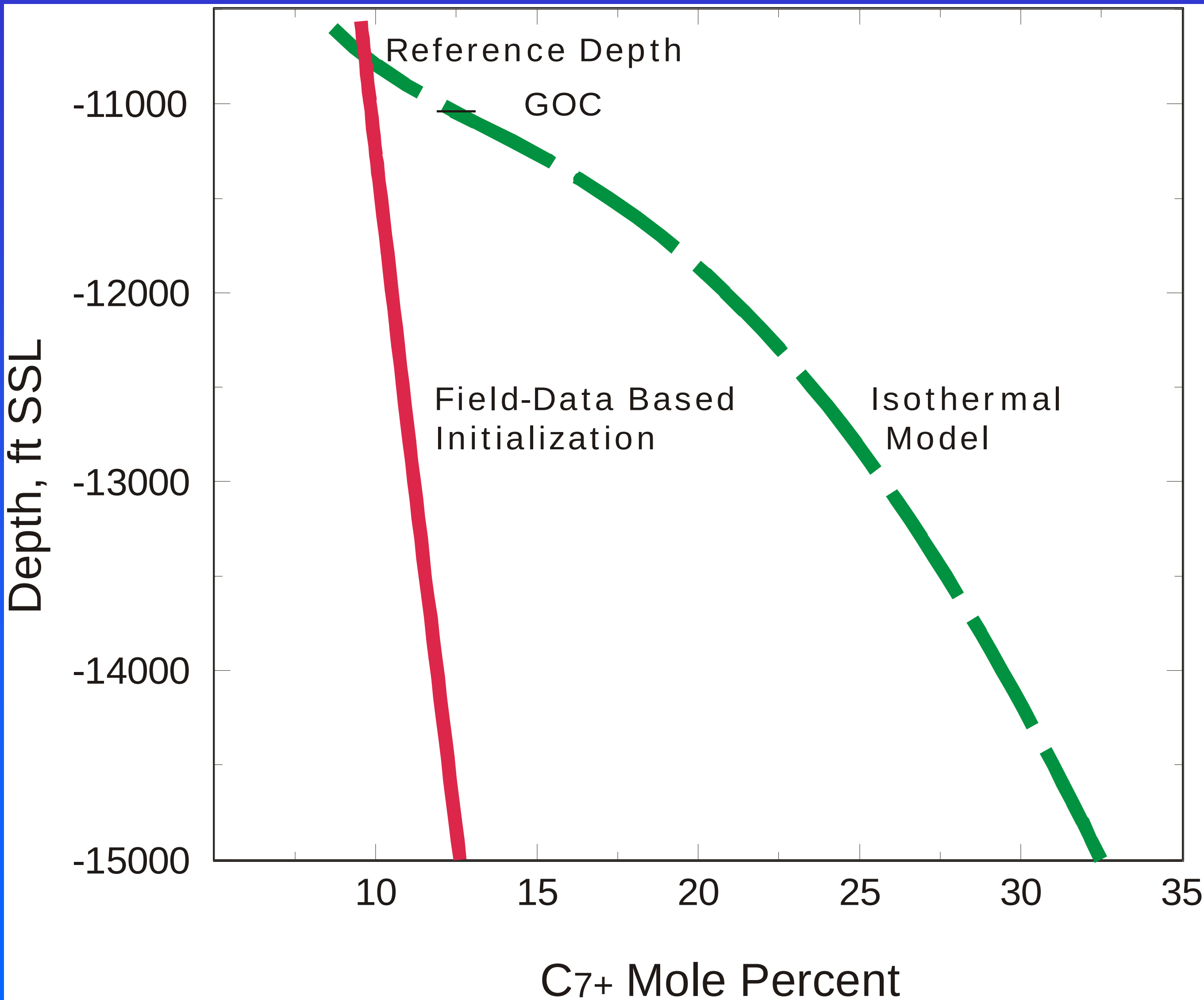
Reference Depth
GOC
-11000
-12000
-13000
-14000
-15000
Depth, ft SSL
Isothermal Model
Field-Data Based Initialization
4000
5000
6000
7000
Pressure, psia

Cupiagua



Reference Depth
GOC
-11000
-12000
-13000
-14000
-15000
Depth, ft SSL
Field-Data Based
Initialization
Isothermal
Model
0.2
0.4
0.6
0.8
IOIP / HCPV, (Sm3 / m3)

Cupiagua



Reference Depth
GOC
Field-Data Based Initialization
Isothermal Model
-11000
-12000
-13000
-14000
-15000
Depth, ft SSL
10
15
20
25
30
35
C7+ Mole Percent

Theory – *Summary*

- **Isothermal model gives maximum gradient**
- **Convection tends to eliminate gradients**
- **Non-isothermal models generally give a gradient between these two extremes**

Complicating Factors

when traditional 1D models are inadequate

- **Thermally-induced convection**
- **Stationary State not yet reached**
- **Dynamic aquifer depletes light components**
- **Asphaltene precipitation**
- **Varying PNA distribution of C_{7+} components**
- **Biodegredation**
- **Regional methane concentration gradients**
- **Multiple source rocks**

“Practice”

- Using Samples
- Quantifying Uncertainties

  … Develop a Consistent EOS Model

- Defining Trends
- Fluid Communication
- Initializing Reservoir Models
- History Matching

Using Samples

- Plot C_{7+} mol-% versus depth
- $z_{C7+} \sim 1/B_o = OGR/B_{gd}$ – *i.e. IOIP=f(depth)*

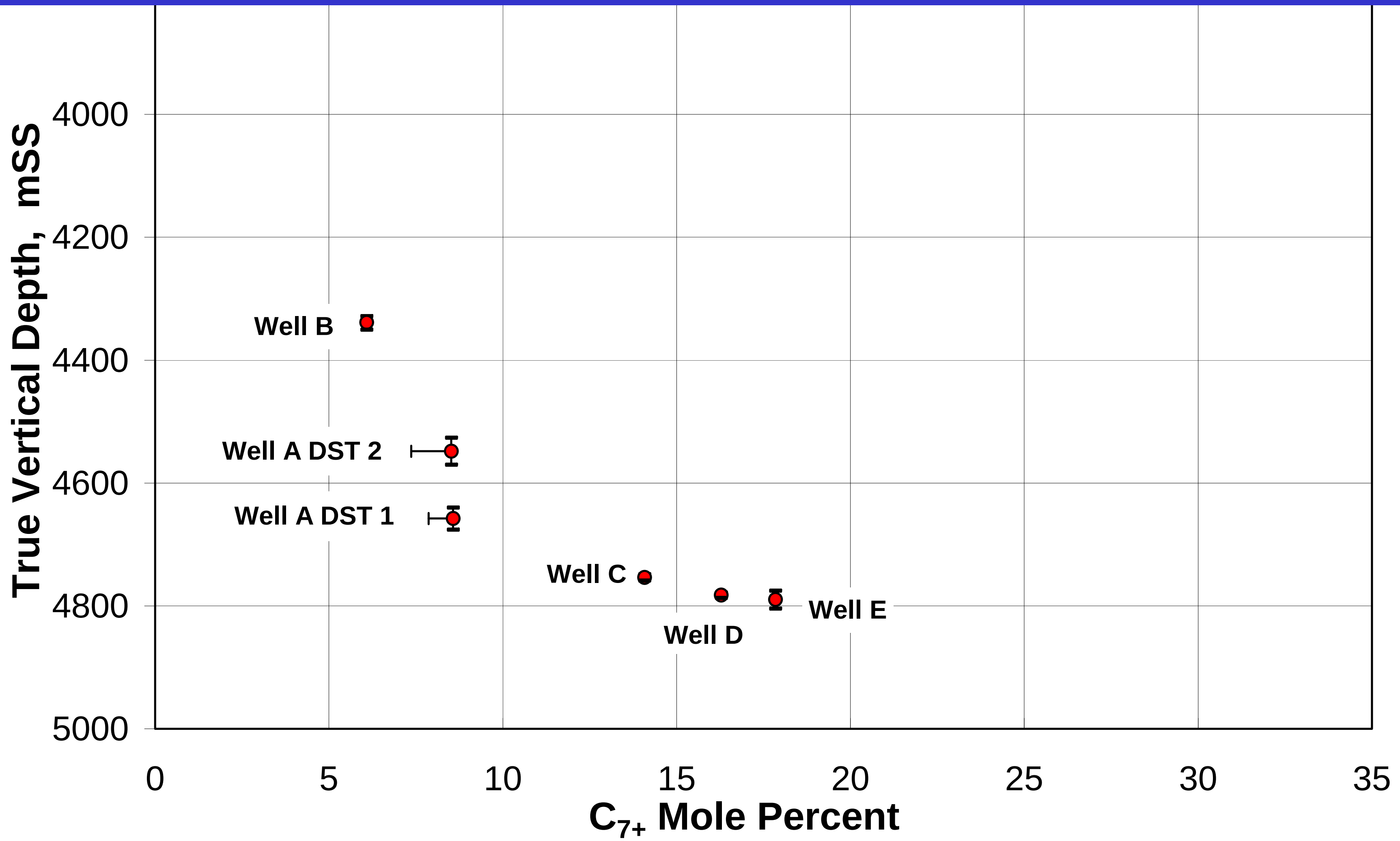
Quantifying Uncertainty

- Use error bars for <u>depth</u> & <u>composition</u>
  - $\Delta C_{7+} \approx \Delta OGR / (C_o + \Delta OGR)$

    $C_o=(M/\rho)_{7+} (p_{sc}/RT_{sc})$

Åsgard, Smørbukk Field

Geologic Layer "A"



Develop a Consistent EOS

- Use <u>All</u> Available Samples *with*
  - Reliable Compositions
  - Reliable PVT Data
- Fit <u>Key</u> PVT and Compositional Data
  - Reservoir Densities
  - Surface GORs, FVFs, STO Densities
  - CVD Gas C_{7+} Composition vs Pressure
  - Reservoir Equilibrium Phase Compositions

Defining Trends

Use All Samples Available

- Sample Exploration Wells
  - Separator Samples
  - Bottomhole Samples
  - MDT Samples (water-based mud only)
    - Oil Samples *may* be Corrected
    - Gas Samples with Oil-Based Mud should not be used

Defining Trends

Use <u>All</u> Samples Available

- **Production Wells**
  - **“Early” Data not yet affected by**
    - **Significant Depletion**
    - **Gas Breakthrough**
    - **Fluid Displacement / Movement**

Defining Trends

- Any sample's “value” in establishing a trend is automatically defined by inclusion of the samples error bars in depth and composition.

- Samples considered more insitu-representative are given more "weight" in trend analysis.

Fluid Communication

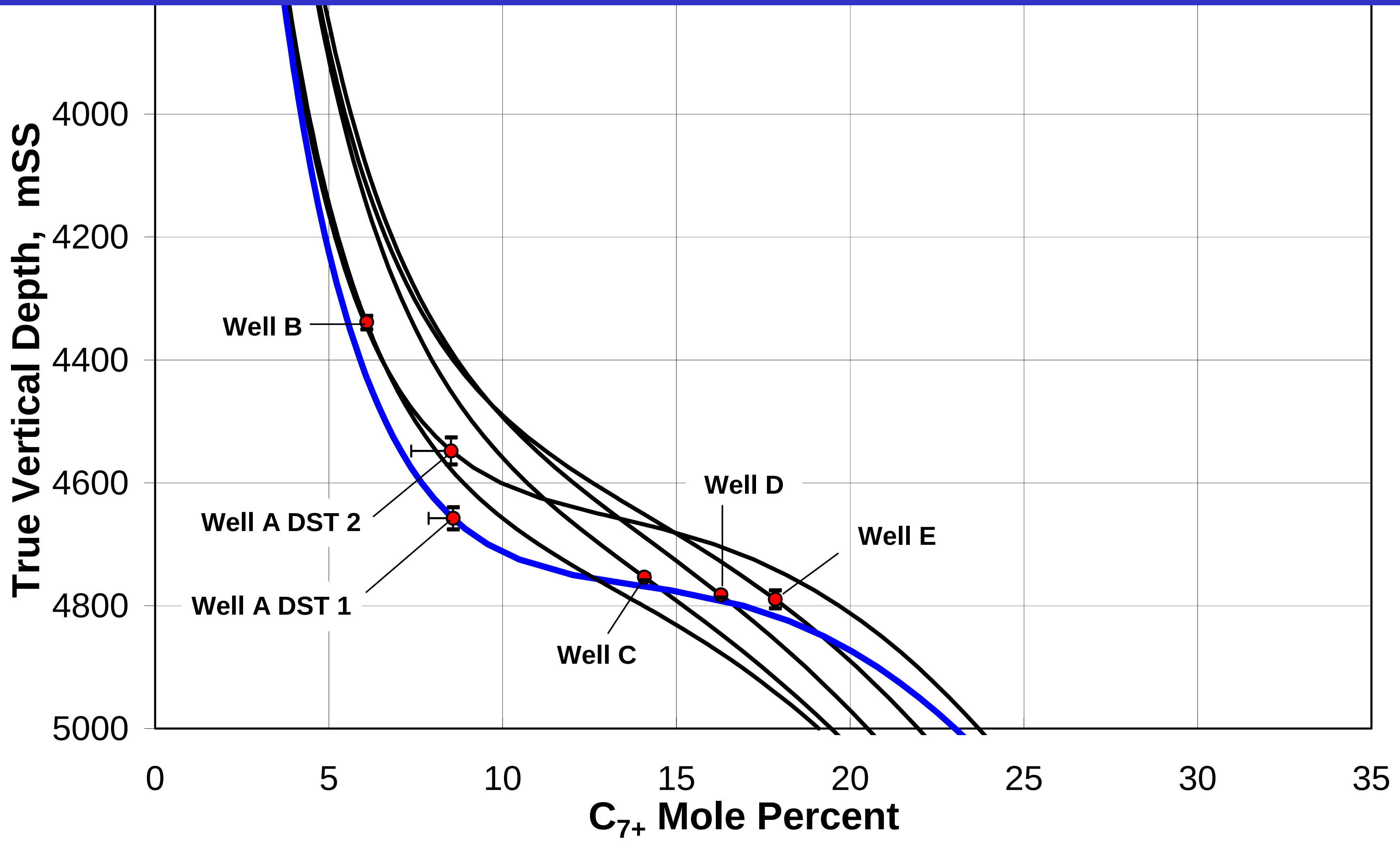
- Compute isothermal gradient for each and every sample

- Overlay all samples with their predicted gradients

  - Don't expect complete consistency
  - Do the gradient predictions have similar shape ?
  - Do the gradient predictions cover similar range in C_{7+} ?

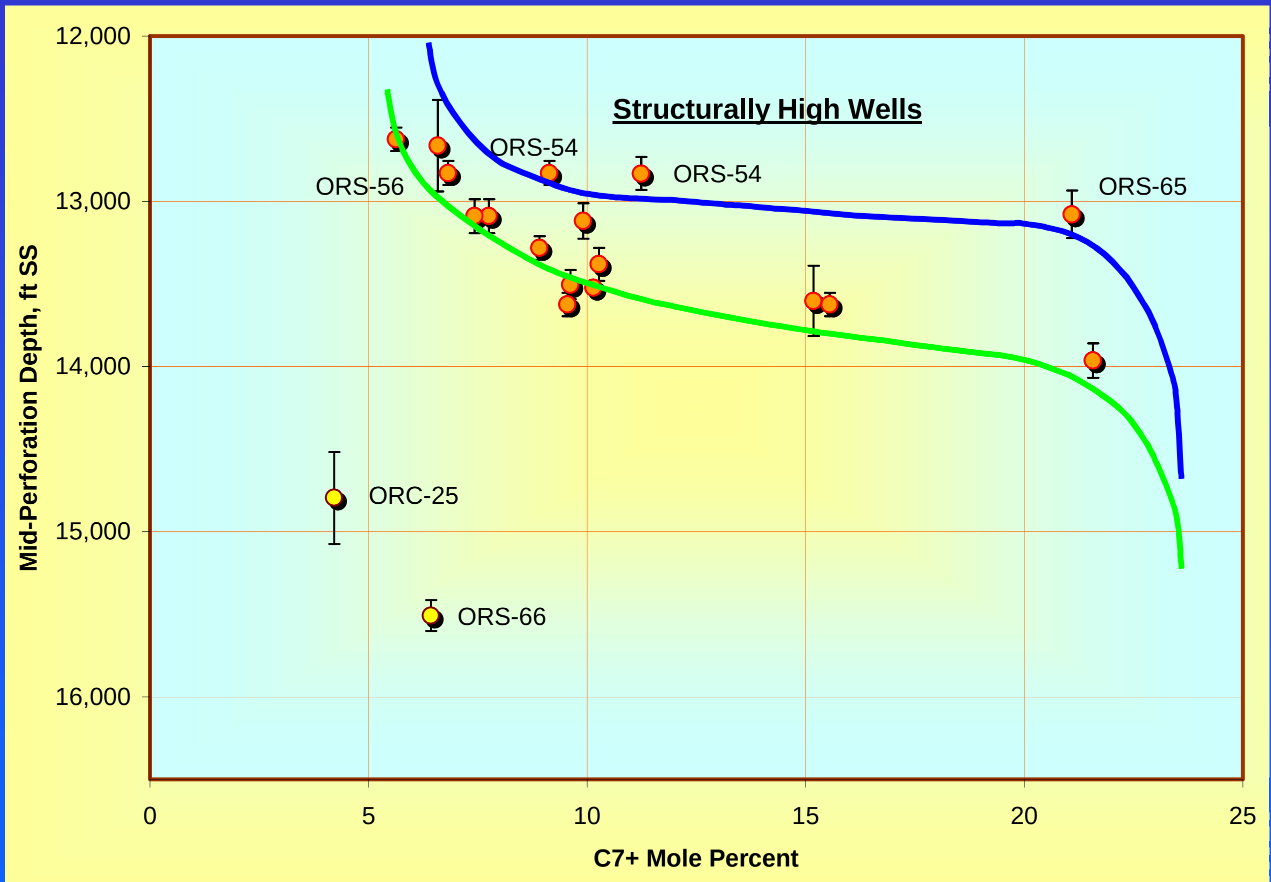
Åsgard, Smørbukk Field

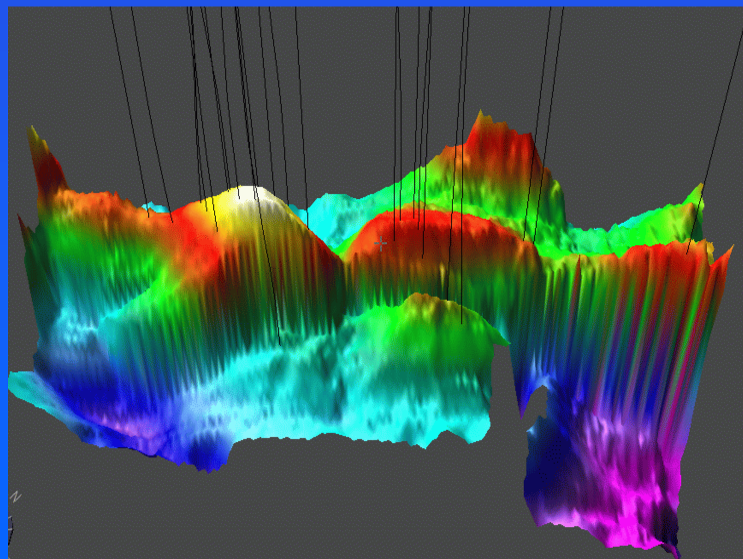
Geologic Layer "A"



Orocual Field

Venezuela





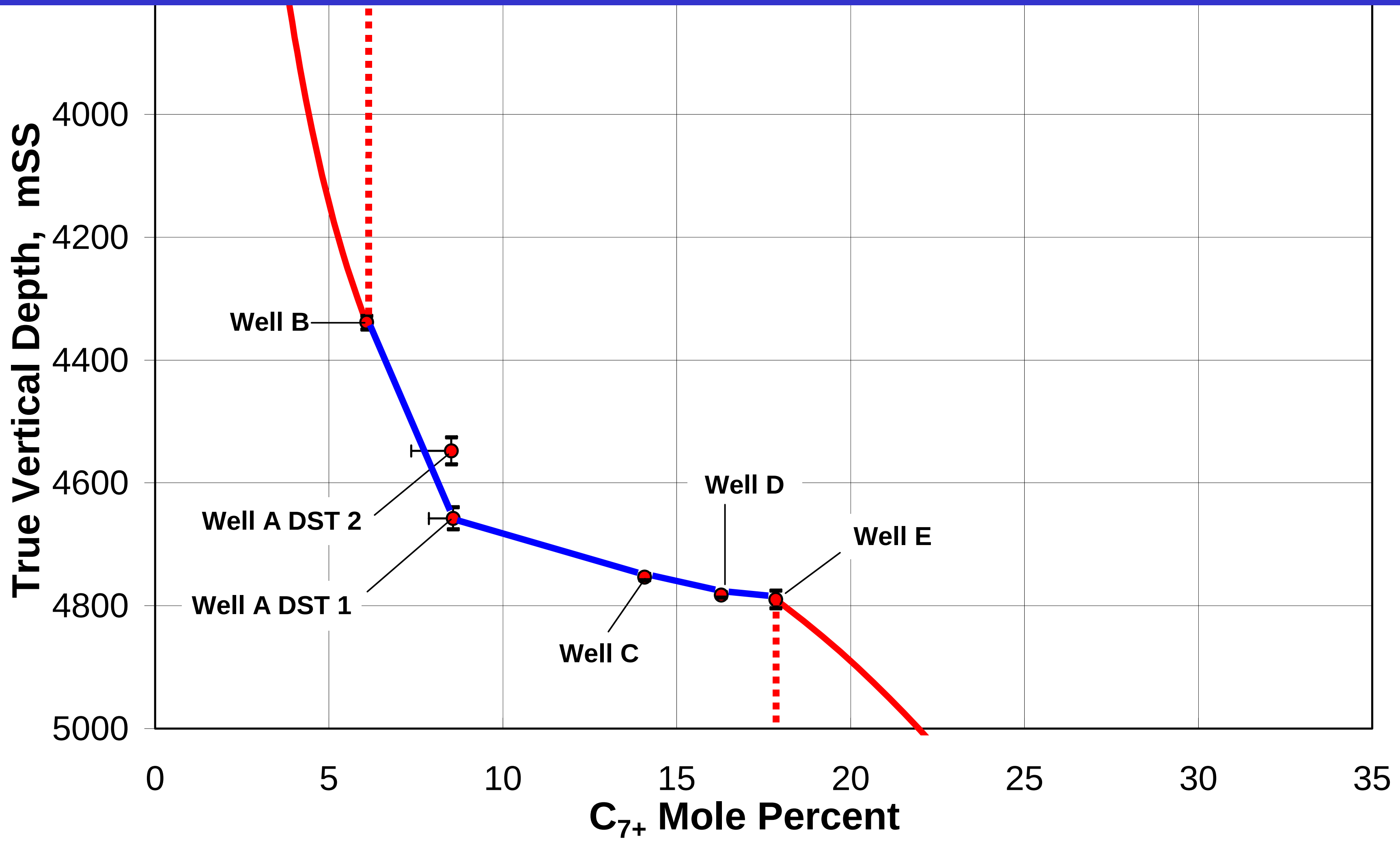
Initializing Reservoir Models

- **Linear interpolation between "select" samples**
  - **Guarantees Automatic "History Matching"**
  - **Check for consistent of p_{sat} vs depth**

- **Extrapolation**
  - ***Sensitivity 1* : isothermal gradient of outermost samples**
  - ***Sensitivity 2* : constant composition of outermost samples**

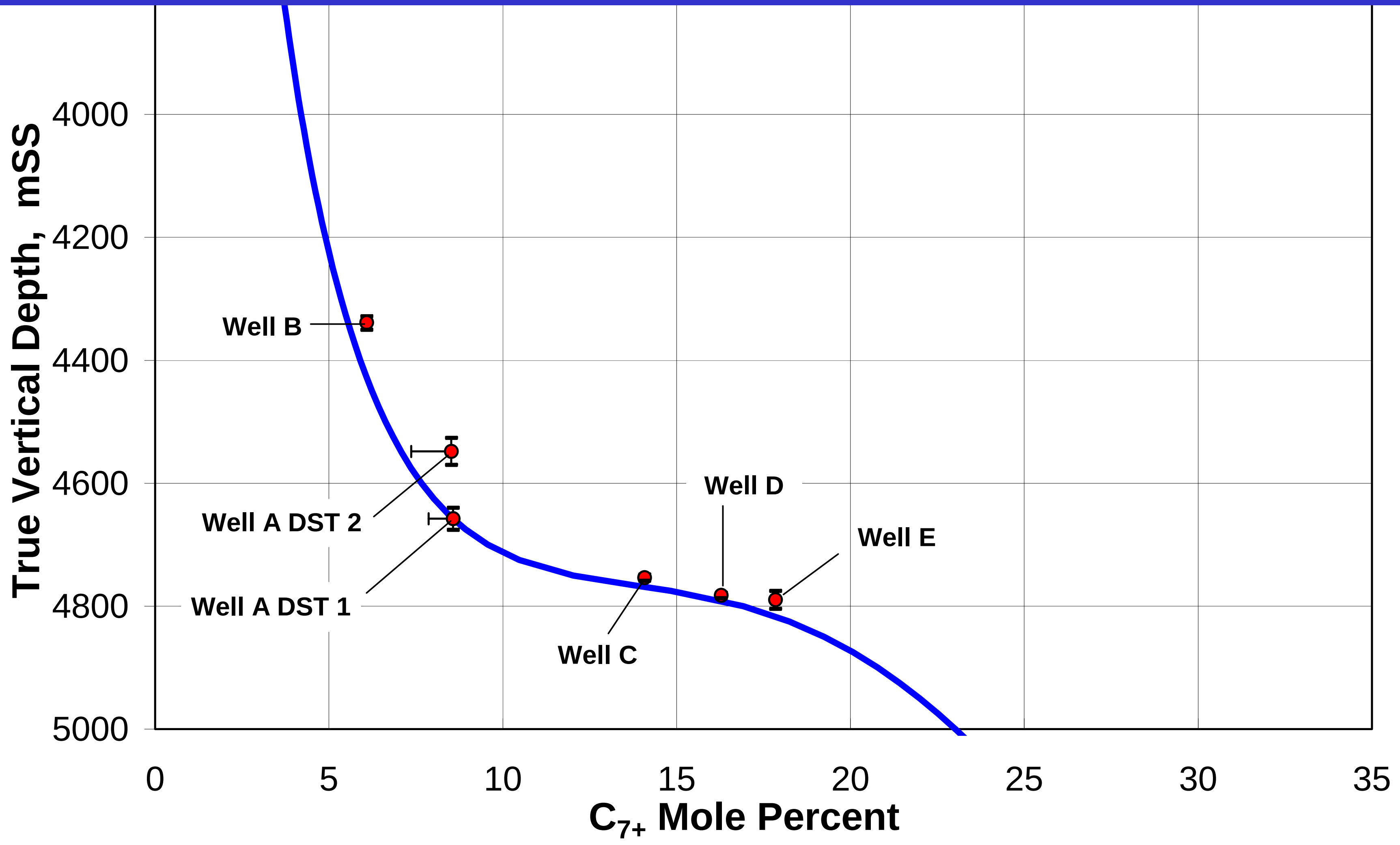
Åsgard, Smørbukk Field

Geologic Layer "A"



Åsgard, Smørbukk Field

Geologic Layer "A"



Predicting a Gas-Oil Contact

… "Dangerous" but Necessary

- **Use Isothermal Gradient Model**
  - Predicts minimum distance to GOC
- **Most Uncertain Prediction using Gas Samples**
  - 10 – 50 m oil column per bar uncertainty in dewpoint !
  - 2 – 10 ft oil column per psi uncertainty in dewpoint !

… Treat dewpoints (and bubblepoints) with special care