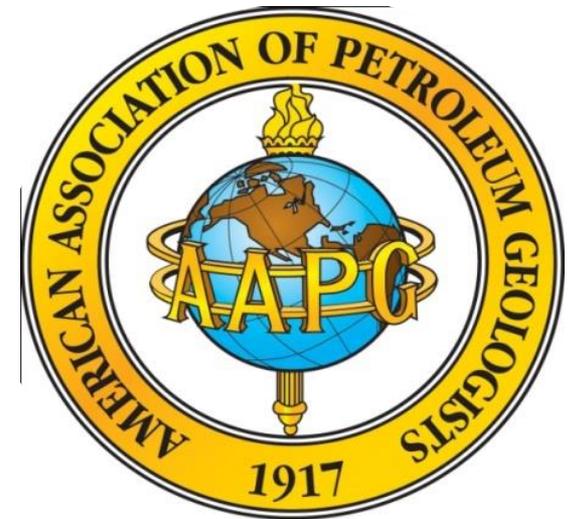
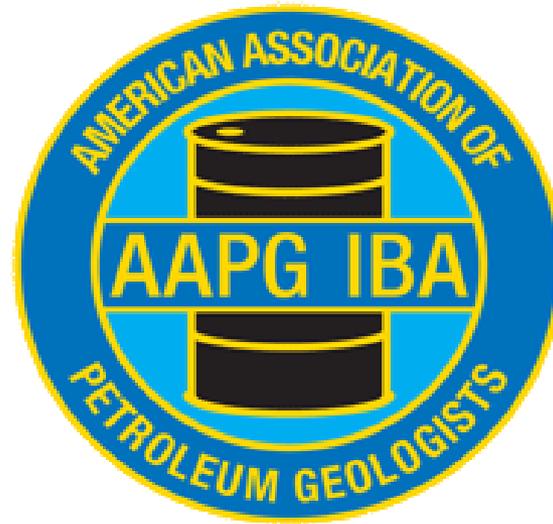
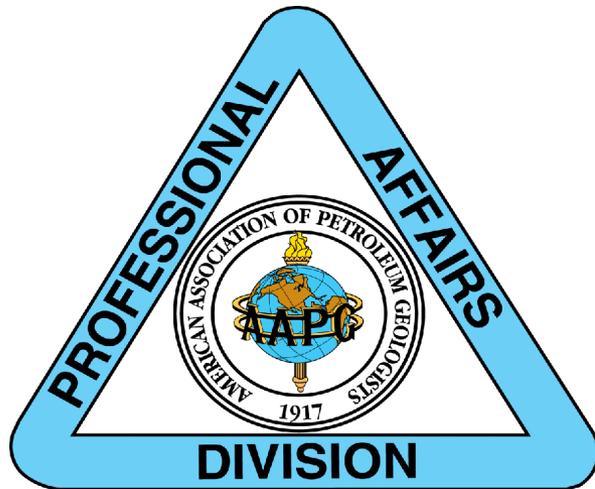


# The Imperial Barrel Award Committee



In Conjunction With The  
**AAPG Division of Professional Affairs**

# Presents



## Estimating and Risking Hydrocarbon Reserves and Resources

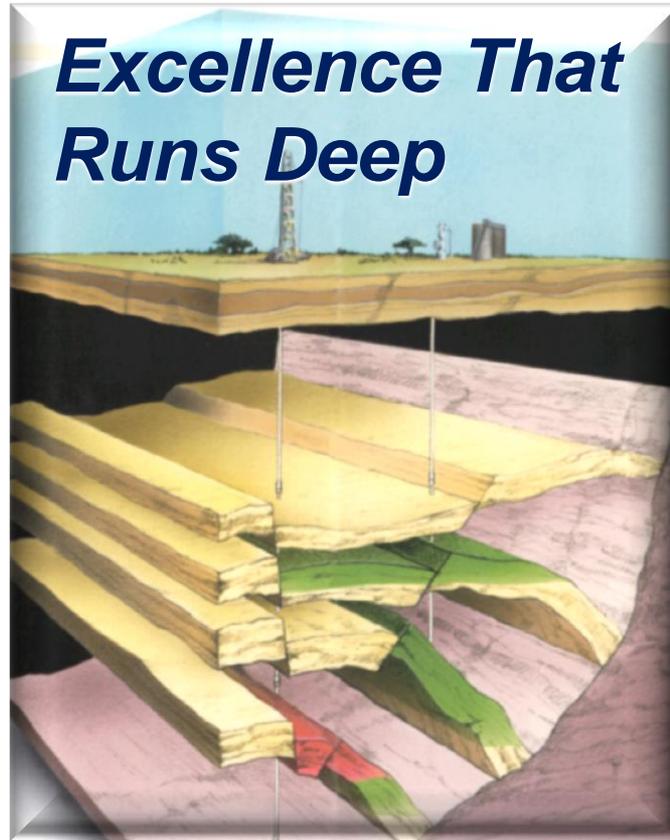


**By**

# **Subsurface Consultants & Associates, LLC**



**Consulting**



**Projects  
&  
Studies**



**Direct  
Hire**



**Training**

**An International Consultancy & Training Company**



# Subsurface Consultants & Associates, LLC

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We invite you to judge us by our results: a history of successful

# Susan Howes, PE, PHR

## VP of Engineering at SCA



### **33+ years industry experience**

- **Joined SCA in 2016**
- **8 years with Chevron – reservoir management and organizational capability**
- **25 years with Anadarko – reservoir engineering, business development, talent management**

### **SPE**

**Susan has coauthored several papers and articles on the topics of uncertainty management, risk management, and talent management for SPE conferences and publications. She is an SPE Distinguished Member.**



# Bob Shoup

## Board Certified Petroleum Geologist

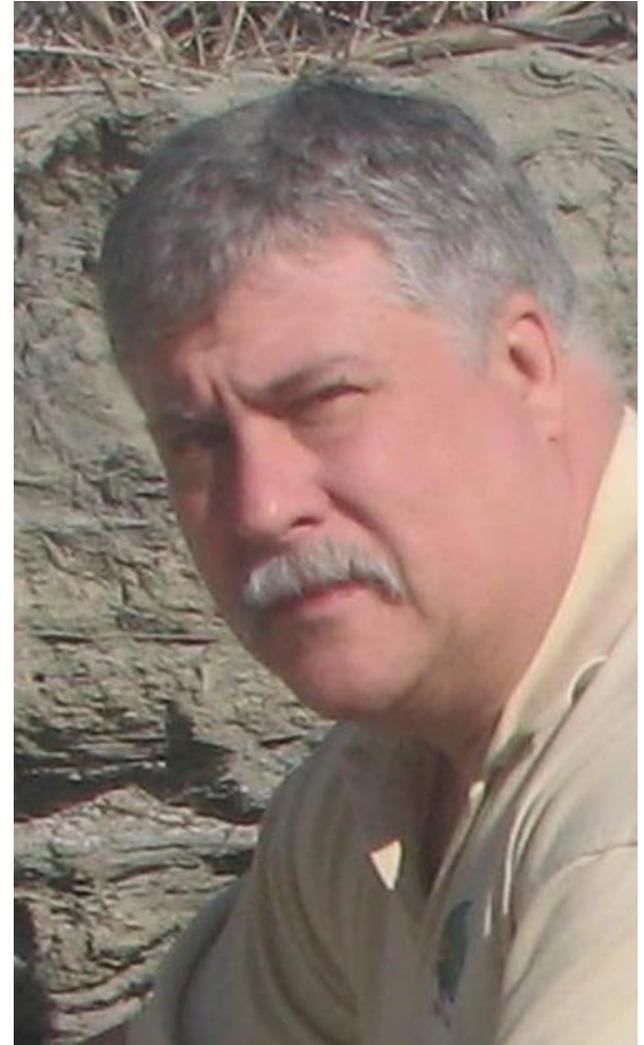
36+ years industry experience

- 19 years with Shell
- 4 years with independents
- 13 years consulting and training

Discovered over 100 MMBeq  
Exploration Success Rate of 46%

SCA Instructor for:

Applied Subsurface Geological Mapping  
Clastic Depositional Environments  
Project Management  
Reserve Estimation  
Basin, Play, and Prospect Evaluation



# Estimating and Risking



## Hydrocarbon Reserves and Resources



## Petroleum Resource Management System (PMRS)

- Resource
- Reserves

OOIP and OGIP

Volumetric Methodologies

Uncertainty versus Risk





**Many interpreters believe that their objective is to make maps of the subsurface for the purpose of finding hydrocarbons**



**Your real objective is to make money for your company.**

**Your company makes money by finding and developing hydrocarbons**



**To make money,  
managers need to know,  
as accurately as possible,  
how much hydrocarbon  
reserves they have, and  
are likely to find**



## Petroleum Resource Management System (PMRS)

- Resource
- Reserves

OOIP and OGIP

Volumetric Methodologies

Uncertainty versus Risk





# PRMS

## Petroleum Resource Management System



World Petroleum Council

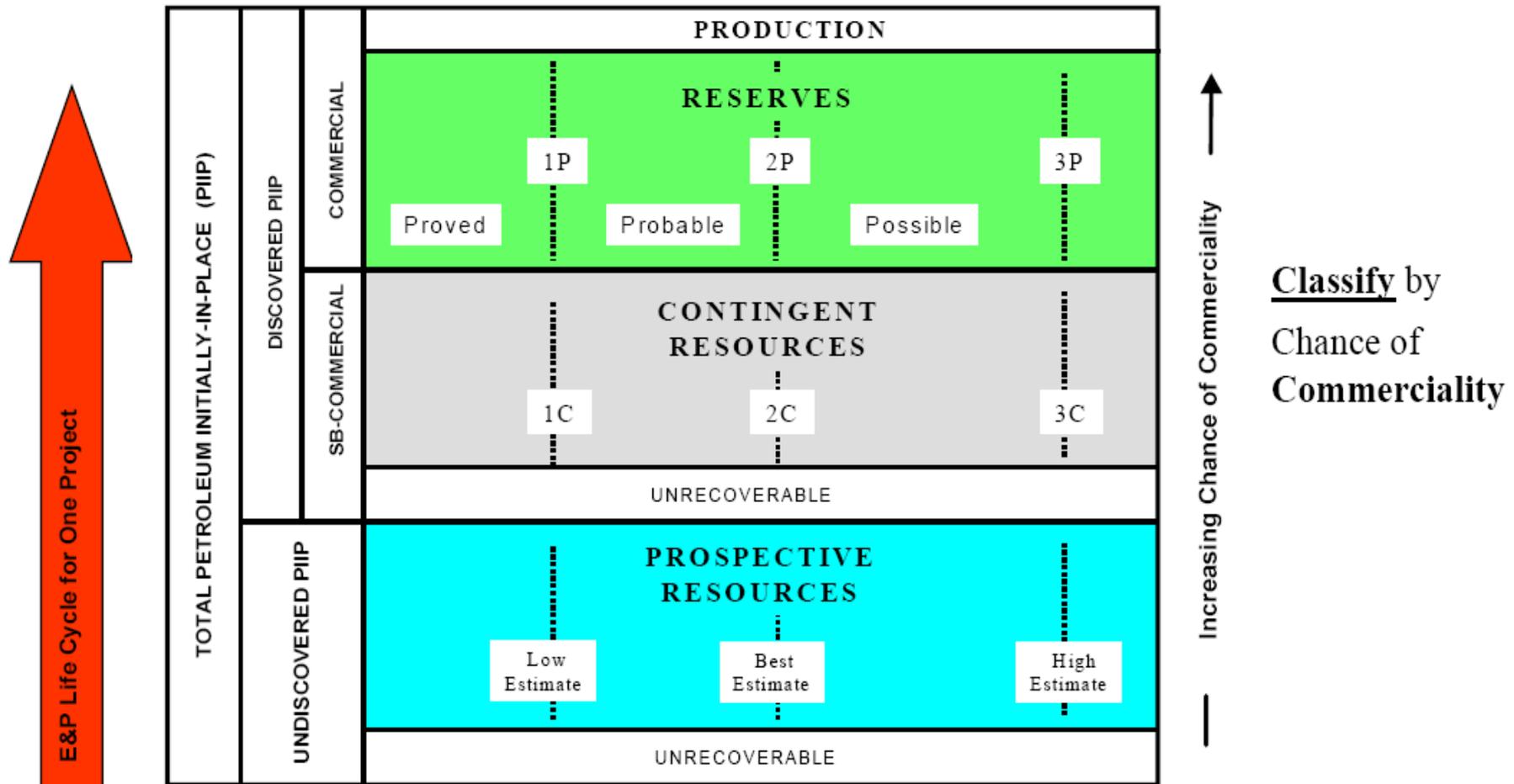


## Guidelines for Application of the Petroleum Resources Management System

November 2011



# PRMS

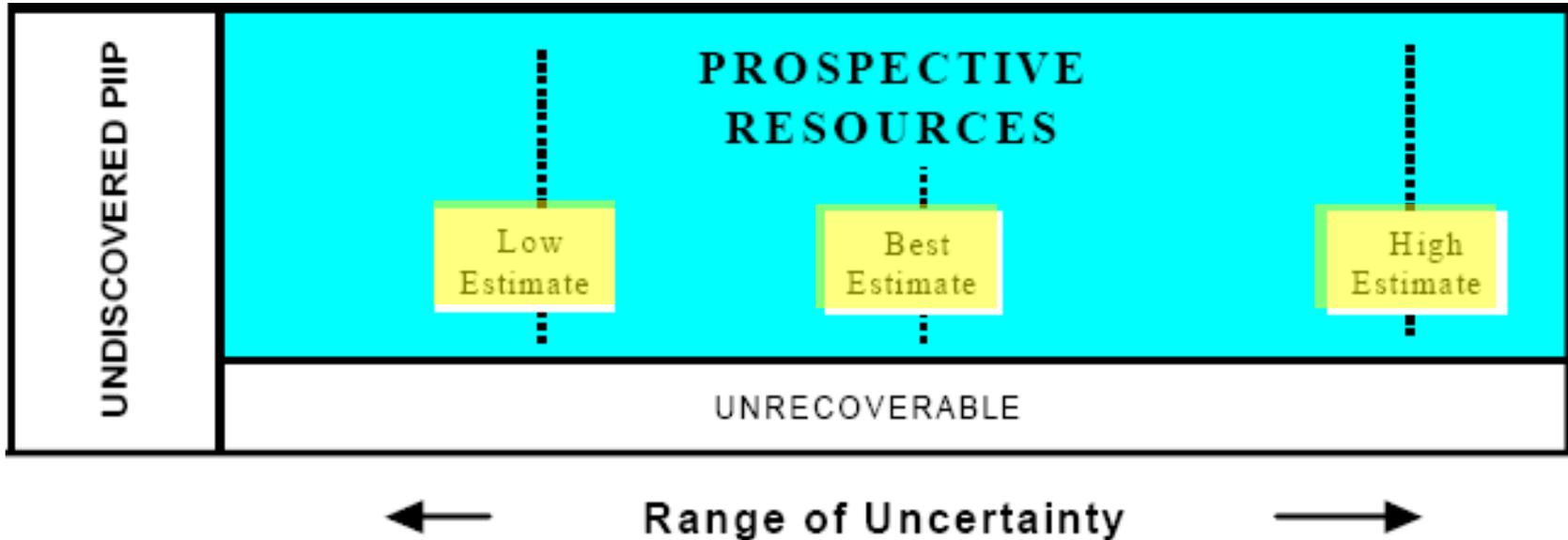


This Figure from the PRMS is a graphical representation of the resources classification framework. The framework defines the major recoverable resources classes: Production, Reserves, Contingent Resources, and Prospective Resources, as well as Unrecoverable petroleum.



# PRMS

## Prospective Resources



Estimate of recoverable sales volumes for

Leads

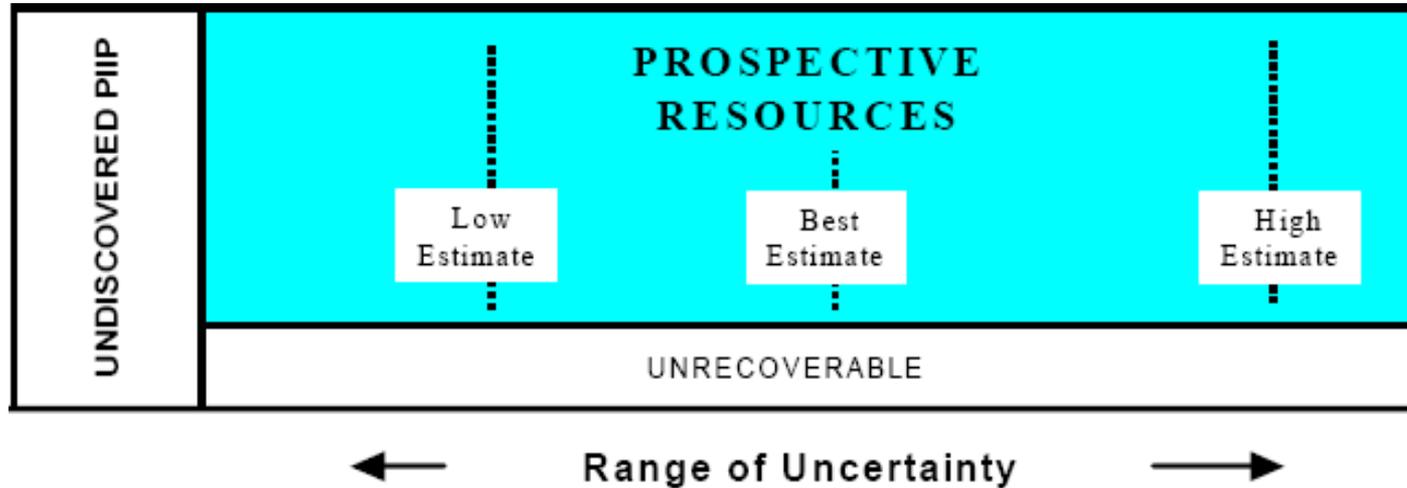
Prospects

**SPE Guidelines**



# PRMS

## Prospective Resources



**Estimate of recoverable sales volumes for  
Prospects**

**Leads**

**Plays**

**Monetization Pathway**



# PRMS

## Prospective Resource

**Those quantities of petroleum estimated, as of a given date, to be potentially recoverable from undiscovered accumulations by application of future development projects.**

**Prospective Resources have both an associated chance of discovery and a chance of development.**



# PRMS

## Prospective Resource

**Minimum**  $P_{100}$

**Low Estimate**  $P_{90}$

**Best Estimate**  $P_{50}$

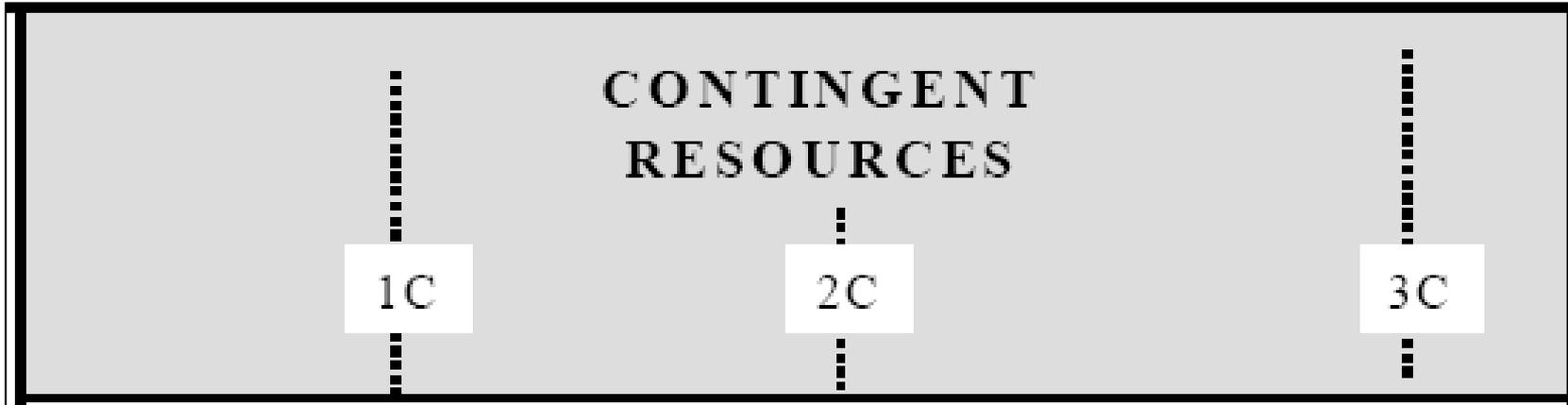
**High Estimate**  $P_{10}$

**Maximum**  $P_0$



# PRMS

## Contingent Resources



**Estimate of recoverable sales volumes for**

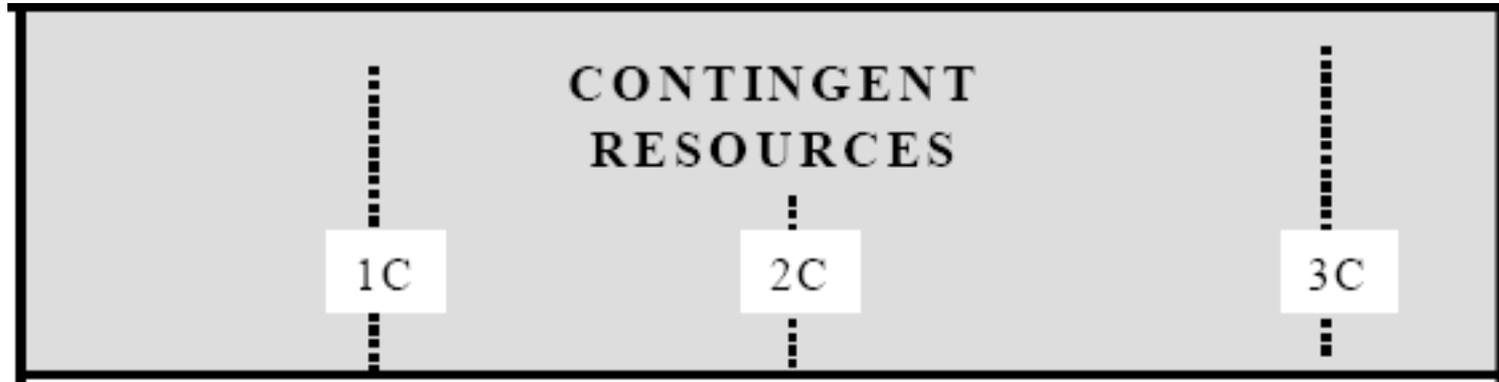
**Discoveries**

**Appraisals**

**Contingent Resources are discovered but not currently commercial or approved for development**

# PRMS

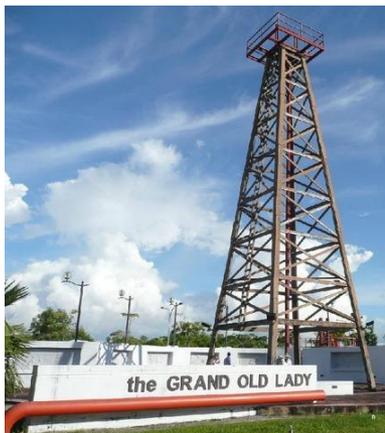
## Contingent Resources



Estimate of recoverable sales volumes for

Pending  
Development  
Sanction

Appraisals



**Monetization Pathway**



# PRMS

## Contingent Resource

### 1C: Proven

Quantity of hydrocarbons estimated with reasonable certainty

Low Estimate  $P_{90}$

Observed Contact or Lowest Known Oil (LKO) or Gas (LKG)

### 2C: Proven + Probable

1C + probable hydrocarbons

Most Likely Estimate or  $P_{50}$

Amplitude or column height defined

### 3C: Proven + Probable + Possible

1C + 2C + possible hydrocarbons

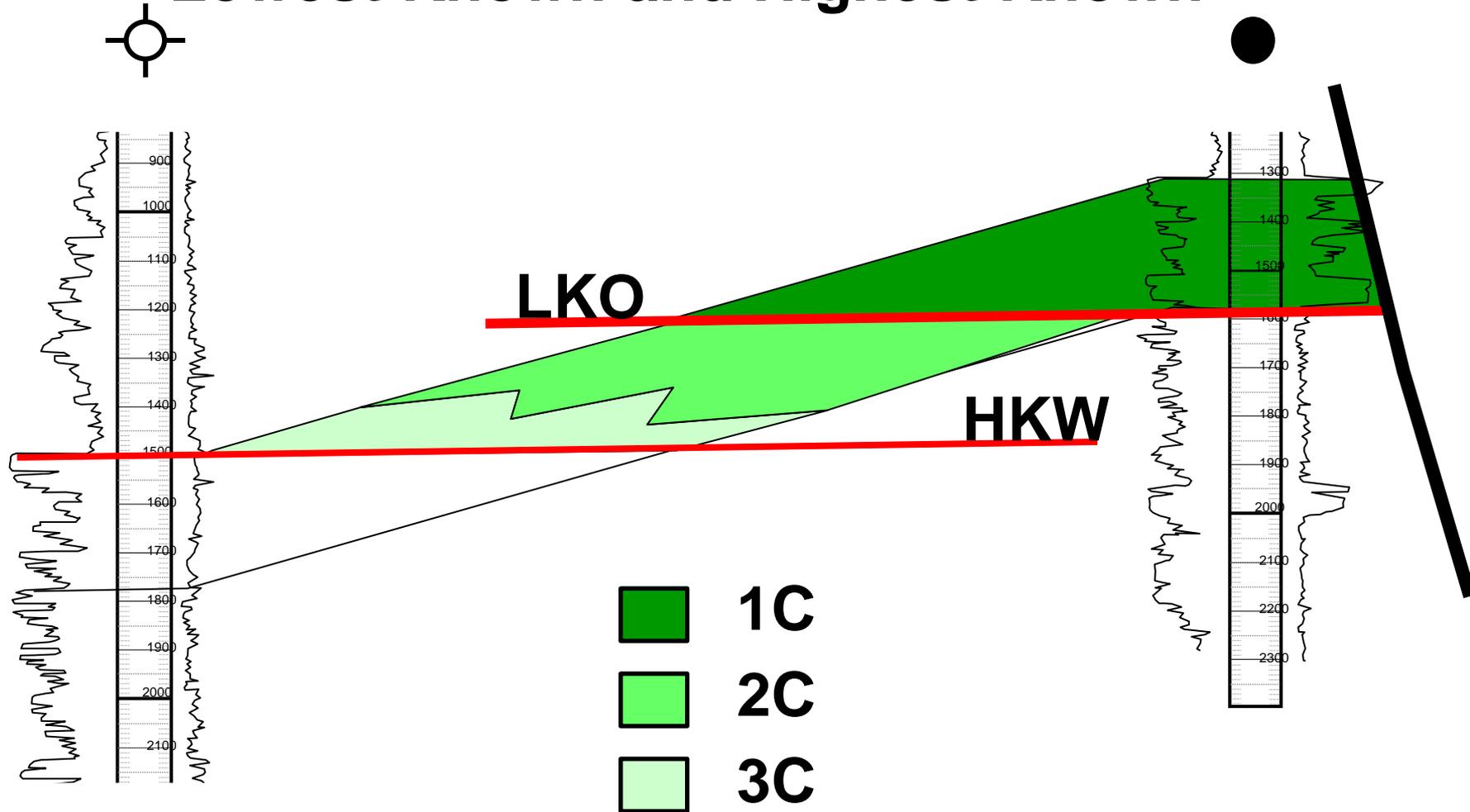
High Estimate or  $P_{10}$

Highest Known Water or Spill Point defined



# PRMS

## Lowest Known and Highest Known

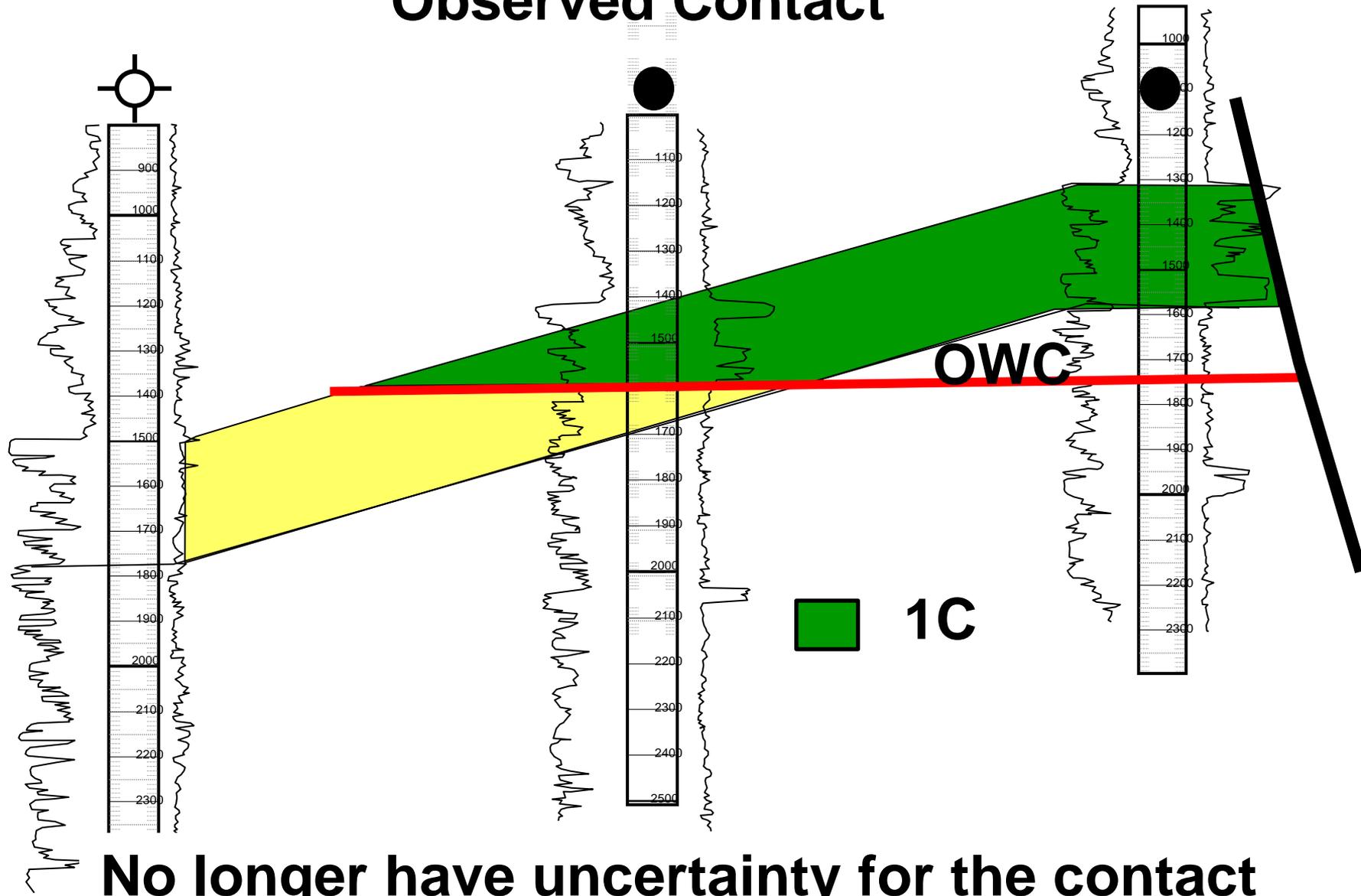


LKHC =  $P_{99}$  and the HKW =  $P_1$



# PRMS

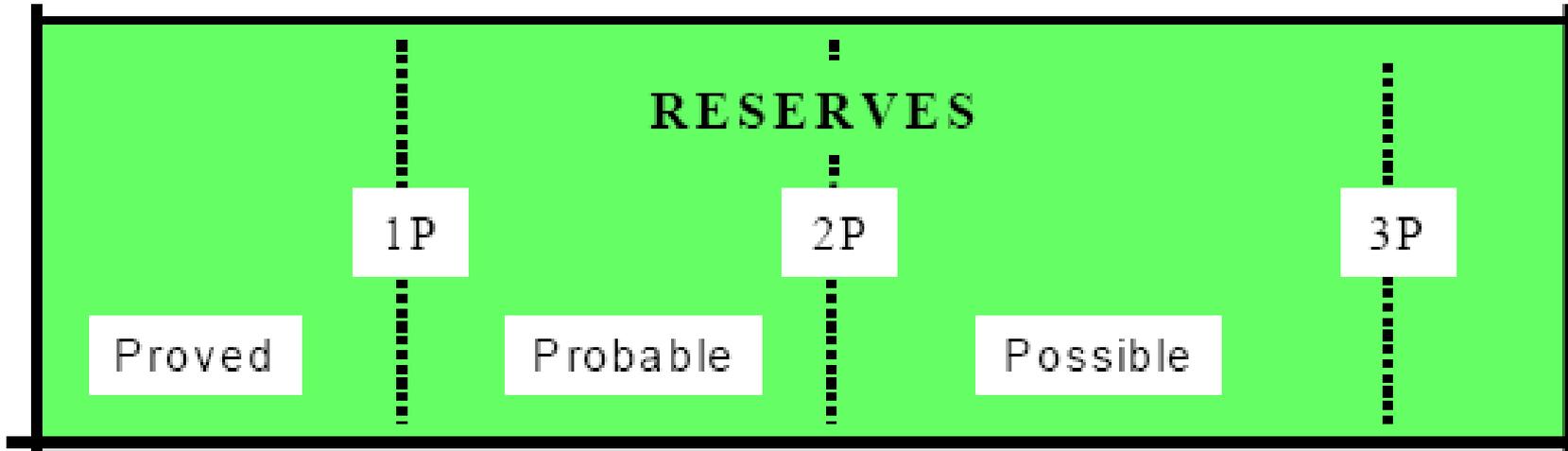
## Observed Contact





# PRMS

## Reserves



**Estimate of commercially recoverable sales volumes for  
Developments**

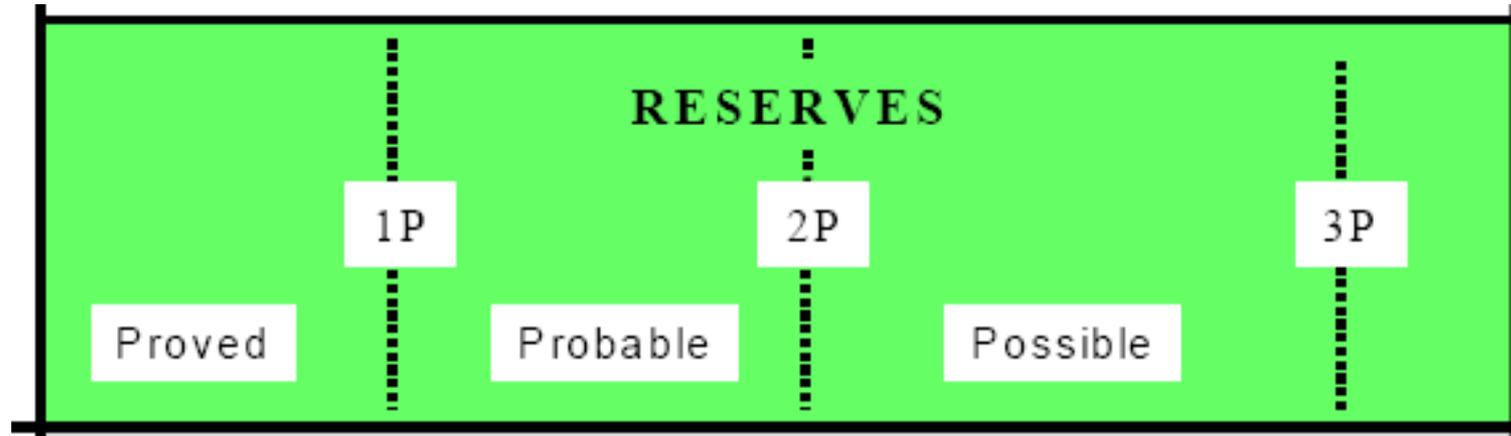
**Producing Fields**

**Must satisfy four criteria: discovered, recoverable,  
commercial, and remaining (as of a given date)  
based on the development project(s) applied.**



# PRMS

## Reserves



**Estimate of recoverable sales volumes for**

**Enhanced Recovery  
Projects**

**Producing Fields**

**Developments**

**Monetization Pathway**



# PRMS

## Reserves

### 1P: Proven

Quantity of hydrocarbons estimated with reasonable certainty

Low Estimate or  $P_{90}$

Observed Contact or Lowest Known Oil (LKO) or Gas (LKG)

### 2P: Proven + Probable

1P + probable hydrocarbons

Most Likely Estimate or  $P_{50}$

Amplitude or column height defined

### 3P: Proven + Probable + Possible

1P + 2P + possible hydrocarbons

High Estimate or  $P_{10}$

Highest Known Water or Spill Point defined



# PRMS

## Reserves

**Reserves are estimated remaining quantities of discovered hydrocarbons to be commercially produced from a known accumulation as of a given date based on the applied development project under specified definitions and economic conditions.**

- Represent remaining commercial volumes to be produced from a specific “As of” date.
- Cumulative production plus reserves constitute ultimate recoverable volume.

At any given “As of” date

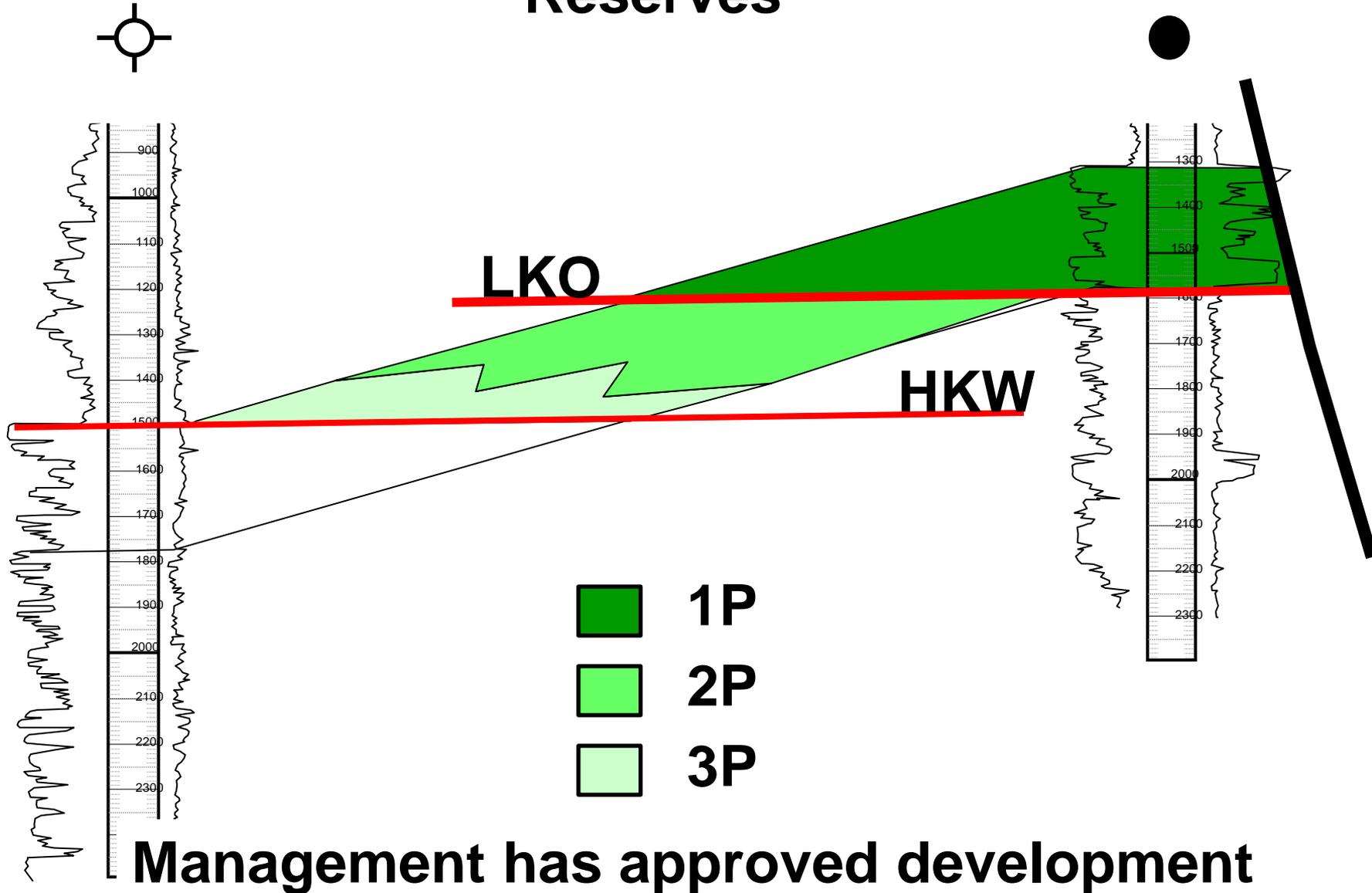
Ultimate Recoverable = Cumulative Production + Reserves

Reserves = Ultimate Recoverable – Cumulative Production



# Portfolios and PRMS

## Reserves





# Estimating and Risking Hydrocarbon Reserves and Resources

## Petroleum Resource Management System (PMRS)

- Resource
- Reserves

## OOIP and OGIP

## Volumetric Methodologies

## Uncertainty versus Risk





# STOOIP & OGIP



**OGIP: Original Gas in Place**

**OOIP: Original Oil in Place**

The Point of Sale is the surface, so the calculations convert the volume from subsurface conditions to surface conditions



# Volumetric Calculation

## Original Oil in Place

$$\text{OOIP}_{(m^3)} = \frac{10^4 * A * h_{\text{net}} * \Phi * (1 - S_w)}{B_{oi}}$$

$10^4$  = hectare conversion; 1 ha =  $10^4 m^2$

A = drainage area in hectares

h = net height of reservoir rock in meters

$\Phi$  = porosity

$S_w$  = water saturation

$B_{oi}$  = oil formation volume factor ( $m^3/m^3$ )

shrinkage factor to account for the volume change from subsurface to surface conditions



# Volumetric Calculation

## Stock Tank Original Oil in Place

$$\text{STOOIP}_{(\text{STB})} = \frac{7758 * A * h_{\text{net}} * \Phi * (1 - S_w)}{B_{\text{oi}}}$$

7758 = barrels per acre foot

A = drainage area in acres

H = net height of reservoir rock in feet

$\Phi$  = porosity

$S_w$  = water saturation

$B_{\text{oi}}$  = oil formation volume factor



# Volumetric Calculation Original Gas in Place

$$\text{OGIP}_{(10^3\text{m}^3)} = \frac{10^4 * A * h_{\text{net}} * \Phi * (1 - S_w) * (1 - Q_{\text{nc}})}{B_{\text{gi}}}$$

$10^4$  = hectare conversion; 1 ha =  $10^4\text{m}^2$

A = drainage area in hectares

h = net height of reservoir rock in meters

$\Phi$  = porosity

$S_w$  = water saturation

$Q_{\text{nc}}$  = non-combustible gas

$B_{\text{gi}}$  = gas formation volume factor ( $\text{m}^3/\text{m}^3$ )

shrinkage factor to account for the volume change from subsurface to surface conditions



# Volumetric Calculation Original Gas in Place

$$\text{OGIP}_{(\text{mmcf})} = \frac{43,560 * A * h_{\text{net}} * \Phi * (1 - S_w) * (1 - Q_{\text{nc}})}{B_{\text{gi}}}$$

43,560 = sqf per acre

A = drainage area in acres

H = net height of reservoir rock in feet

$\Phi$  = porosity

$S_w$  = water saturation

$Q_{\text{nc}}$  = non-combustible gas

$B_{\text{gi}}$  = gas formation volume factor



# Volumetric Calculation

## Recoverable Resources and Reserves

$$\text{Recoverable Oil} = \text{STOOIP}_{(\text{STB})} * \text{R.F.}$$

**Recovery Factor per unit area**

for example 1,750 MMCFe per acre foot

**Recovery Factor as a percent of in-place**

for example 30%



# Estimating and Risking Hydrocarbon Reserves and Resources

## Petroleum Resource Management System (PMRS)

- Resource
- Reserves

## OOIP and OGIP

## Volumetric Methodologies

## Uncertainty versus Risk





# Methodologies

**There are three general Methods  
for Calculating Reserves and Resources**



**Volumetric**

**Model-based**

**Performance**



# Methodologies

## Volumetric Methods



**Deterministic**

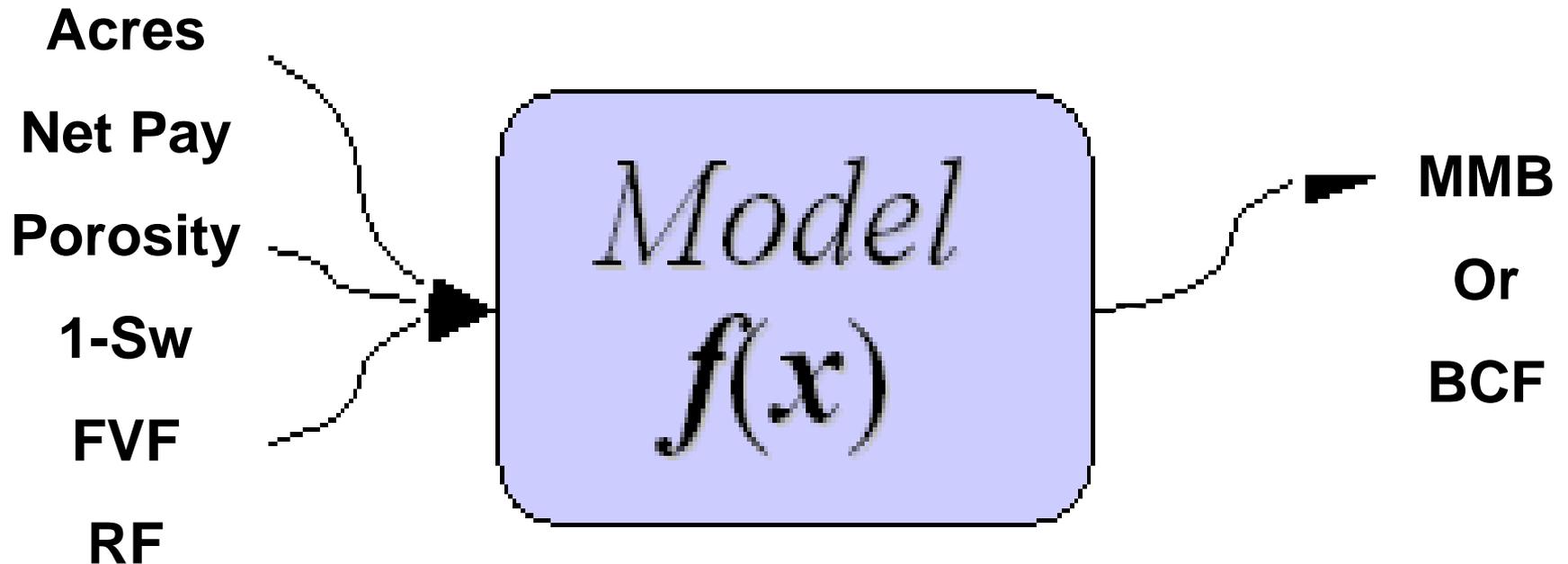
**Monte Carlo**

**Probabilistic**



# Methodologies

## Deterministic Method



**1 answer based on input of single variables**

**Usually calculated for a low, base, and high-side case**



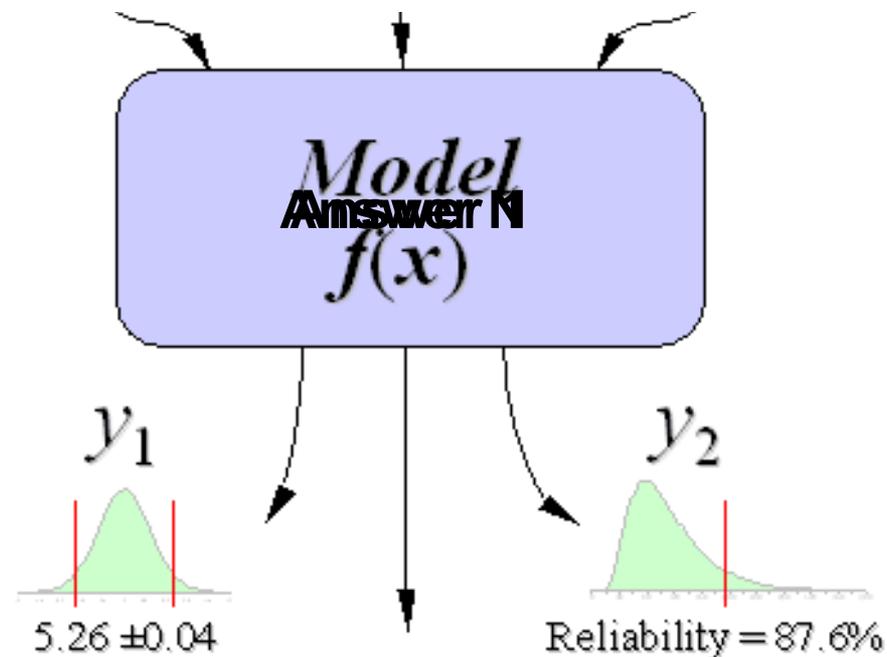
# Methodologies

## Monte Carlo Method

Min:

ML: Acres, Net Pay, Porosity, 1-Sw, FVF, RF

Max:



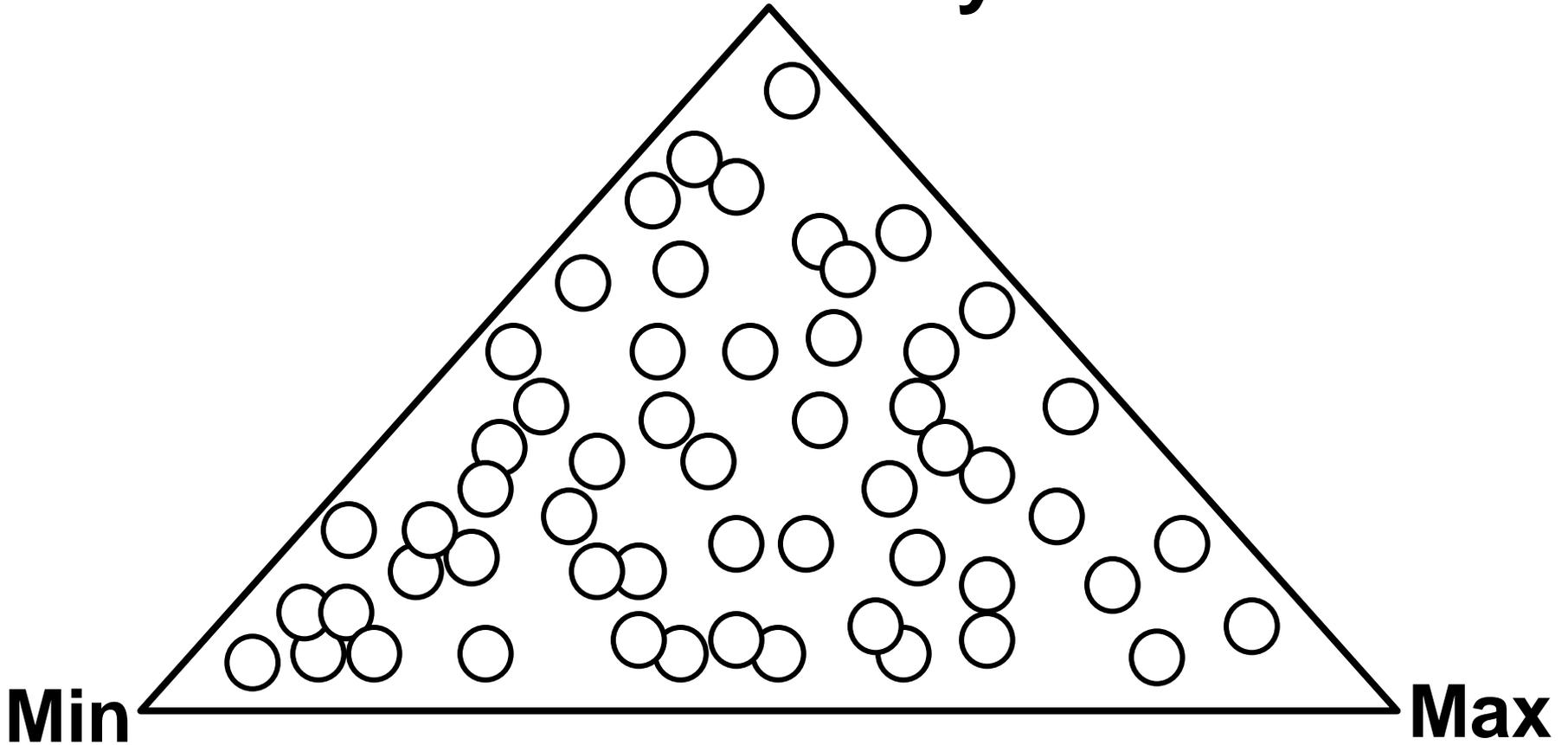
**N Deterministic Volumes**



# Methodologies

## Monte Carlo Method

### Most Likely

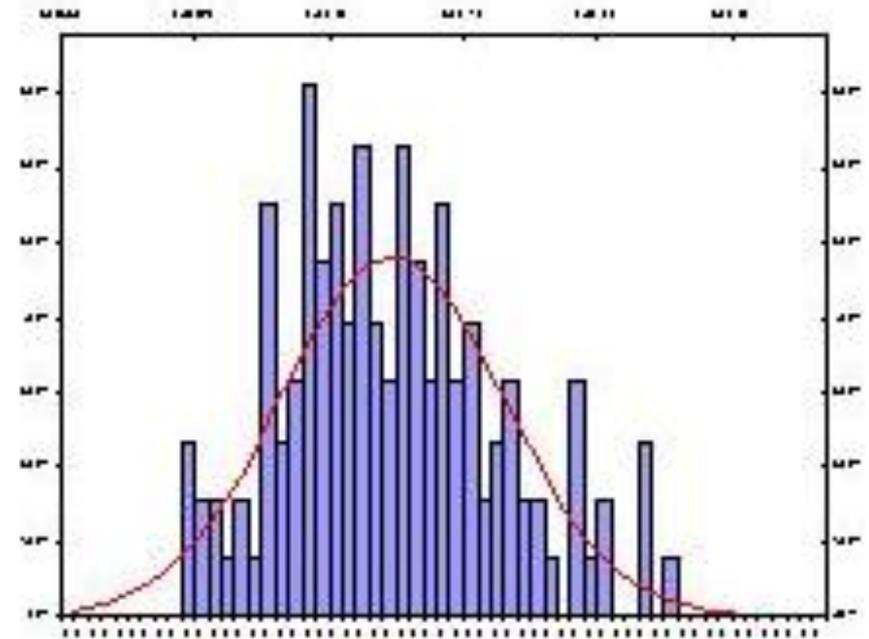
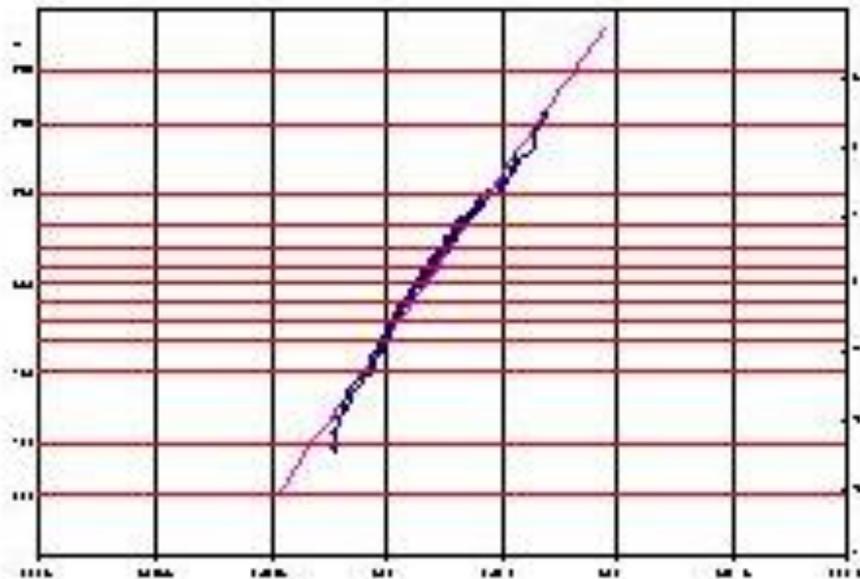


## Random Iterative Analysis of Variables



# Methodologies

## Probabilistic Method



**Assumes Lognormal  
Distribution of Variables**



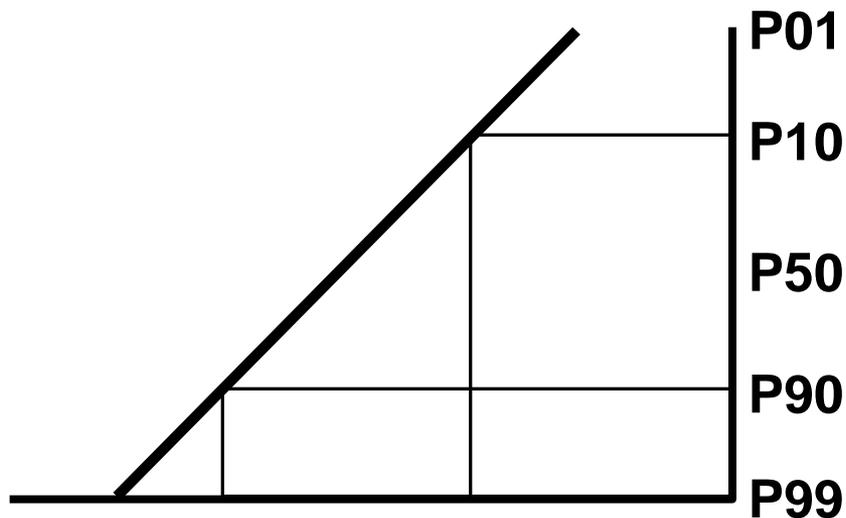
# Methodologies

## Probabilistic Method

Why Lognormal Distribution?

Most geologic parameters fit a lognormal distribution.

Plot Data in Cumulative Lognormal Graph



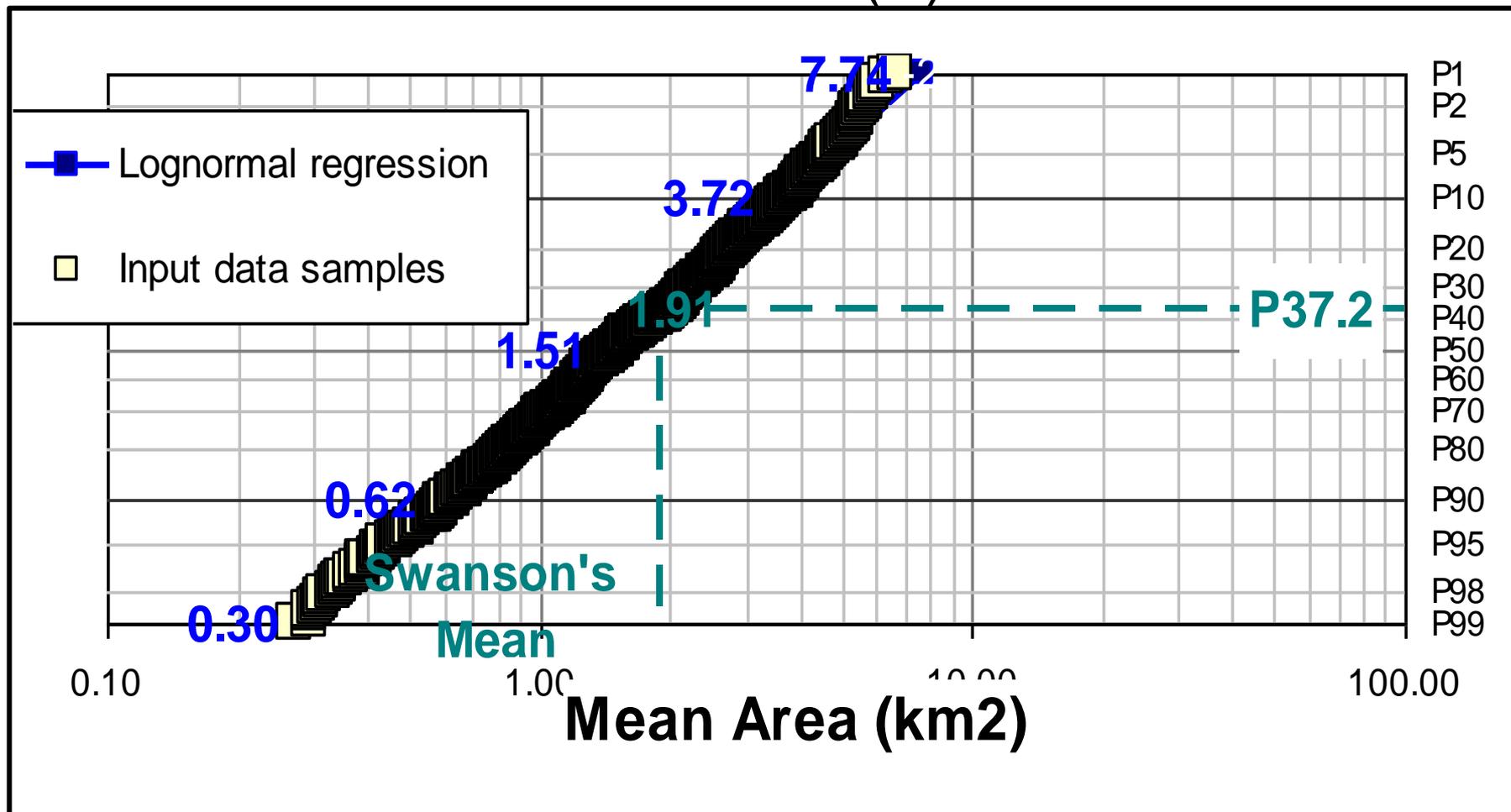
If it's straight line  
→ Lognormal



# Methodologies

## Probabilistic Method

Field Area (A)



50 Fields; North Malay Basin

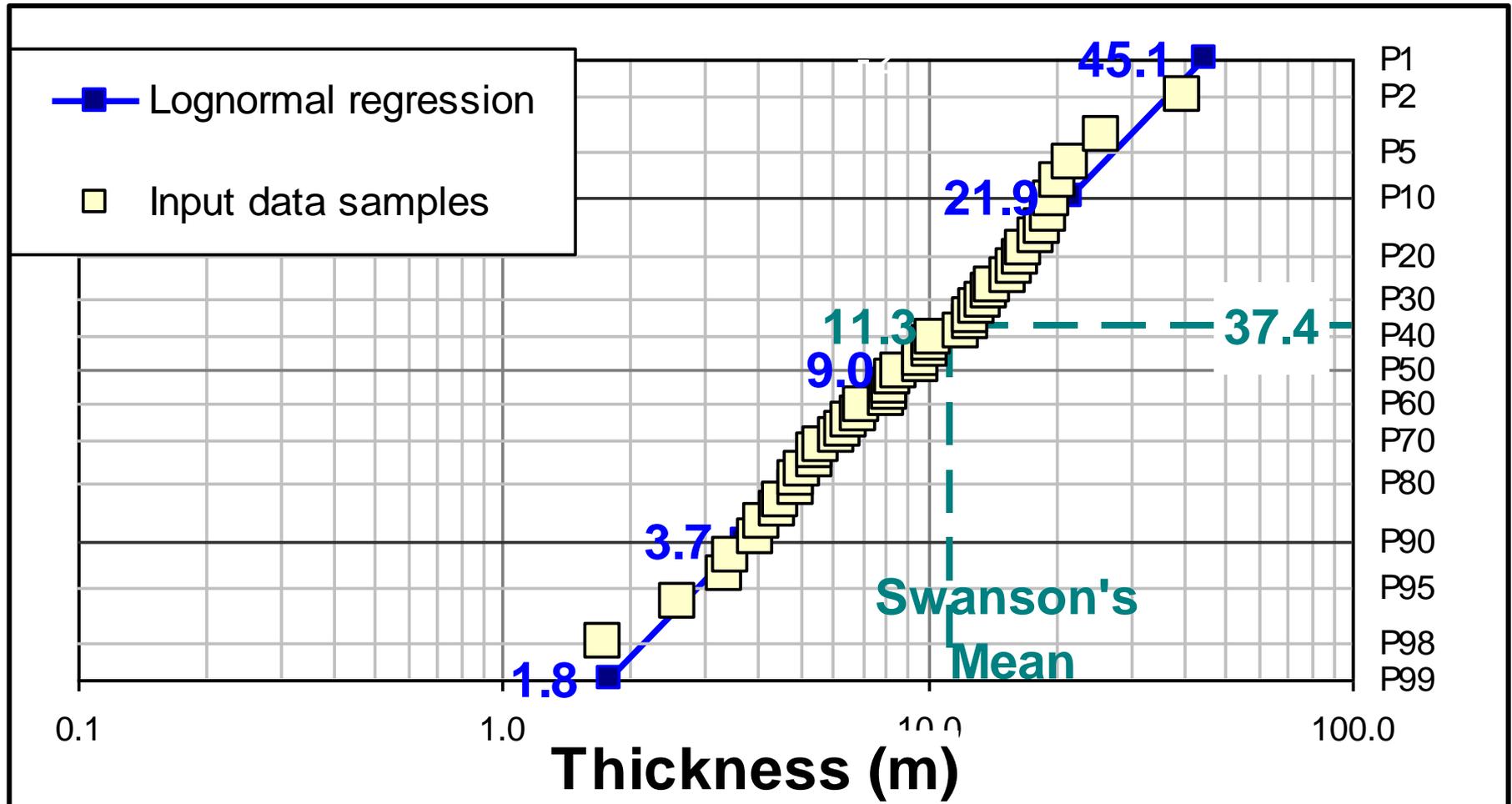
Swanson's mean = 0.3 P90 + 0.4 P50 + 0.3 P10



# Methodologies

## Probabilistic Method

Reservoir Thickness ( $h_{net}$ )



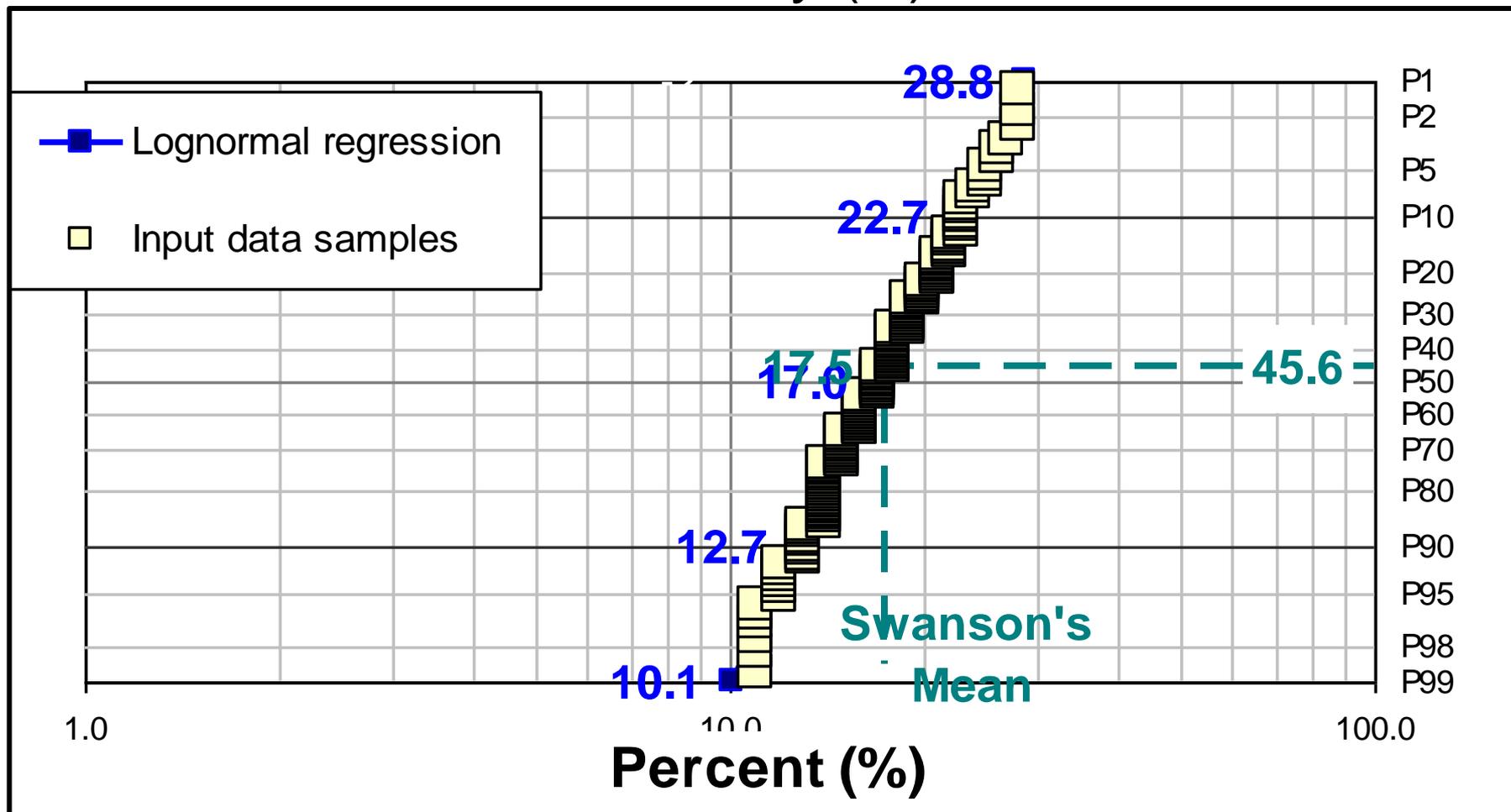
50 Fields; North Malay Basin



# Methodologies

## Probabilistic Method

Porosity ( $\Phi$ )



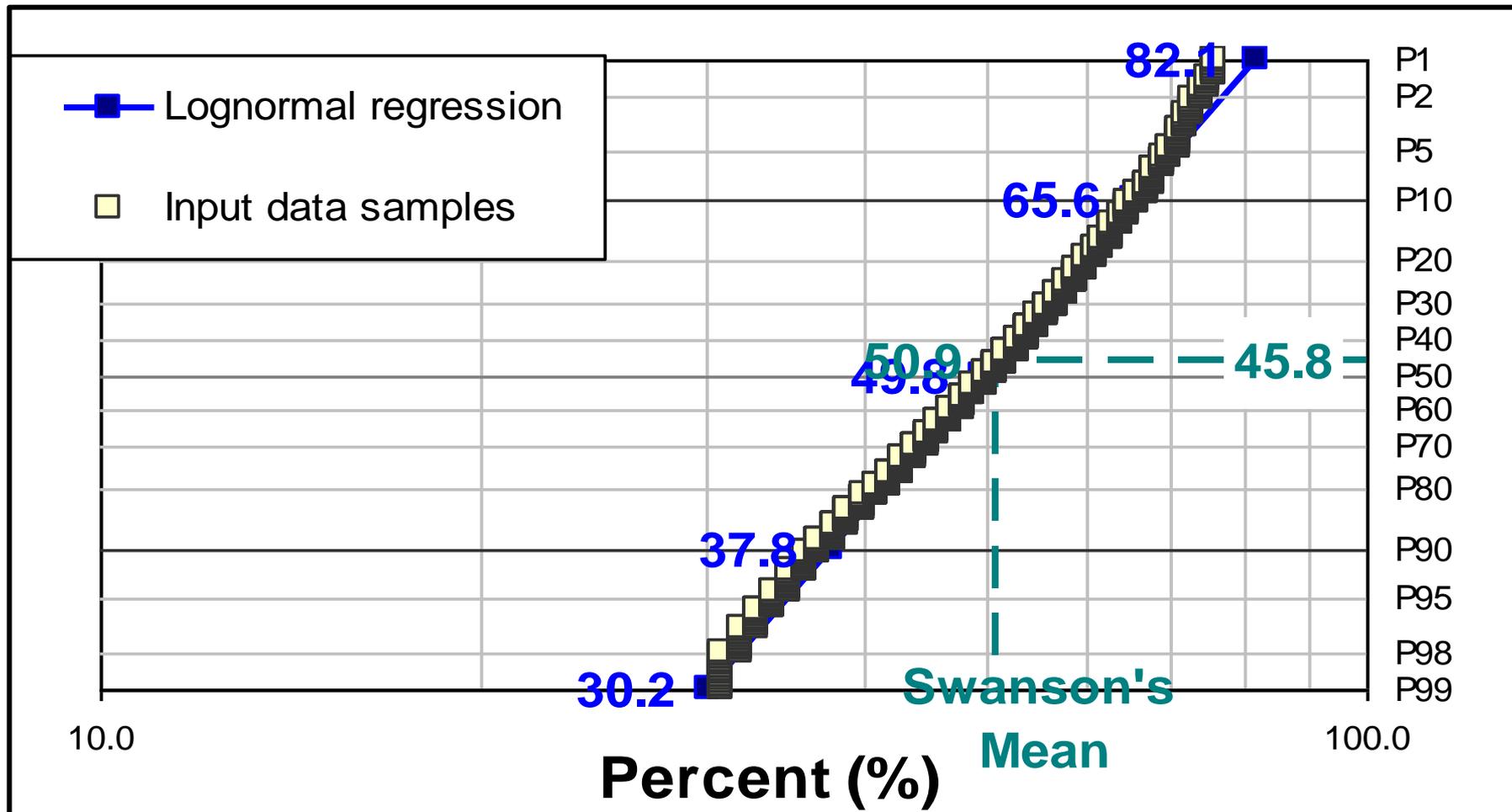
50 Fields; North Malay Basin



# Methodologies

## Probabilistic Method

### Saturation ( $S_w$ )



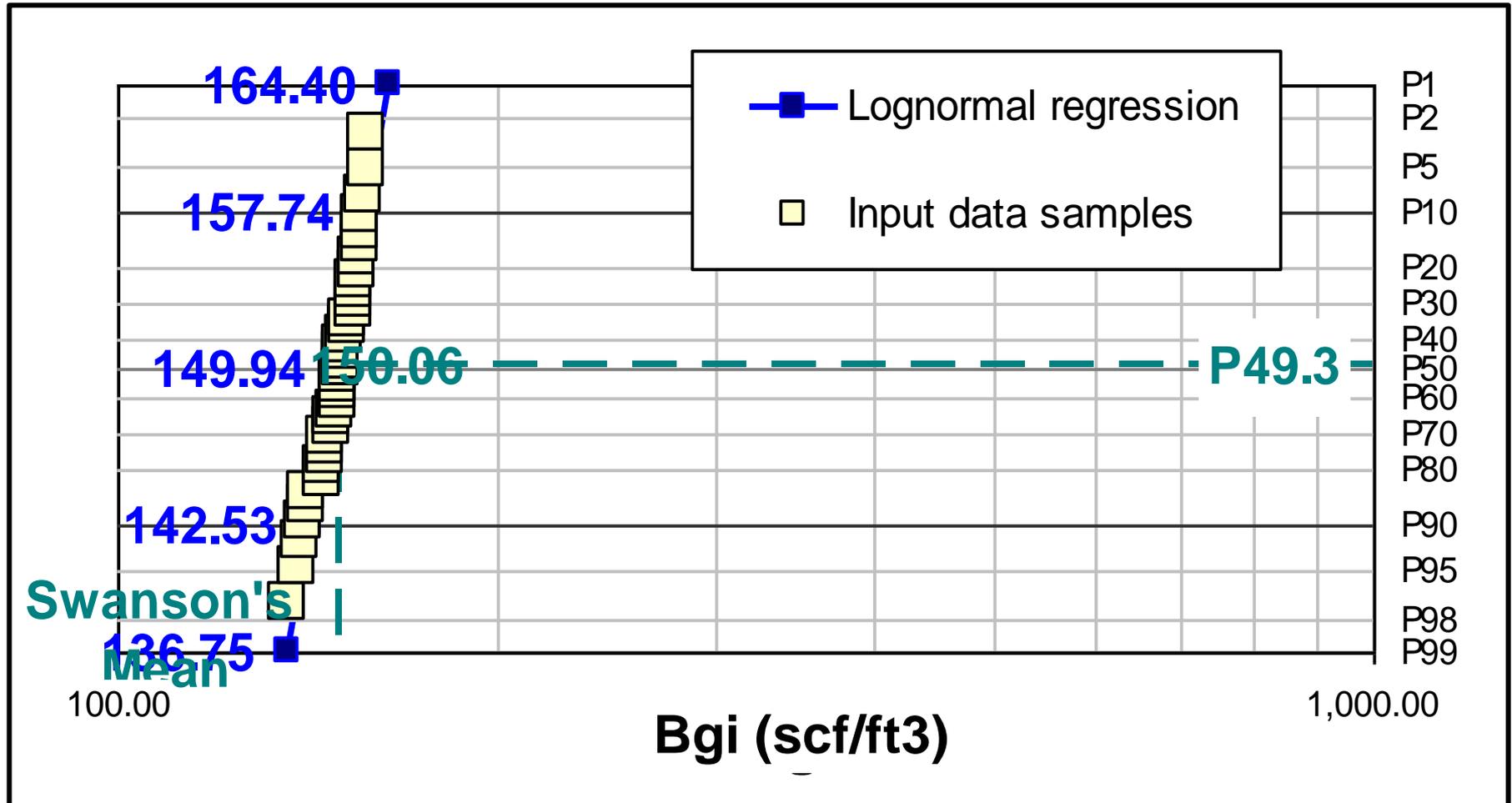
50 Fields; North Malay Basin



# Methodologies

## Probabilistic Method

Formation Volume Factor ( $B_{oi}$ )



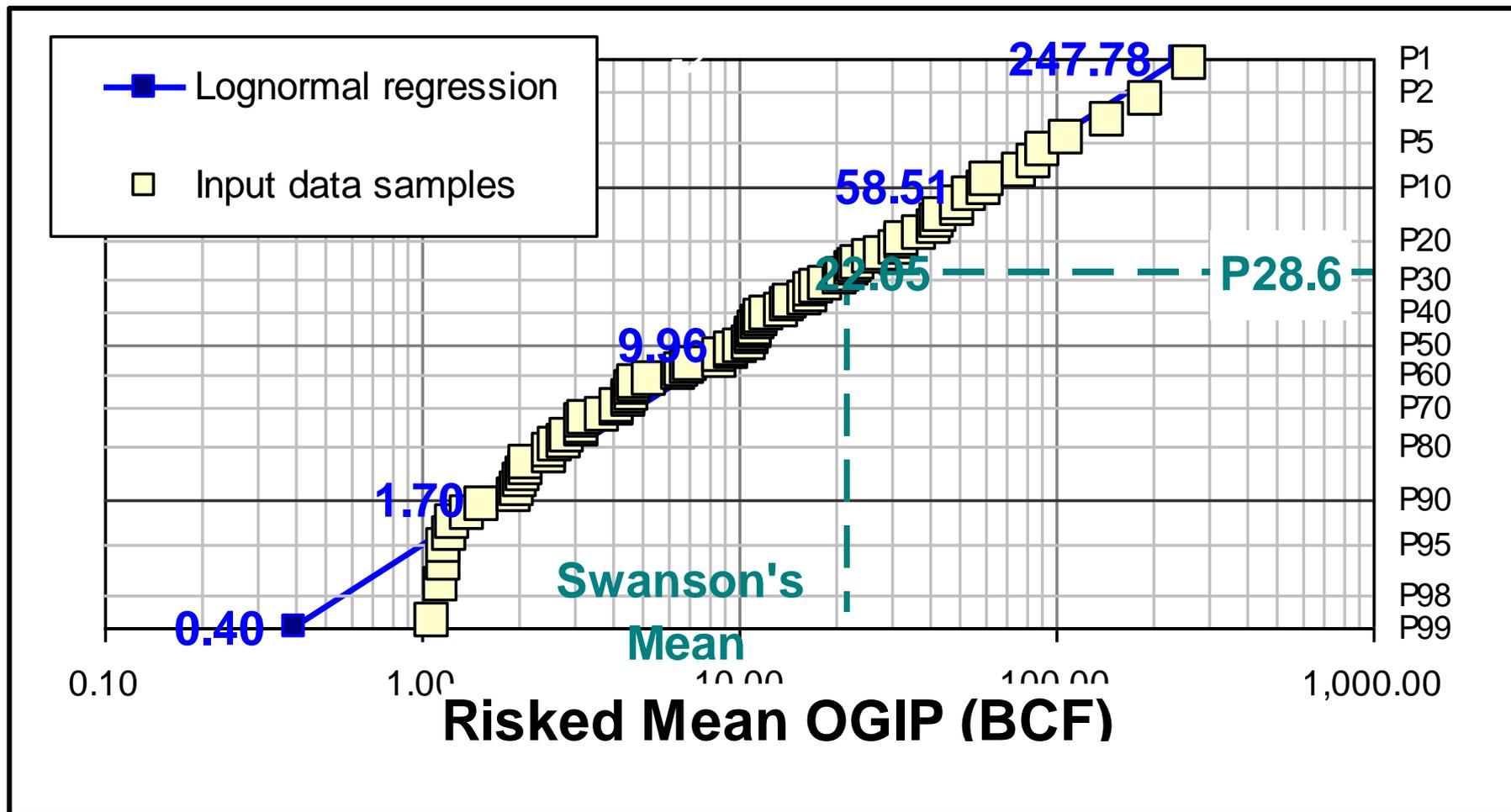
50 Fields; North Malay Basin



# Methodologies

## Probabilistic Method

### OGIP



50 Fields; North Malay Basin



# Methodologies

## Model-based Methods



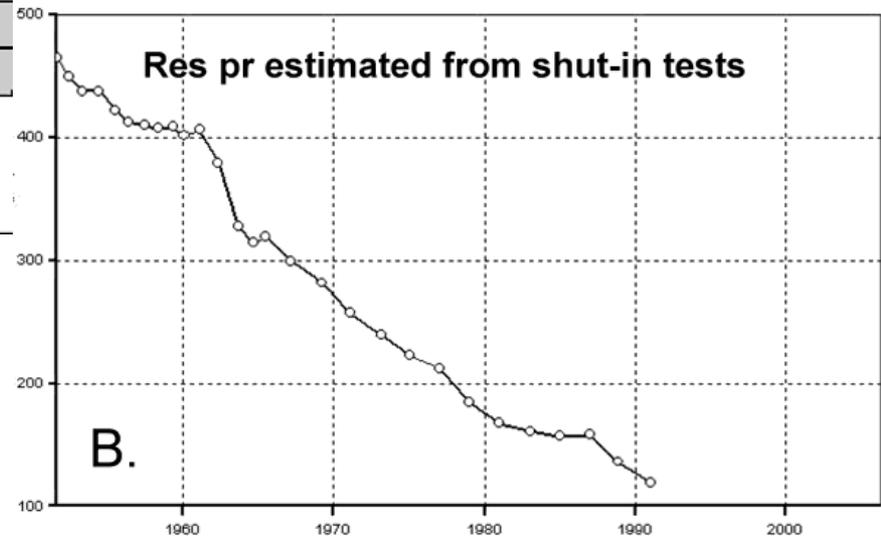
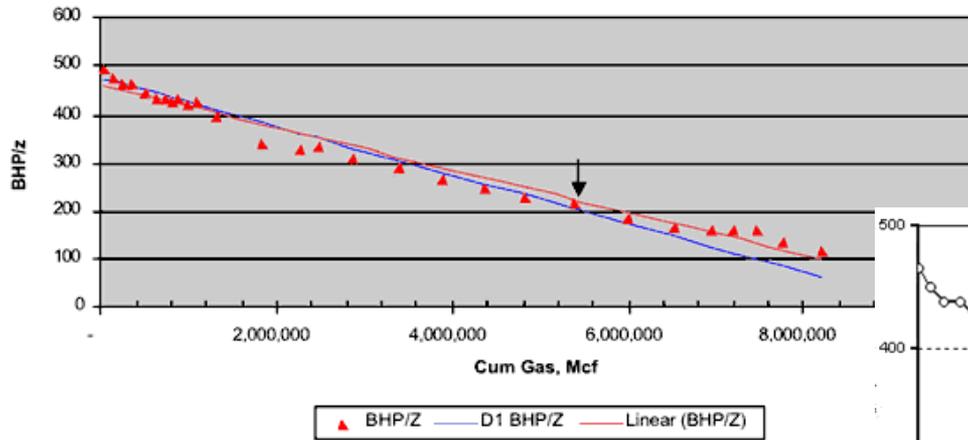
**Material  
Balance**

**Dynamic  
Models**



# Methodologies

## Material Balance



**Input in-Place reserves and Drive Mechanism**

**Measures Production and Pressure Against History**

**Better the Match, Better the Prediction**

**Non-Unique Answer, numerous models will fit**



# Methodologies

## Material Balance

### Gas

$$\begin{array}{ccccccccc} \text{Initial} & & \text{Initial} & & \text{Gas} & & \text{Gas} & & \text{Remaining} & & \text{Remaining} \\ \text{Solution} & + & \text{Free} & - & \text{Produced} & + & \text{Injected} & = & \text{Solution} & + & \text{Free} \\ \text{Gas} & & \text{Gas} & & & & & & \text{Gas} & & \text{Gas} \end{array}$$

### Oil

$$\begin{array}{ccc} \text{Initial} & - & \text{Oil} \\ \text{Oil} & & \text{Produced} \\ \text{Volume} & & = & \text{Oil} \\ & & & \text{Remaining} \end{array}$$

### Water

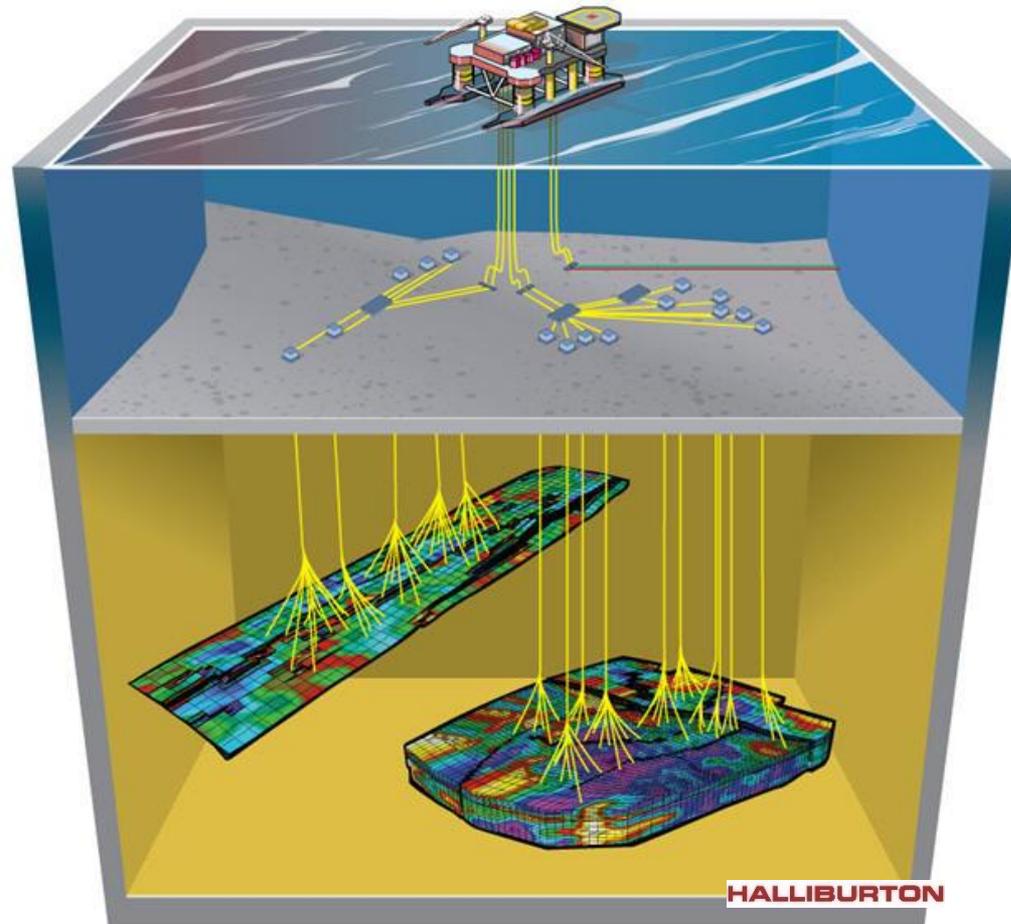
$$\begin{array}{ccccccc} \text{Initial} & & \text{Water} & & \text{Water} & & \text{Aquifer} & & \text{Water} \\ \text{Water} & - & \text{Produced} & + & \text{Injected} & + & \text{Influx} & = & \text{Remaining} \\ \text{Volume} & & & & & & & & \end{array}$$

## CONSERVATION OF MASS



# Methodologies

## Dynamic Model

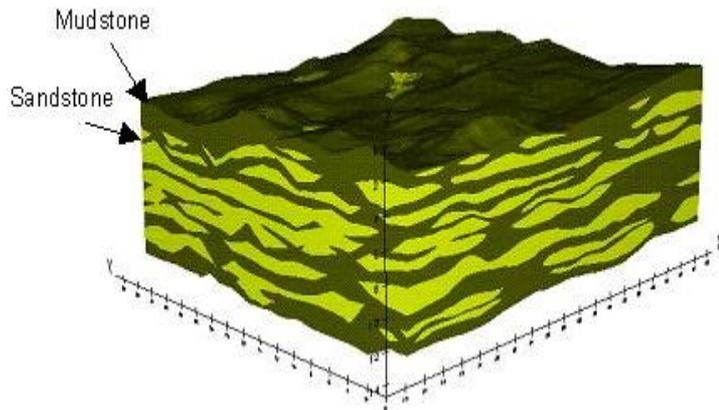
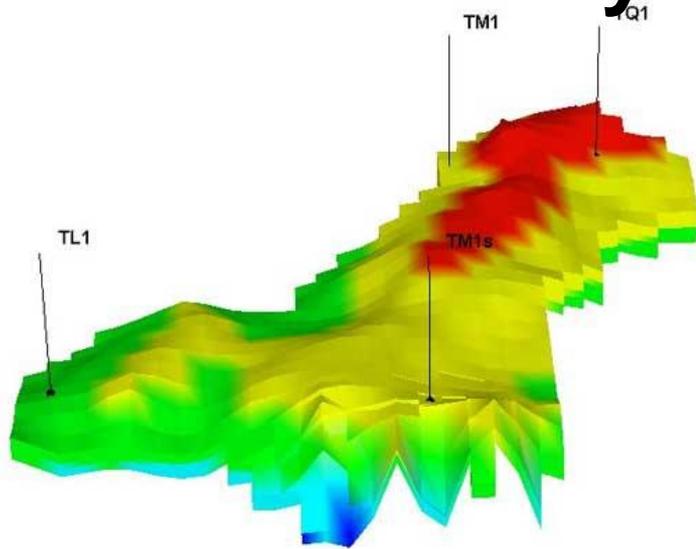


## 3-Dimensional Model

# Methodologies

## Dynamic Model

**Input Structure  
from Seismic**

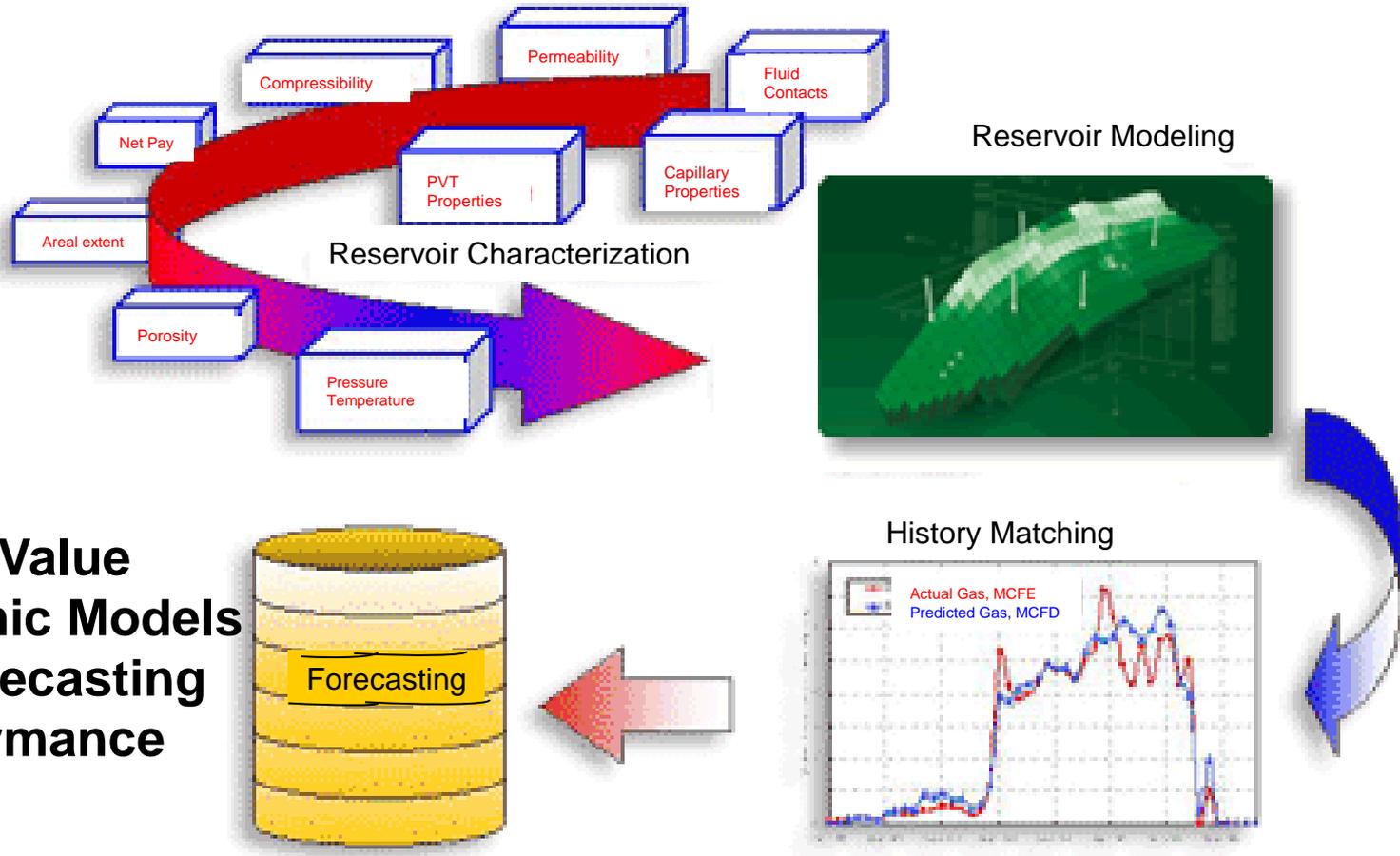


**Stochastically Populate  
With Facies Types**

**3-Dimensional Deterministic Volume**

# Methodologies

## Dynamic Model



**For Fields, History Matching increases the reliability of the volumes**



# Methodologies

## Performance-based Methods

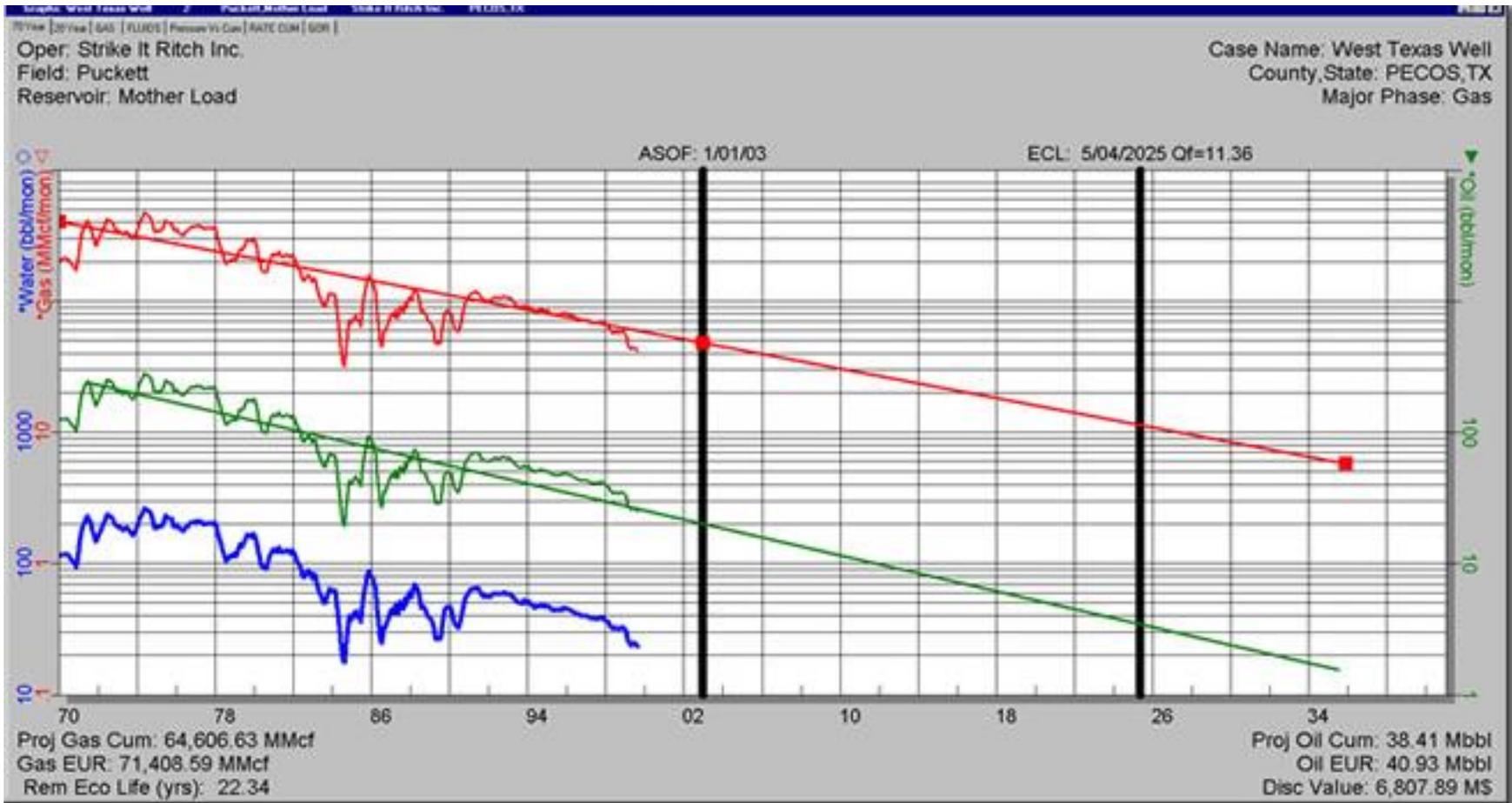


## Decline Curve Analysis



# Methodologies

## Decline Curve Analysis

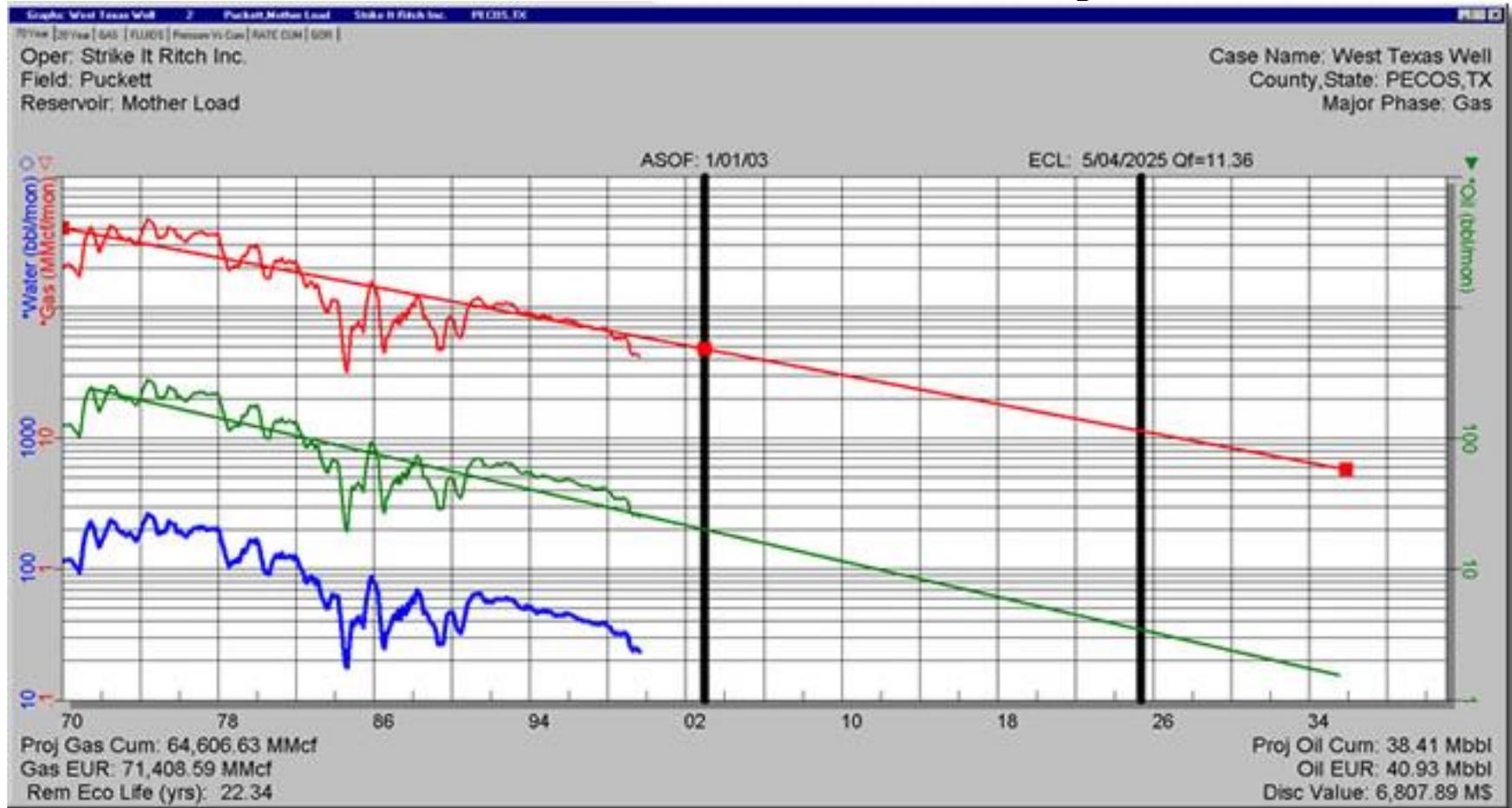


**Project Production Forward  
based on current conditions**



# Methodologies

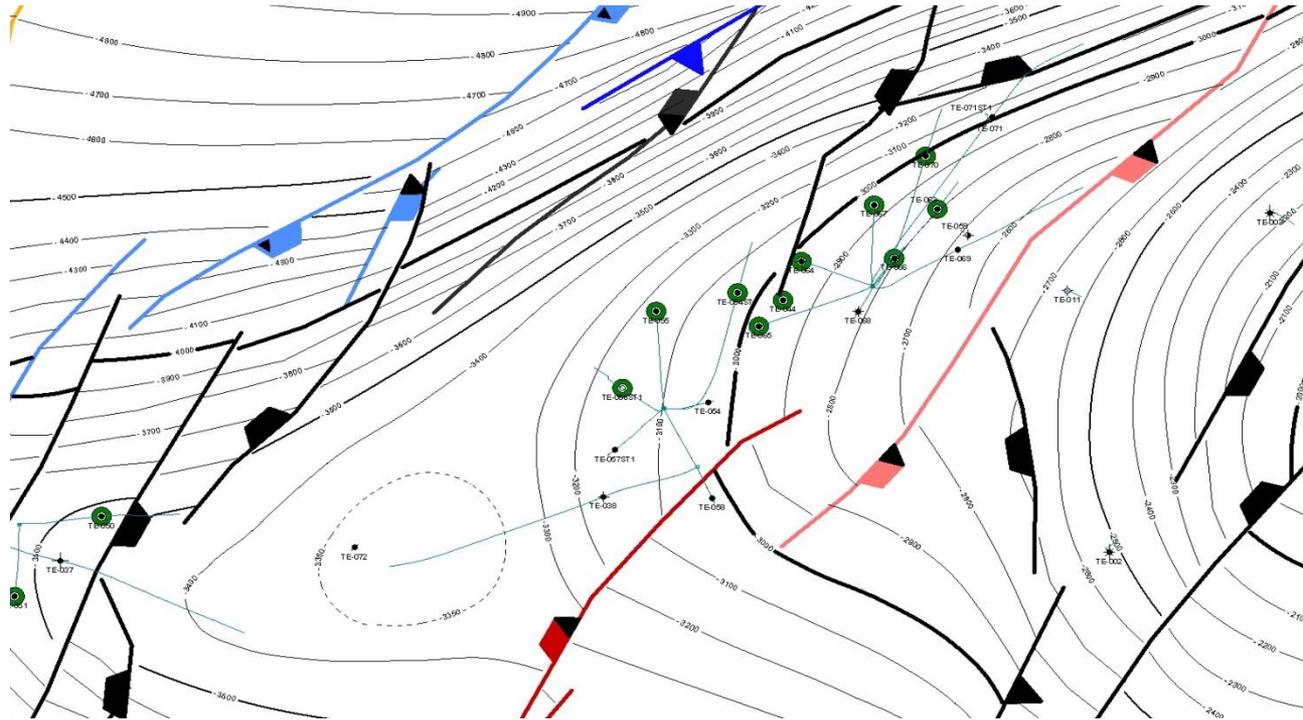
## Decline Curve Analysis



**Measures Reserves Not In-Place Resources**

# Methodologies

## Comparison of Reserve Estimation Methods



## Plunging Nose, Incised Valley Reservoir

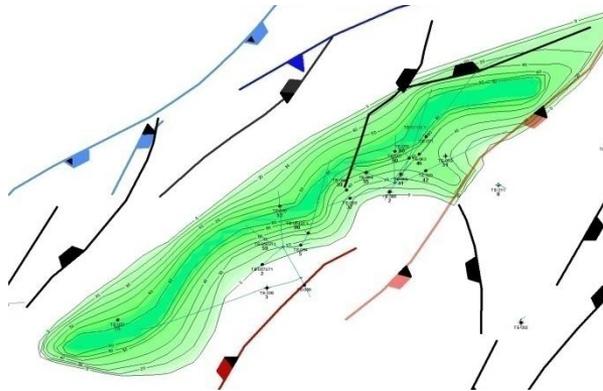
18 Wells, 10 Producers

21 MMBO Production

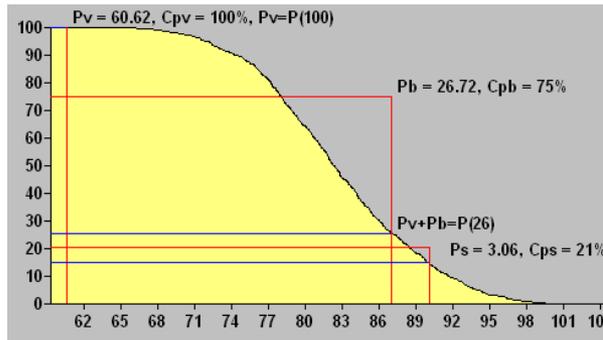


# Methodologies

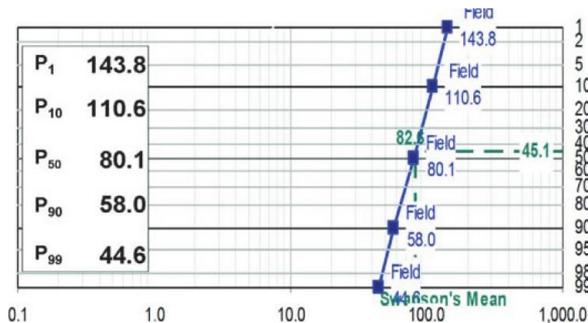
## Volumetric Methods



**Deterministic**  
**87.6** (MMstb)



**Monte Carlo**  
**82.6** (MMstb)



**Probabilistic**  
**80.1** (MMstb)



# Methodologies

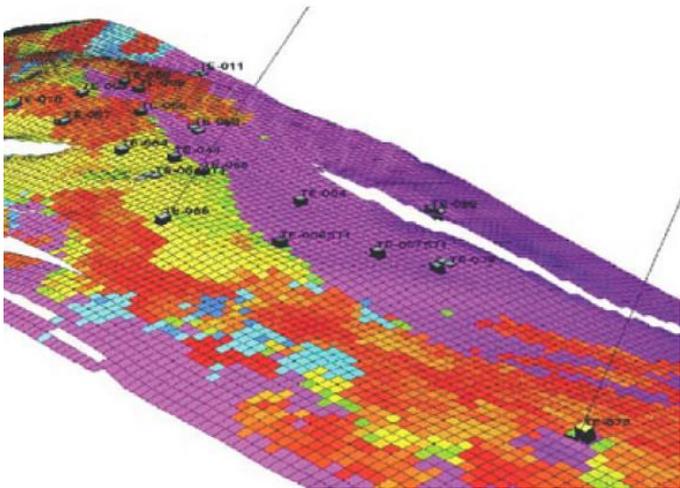
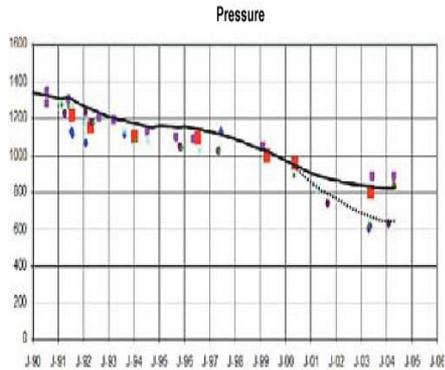
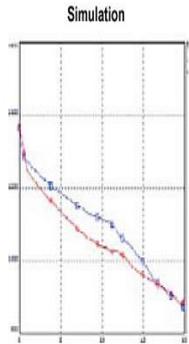
## Model-Based Methods

**Material Balance**

**88.0 (MMstb)**

**Dynamic Model**

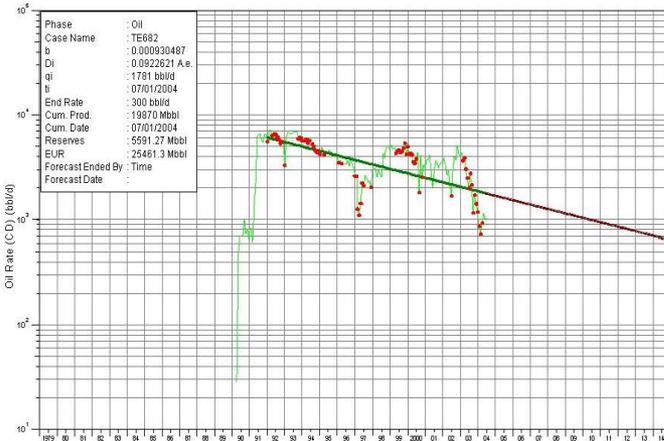
**79.1 (MMstb)**





# Methodologies

## Performance-Based Methods



# Decline Curve Analysis

**77.0** (MMstb)

**Assumed RF = .33**



# Methodologies

## Which Reserve Estimation Method Gave the Best Answer?

	Deterministic	Monte Carlo	Probabilistic	DCA	MBAL	Geomodel
$P_1$		107.72	143.8			
$P_{10}$	104.6	92.09	110.6	85		85.2
$P_{\text{mean}}$	87.6	82.62	80.1	77	88	79.1
$P_{90}$	62	74.62	58.0	73		71.9
$P_{99}$		59.3	44.6			

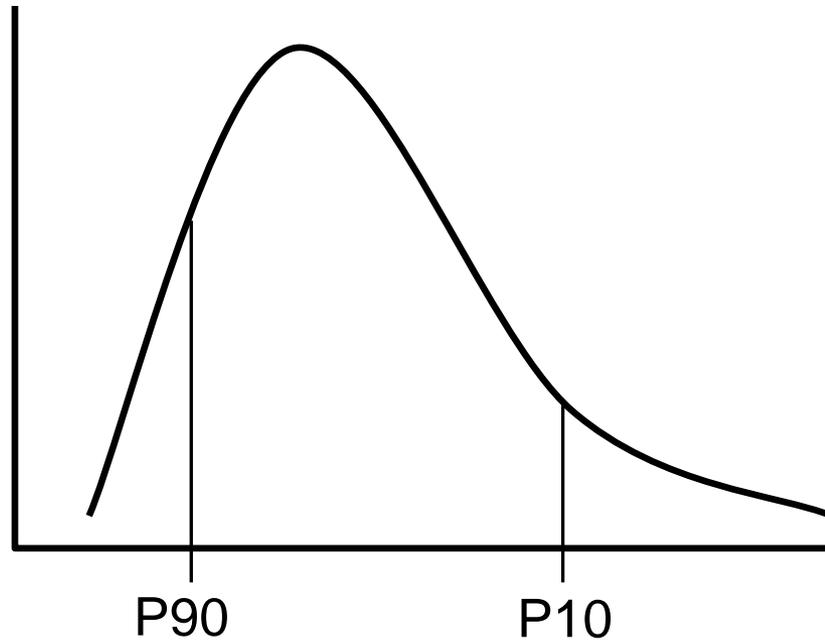
**Range of 12.5%**



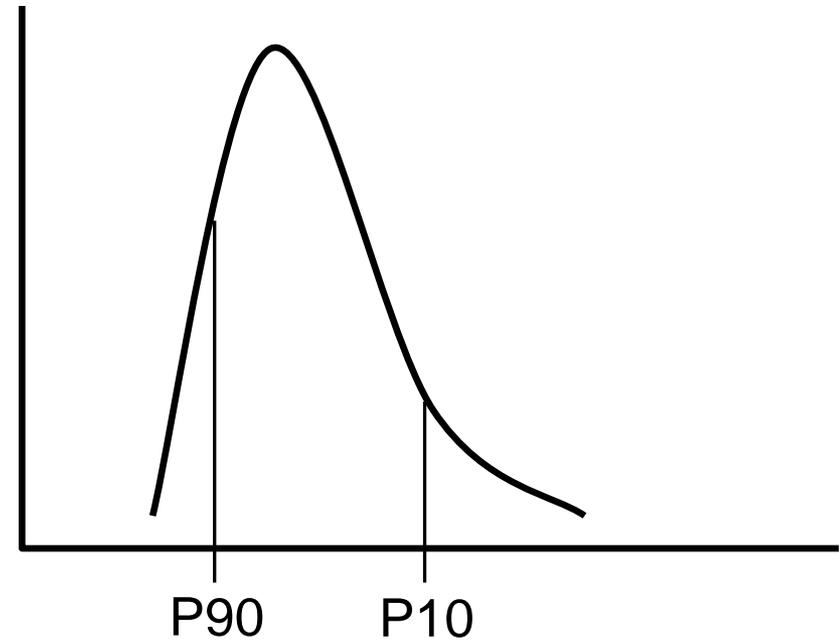
# Methodologies

**Low Information**

**High Information**



**Probabilistic Distribution**



**Probabilistic Distribution**

**High Uncertainty**

**Low Uncertainty**



# Estimating and Risking Hydrocarbon Reserves and Resources

## Petroleum Resource Management System (PMRS)

- Resource
- Reserves

## OOIP and OGIP

## Volumetric Methodologies

## Uncertainty versus Risk





# Uncertainty

## Is Not the Same As

# Risk



# Volumetric Calculation Uncertainty

$$\text{OGIP}_{(\text{mmcf})} = \frac{43,560 * A * h_{\text{net}} * \Phi * (1 - S_w) * (1 - Q_{\text{nc}})}{B_{\text{gi}}}$$

There is uncertainty in our estimation of

Area

Net Pay (h)

Saturation

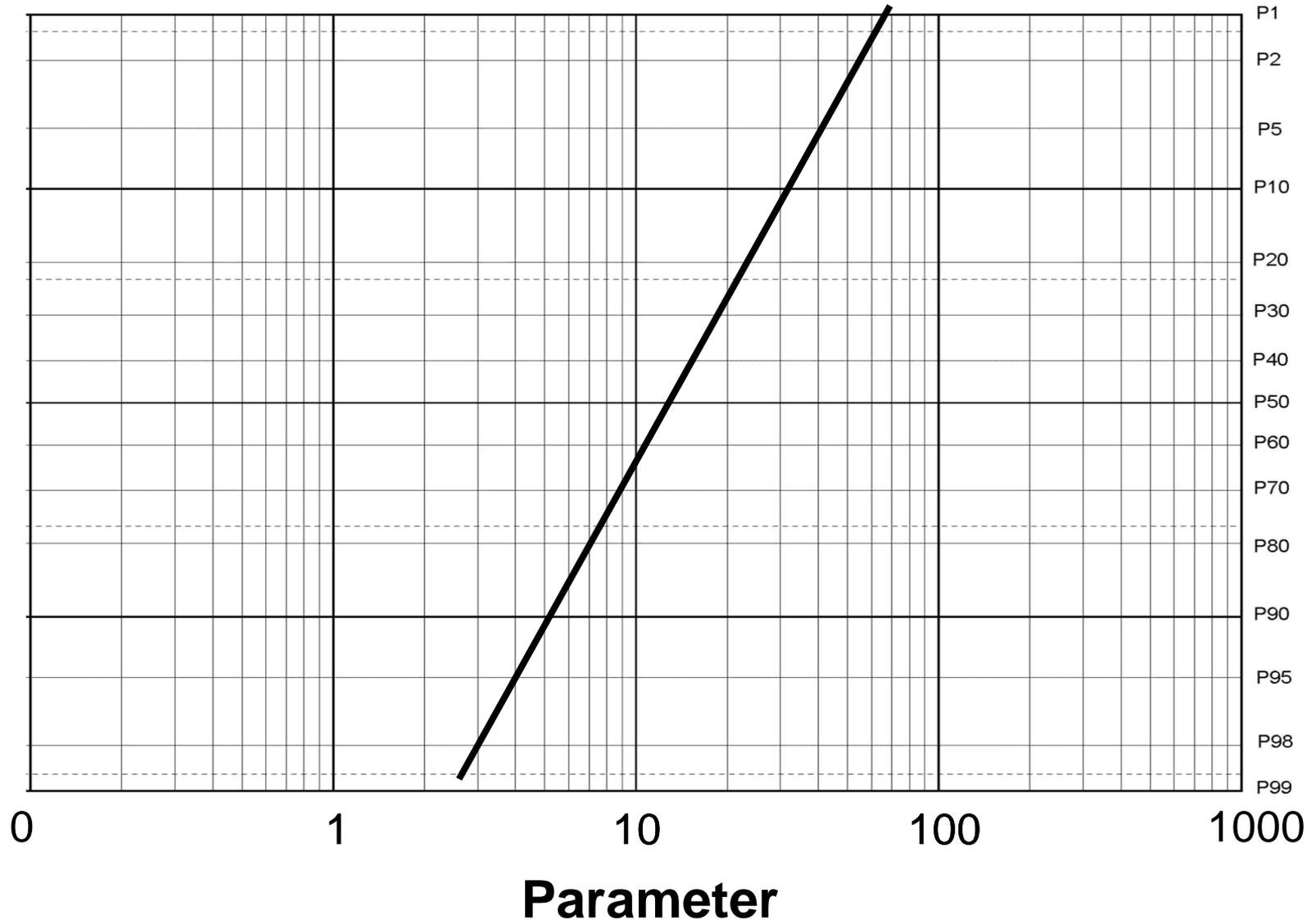
Percent non-combustible gas

Formation Volume Factors



# Uncertainty

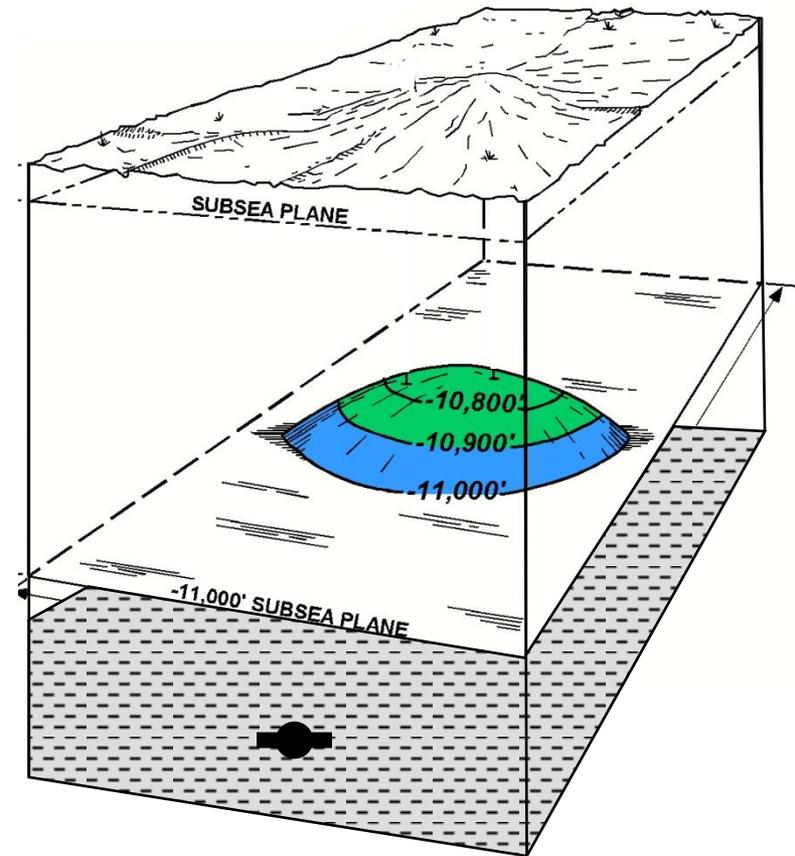
Is the Range of Possible Success Outcomes





# Uncertainty

There is uncertainty for each element of the Petroleum System



## Source Rock

How much – how good – oil, gas, or both?

## Migration Pathway

Where did the HC's go, and when did they go there?

## Reservoir

How many pays, how good and how thick are they?

## Trap

How big is the trap?

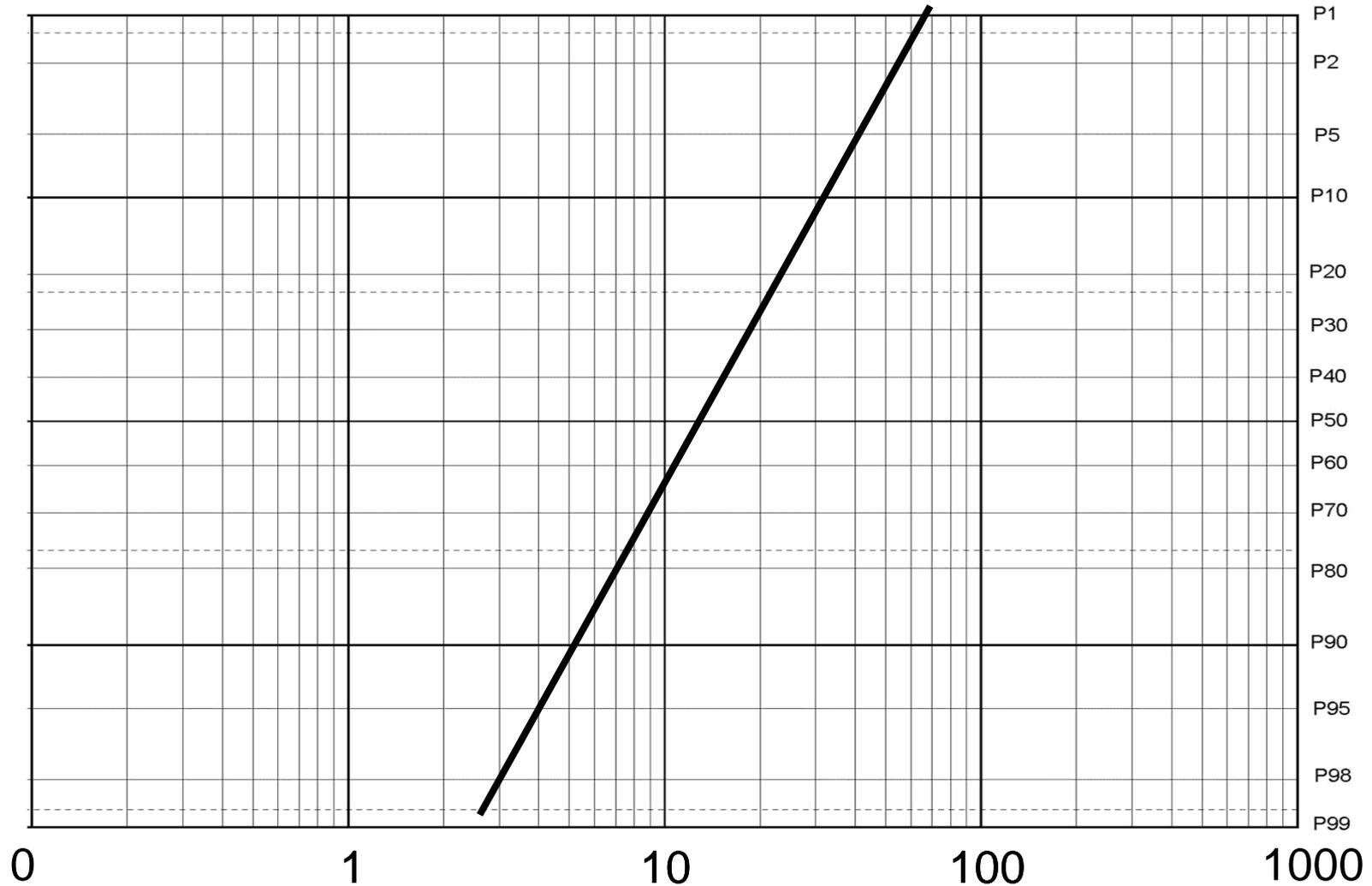
## Seal

How much column can the seal hold?



# Uncertainty

We need to define as narrow a range as we can

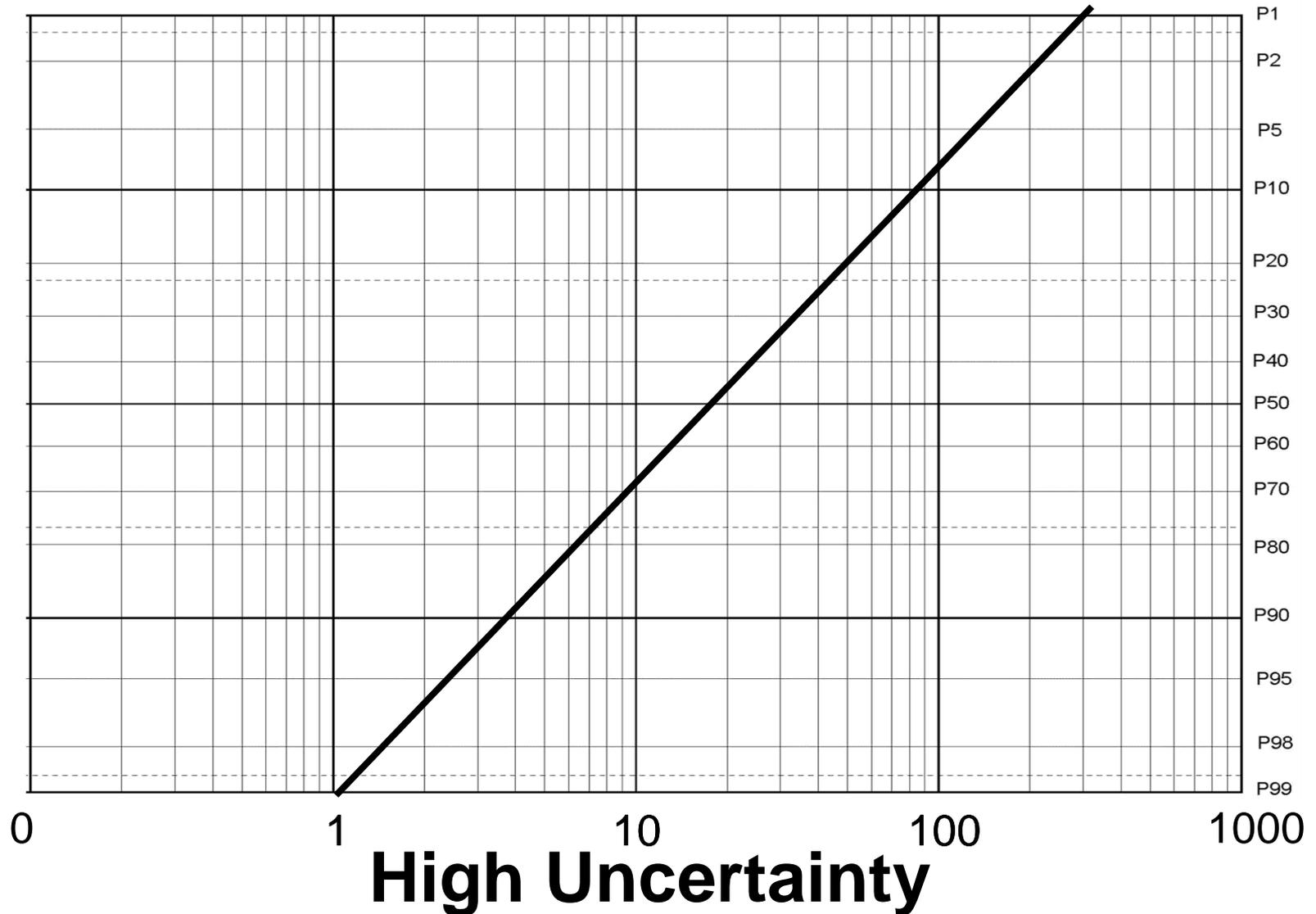


But still account for the full range of uncertainty



# Uncertainty

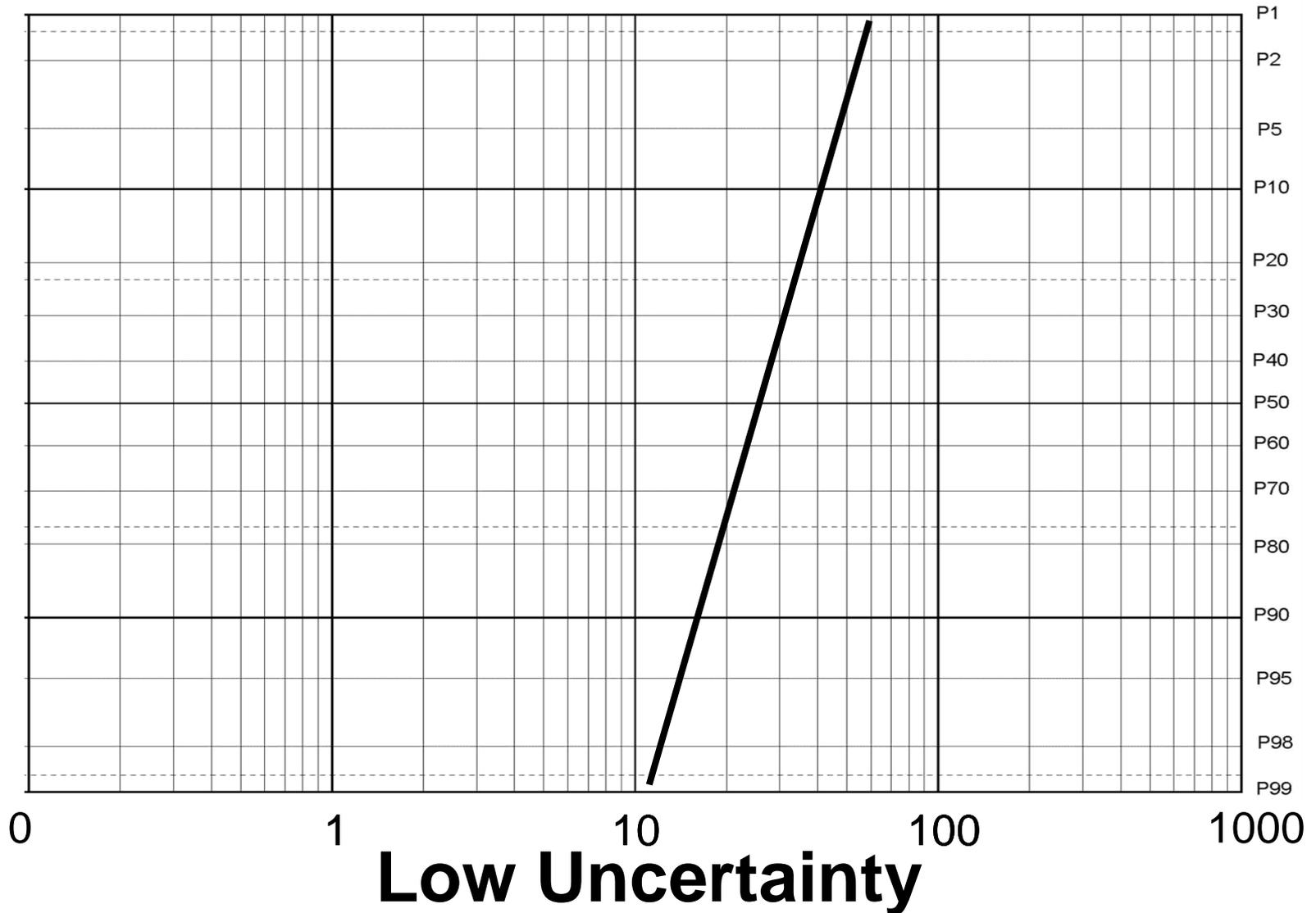
A low angle slope indicates





# Uncertainty

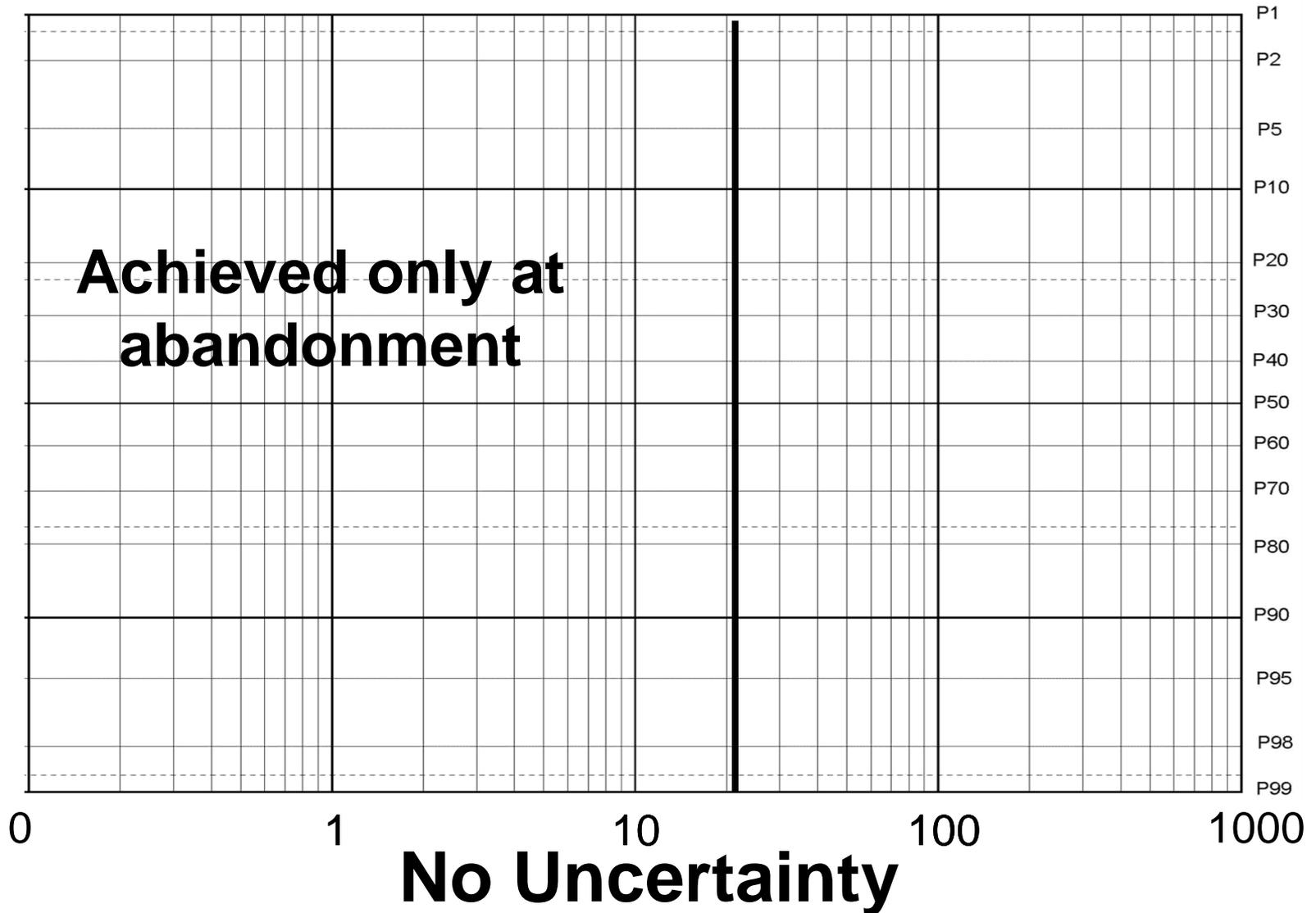
A steep slope indicates





# Uncertainty

A vertical line indicates





# Uncertainty

## Rose Philosophy

**“Define the Full Range of Uncertainty”**

**The  $P_1$  to  $P_{99}$  provide reality checks to the uncertainty distribution**

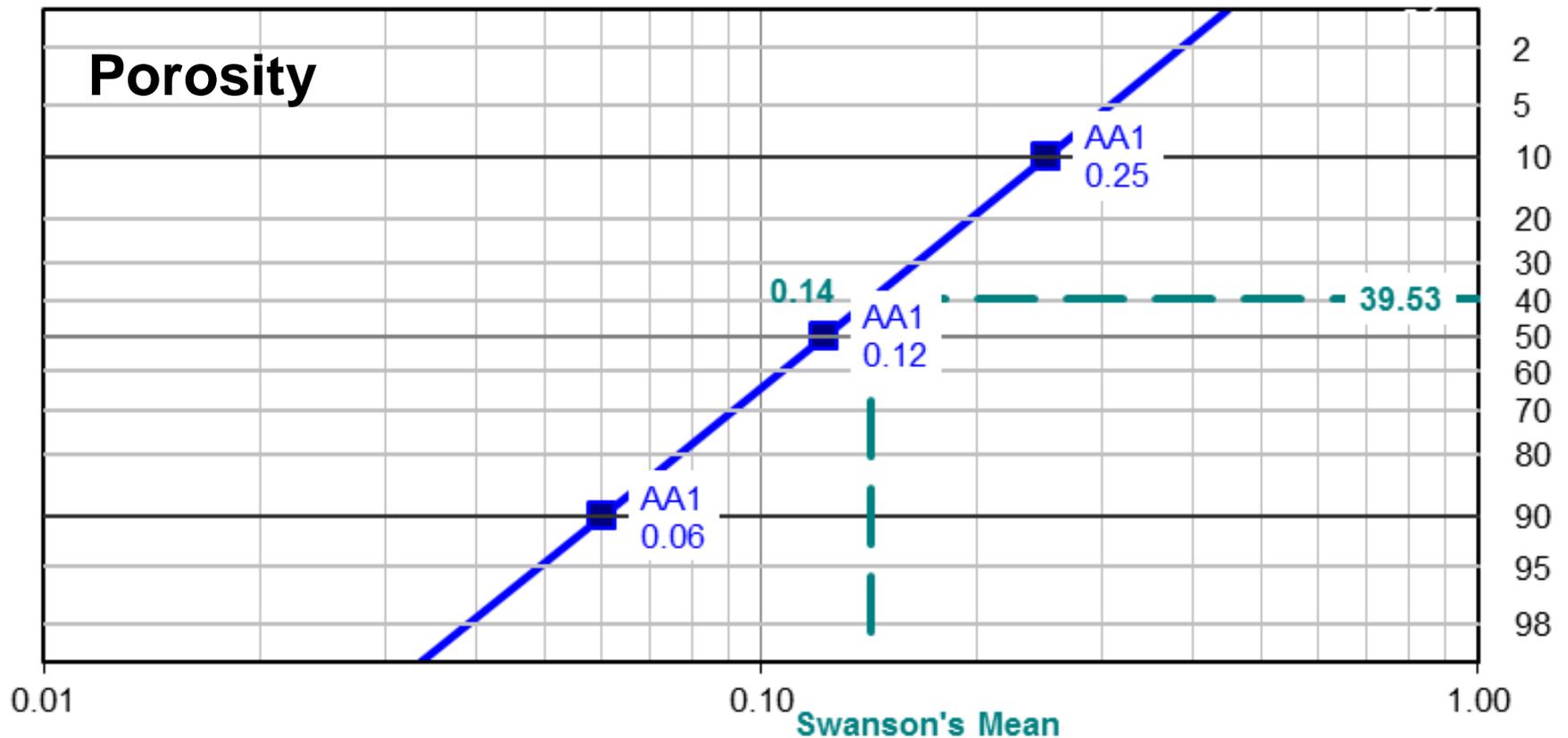
**The  $P_{99}$  must be realistic and measurable**

**The  $P_1$  should be possible but uncomfortable**





# Rose Philosophy



$$P_{90} = 6\% \quad P_{10} = 25\%$$

$P_1 = 45\%$ ; not possible, need to adjust the range

# Risk

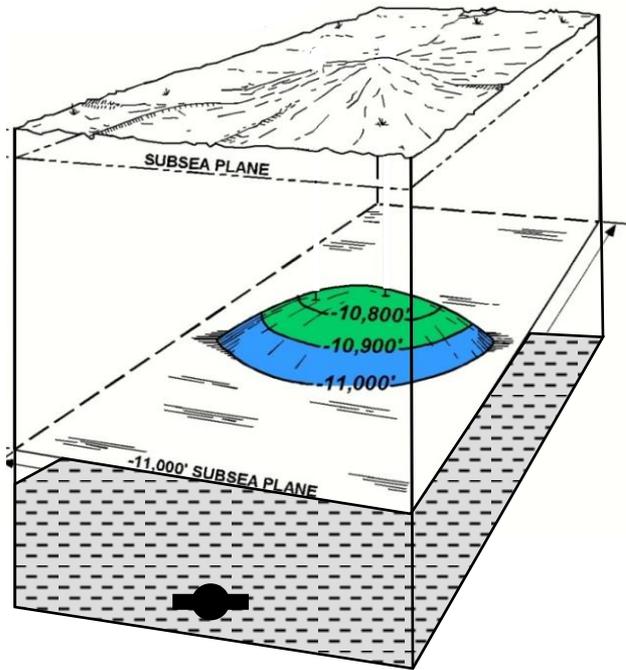
Once we have defined the uncertainty range for each variable, we then assign a probability for the variables



**Probability is the Likelihood of any Outcome**

# Risk

## There is risk for each element of the Petroleum System



### Probability of Source Rock

Chance that source rocks are present and mature

### Probability of a Migration Pathway

Chance that there is a path between source and reservoir

### Probability of a Reservoir

Chance that a reservoir of sufficient quality is present

### Probability of a Trap

Chance that the trap is present

### Probability of a Seal

Chance that the trap is sealed

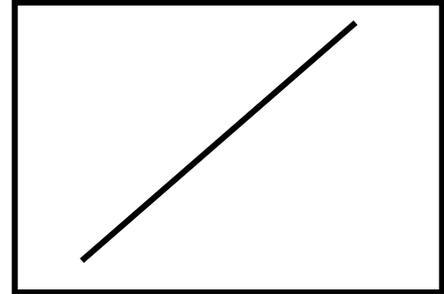


# Risk

## Chance Of Success

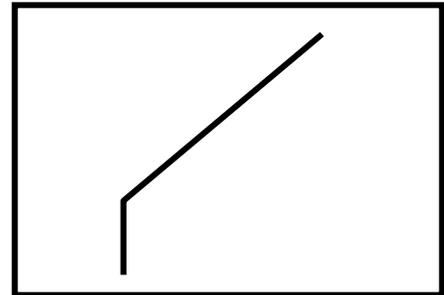
### Geologic COS

The Probability of entering a hydrocarbon distribution



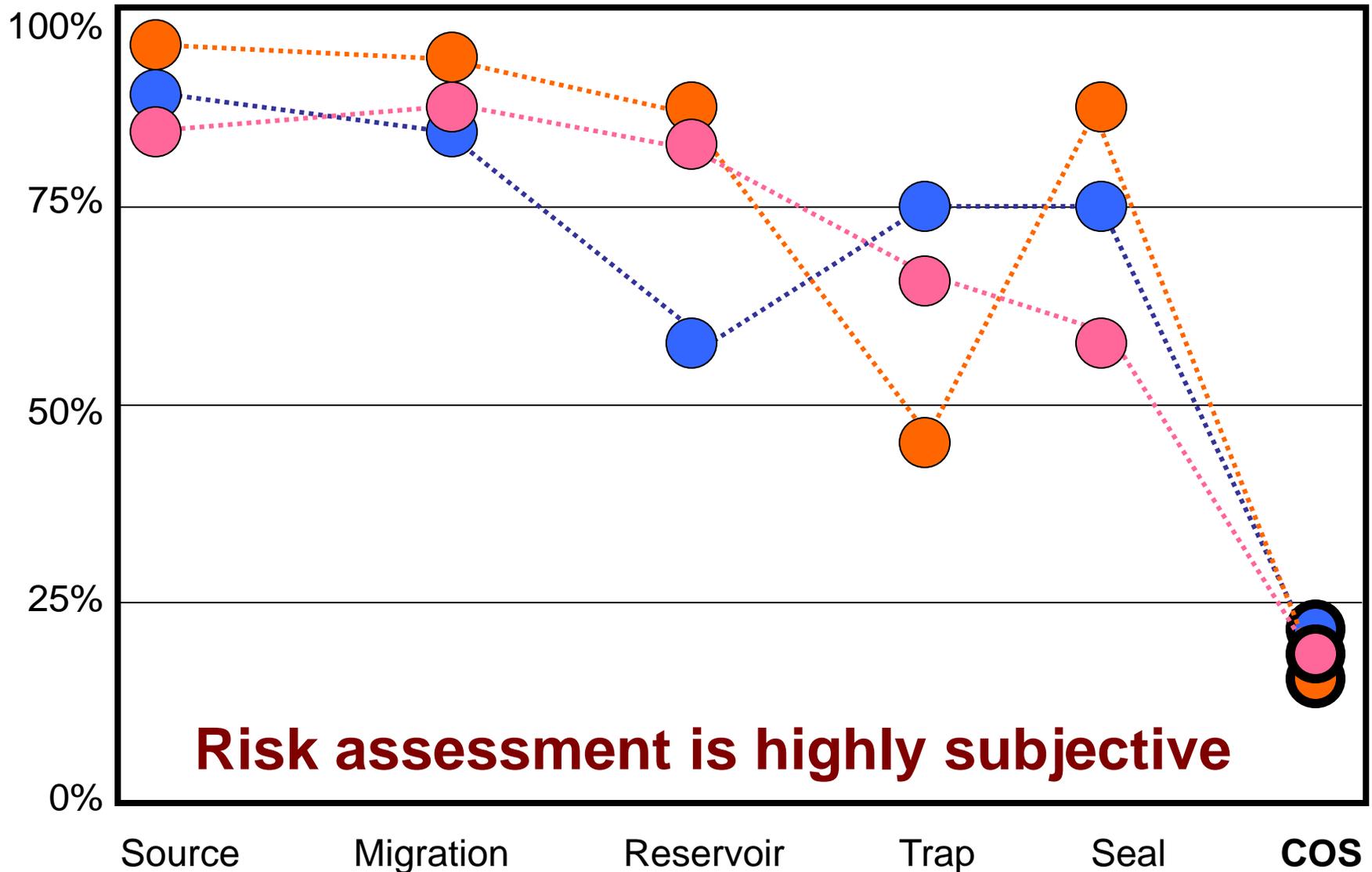
### Economic COS

The Probability of entering a commercial hydrocarbon distribution





# Chance of Success

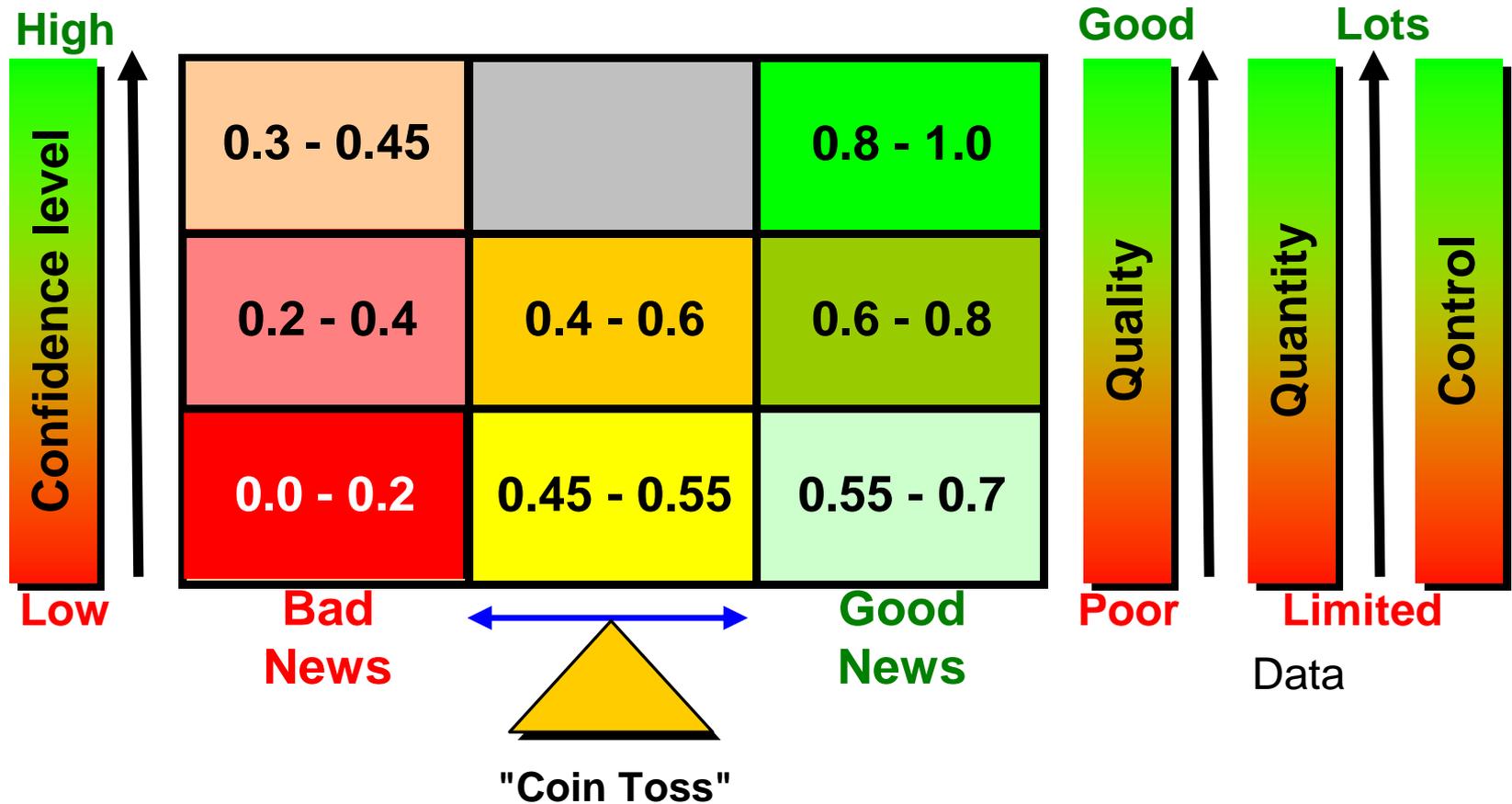


**Risk assessment is highly subjective**



# Chance of Success

## CHANCE ADEQUACY MATRIX



After Rose, 2001, p 38

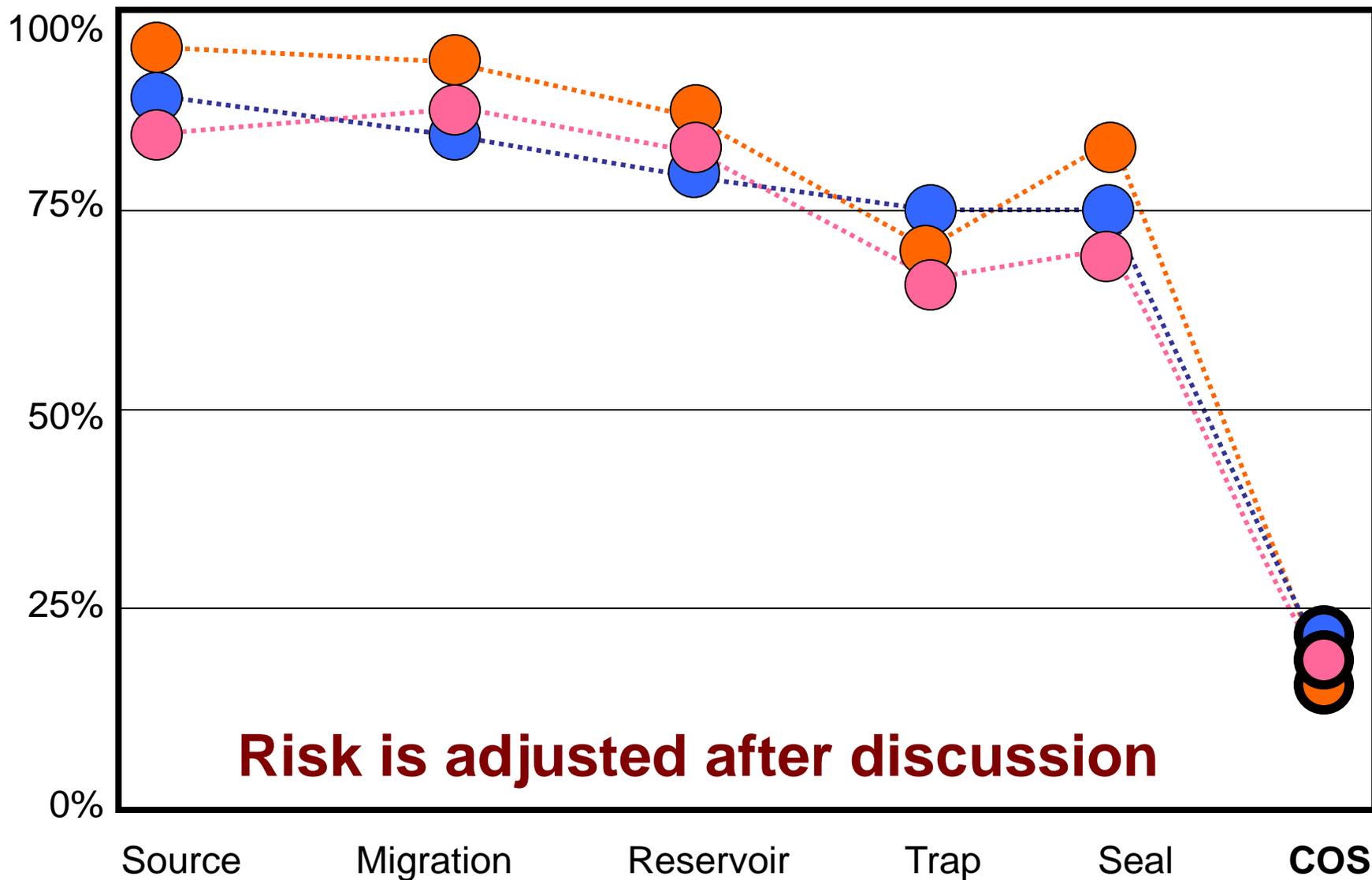
# Chance of Success



**Delphi Method for risk assessment can reduce the subjectivity**



# Chance of Success



**Risk is adjusted after discussion**



# Chance of Success The Petroleum System

Source Rocks

**If one fails**

Generation & Migration

Reservoir

Trap

Seal





# The Imperial Barrel Award Committee

