

2002-03 AAPG Distinguished Lecture

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Reservoir Heterogeneity, Geostatistics, Horizontal Wells and Black Jack Poker

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Outline:

- Uncertainty Example (Clapp & Stibolt)
- Performance Analyses
- Heterogeneity Discussion
- BS Session
- Summary



"Useful Measures of Exploration Performance"

(by Clapp & Stibolt, JPT, Oct 1991)

"...uncertainty about the outcomes of individual wells complicates the development of performance measures..."

...major understatement... d.beliveau



Clapp & Stibolt, JPT, Oct 1991

- Program: drill 20 wells
- P(s): 20%/well
- Reserves: 10 MMB/success
- "Expected" Volume: 40 MMB
- Actual Results: 24 MMB (40% "low")

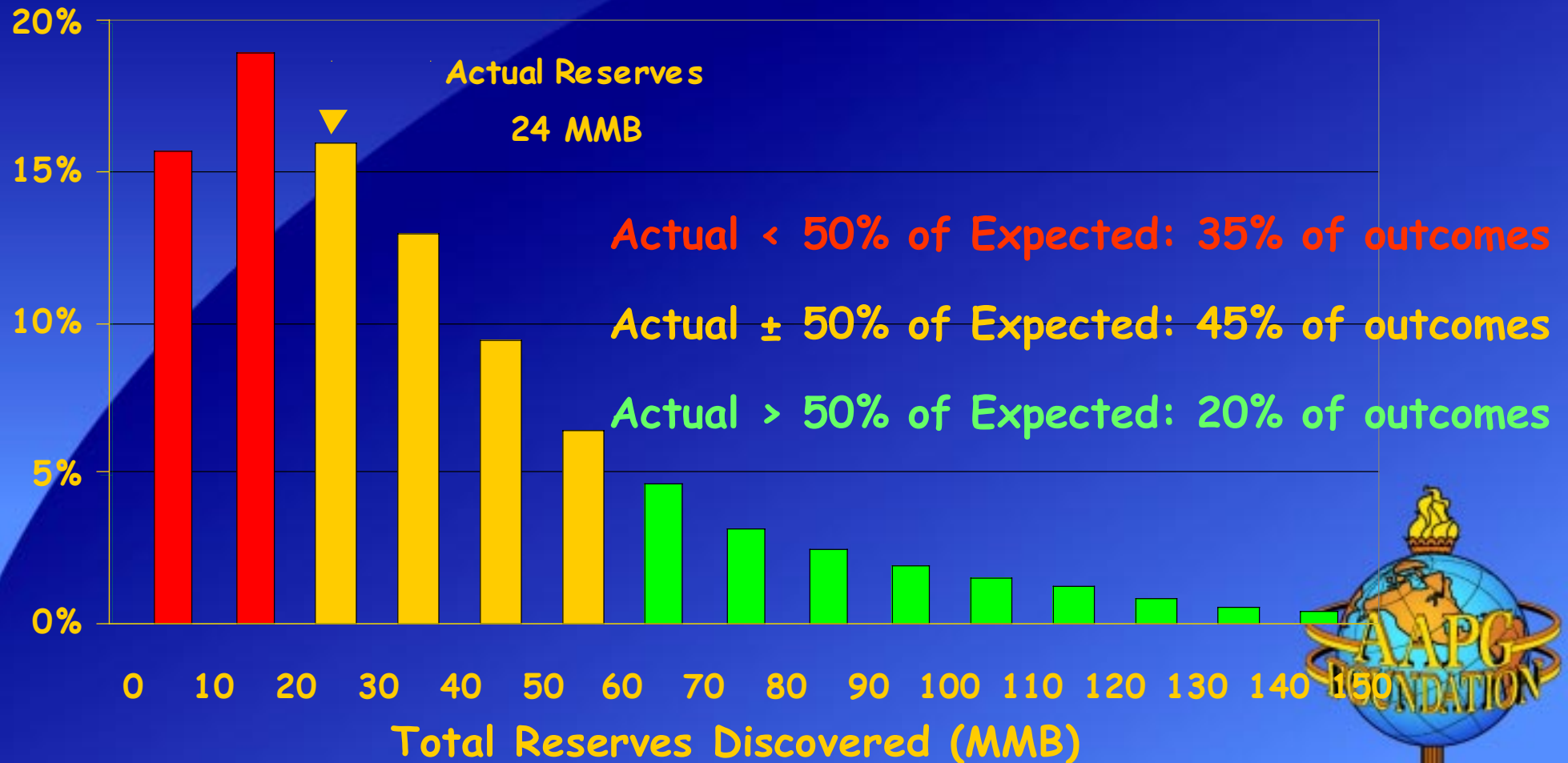
Q1: How disappointed should we be?

Q2: What is $P(0-24 \text{ MMB})$??



Probability Distribution of Reserves

(Clapp & Stibolt, JPT, Oct 1991)



Clapp & Stibolt, JPT, Oct 1991

Q1: How disappointed should we be?

Q2: What is $P(0-24 \text{ MMB})$??

*A2: The probability of getting 0-24 MMB
is more than 40%.*

A1: This is a quite probable outcome! .



Clapp & Stibolt, JPT, Oct 1991

- “Given the multiplicative aspect of estimates, simulation shows uncertainties conform to a log-normal distribution...”
- “Although this is the limiting case, it is surprising how rapidly this convergence occurs in practice”...
- “Laws of probability assure us actual values will converge to expected values as the number of wells drilled becomes large; if estimates are unbiased...”



Clapp & Stibolt, JPT, Oct 1991

- “Unfortunately, for a finite number of wells, there is virtually no chance that actual values will hit expected values..”

In most cases EXPECT Actual < Target



"Productivity Improvement Factors"

- Imagine a 5-yr old heavy oil well:

$$q_{oi} = 100 \text{ bopd (primary)}$$

$$q_{now} = 10 \text{ bopd} + 1,000 \text{ bwpd (w-flood)}$$

- Let's drill a horizontal infill well:

$$q_h = 100 \text{ bopd} + 400 \text{ bwpd}; \text{ SUCCESS!}$$

How would you calculate the "PIF"?



Estimating "PIF":

- Ratio initial h-well oil to initial v-well oil:

$$\underline{\text{PIF} = 1.0}$$

*does not convey "success"

*does not account for change in mechanism over time



Estimating "PIF":

- Ratio initial h-well oil to initial v-well oil:

$$\text{PIF} = 1.0 \quad \times$$

2. Ratio initial h-well fluid to current v-well fluid:

$$\text{PIF} = 0.5$$

*does not convey "success".

*does not account for changing properties of produced fluids.



Estimating "PIF":

- Ratio initial h-well oil to initial v-well oil:

$$\text{PIF} = 1.0 \quad \times$$

- 2. Ratio initial h-well fluid to current v-well fluid:

$$\text{PIF} = 0.5 \quad \times$$

- 3. Ratio initial h-well oil to current v-well oil:

$$\text{PIF} = 10.0 \quad \partial$$

*conveys "success" message ∂

*who cares about water? ∂



Plotting PIF Distributions:

- Based on "stable" h-well oil/gas rate vs. current neighboring v-well rates.
- This allows direct comparison of results from different fields.
- Primary data sources SPE, CIM, Shell & misc. public databases.

| <u>PIF</u> | |
|---------------|-------------|
| <u>Actual</u> | <u>Plot</u> |
| 0-1.5 | 0 |
| 1.5-3 | 2 |
| 3-5 | 4 |
| 5-7 | 6 |
| 7-9 | 8 |
| 9-11 | 10 |
| Etc... | |



±2,500 h-wells
±300 fields:

Data Sources:

**SPE, CIM,
Shell, & misc.
Public Data**

Environments:

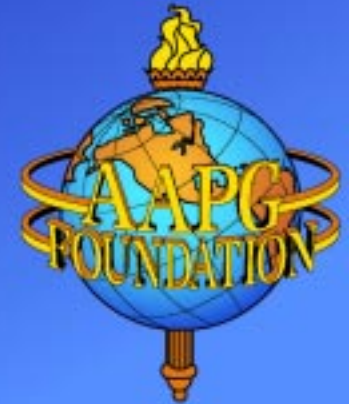
**Clastics
Carbonates**

Applications:

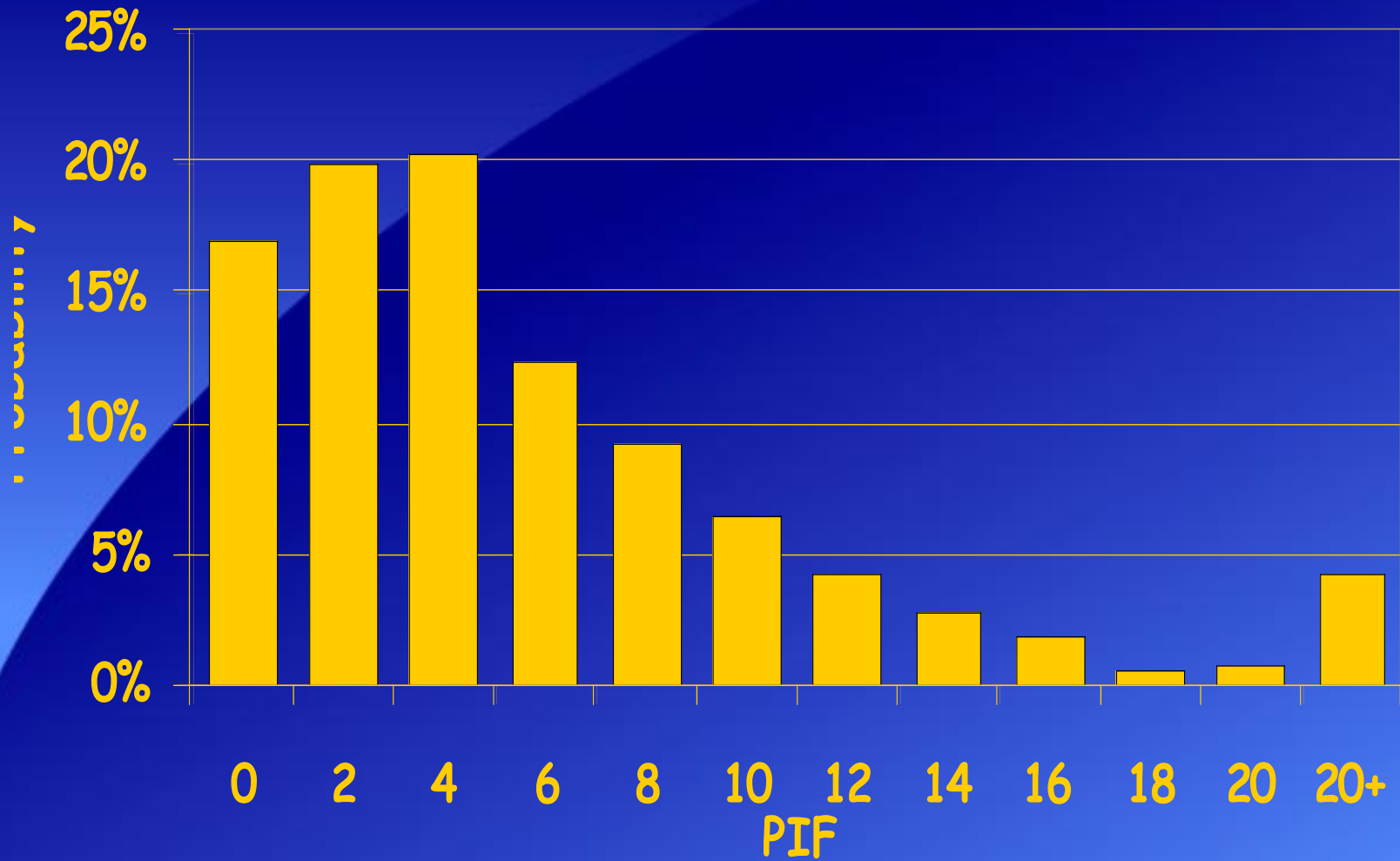
**Primary
Waterflood
EOR
Prod/Inj**

Fluids:

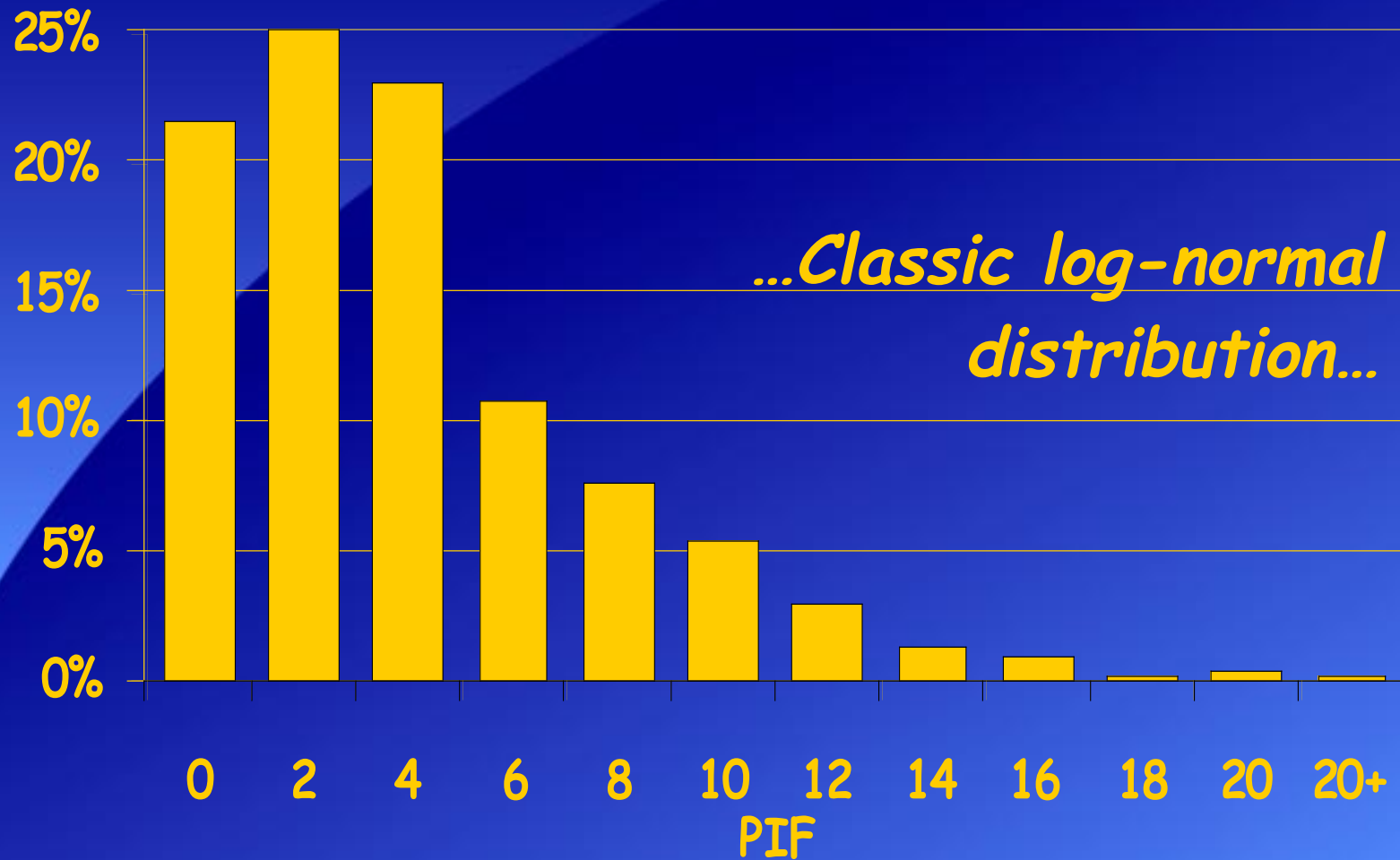
**Light Oil
Heavy Oil
Gas
Water**

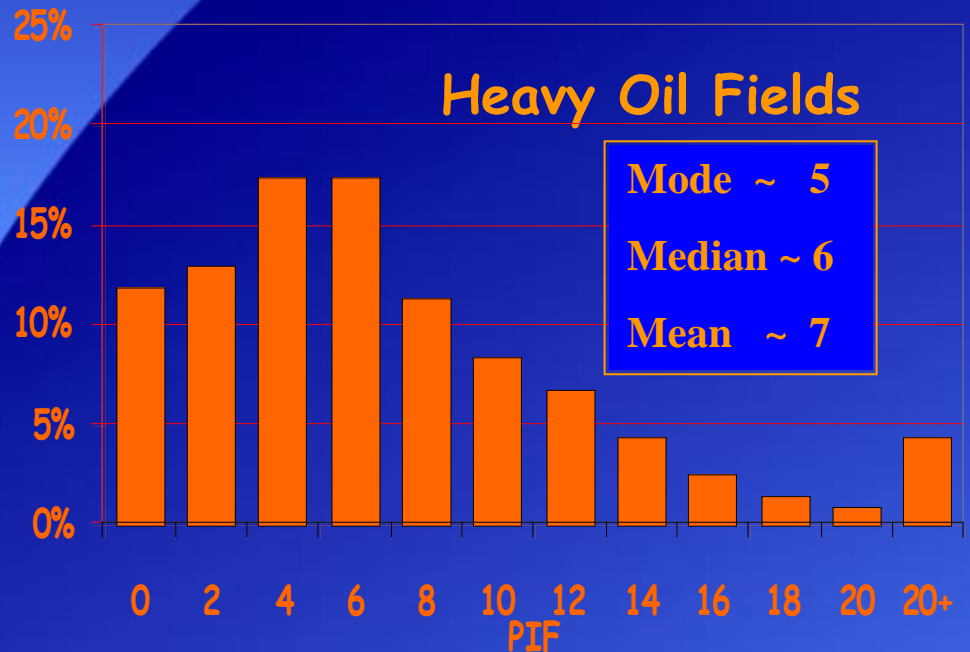
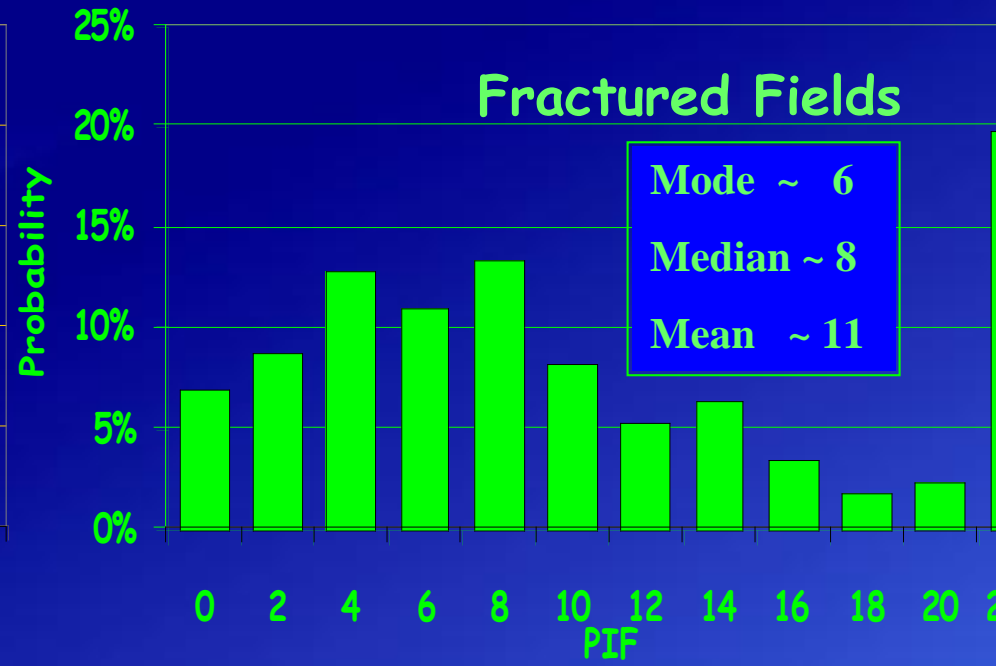
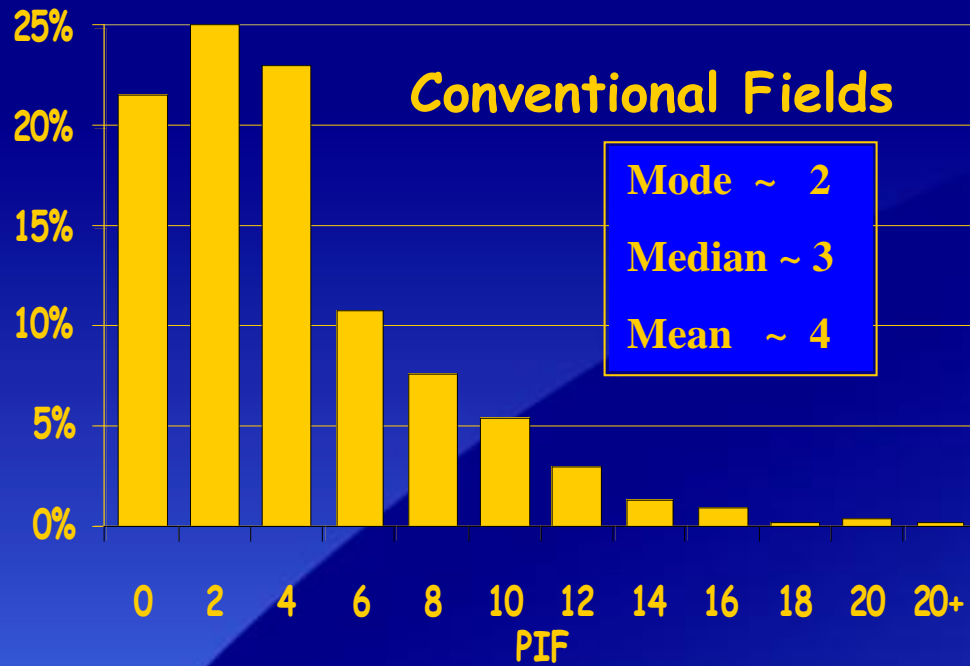


PIF Distribution: ALL Fields/ALL Wells



PIF Distribution: "Conventional Fields"



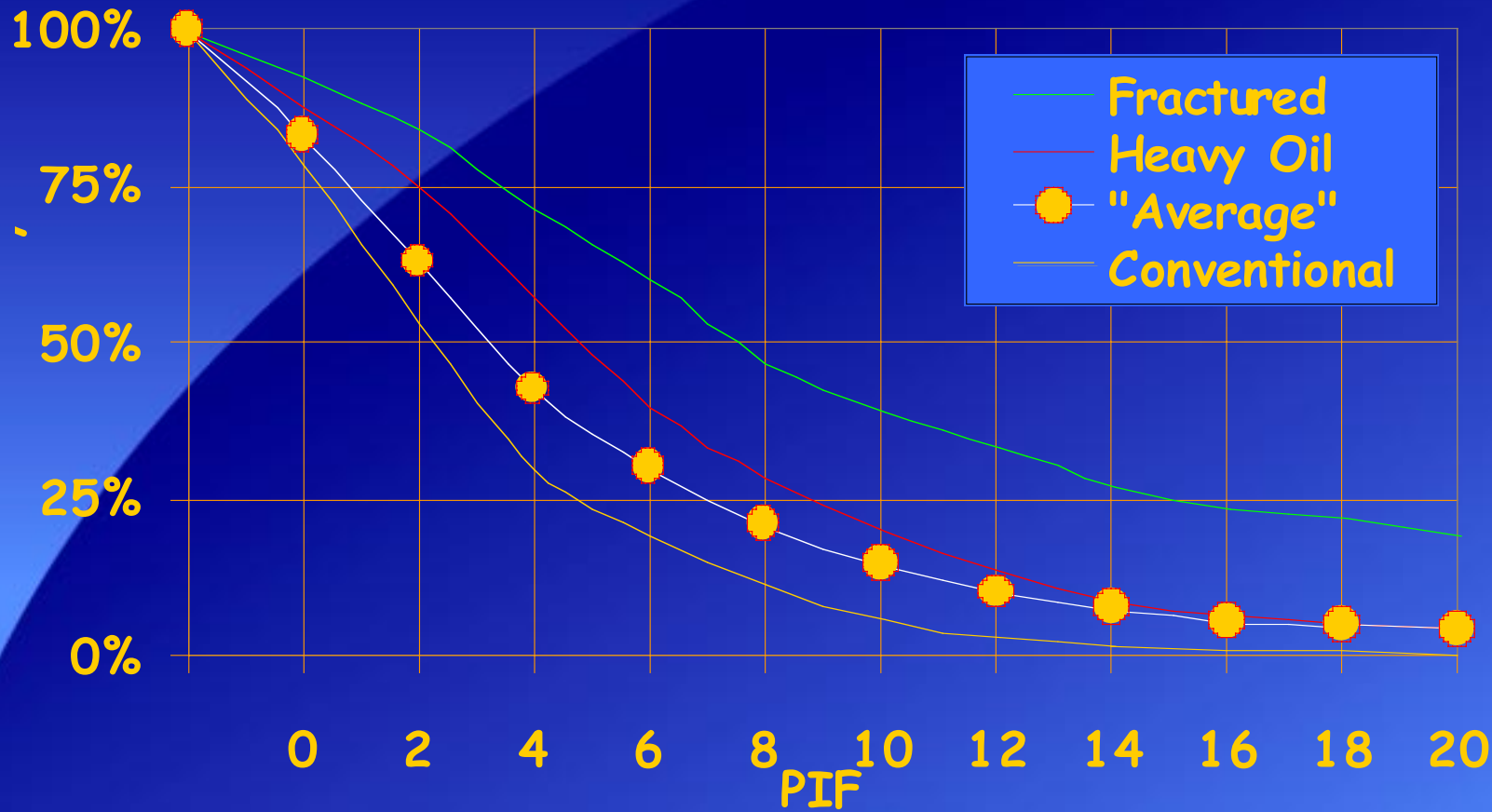


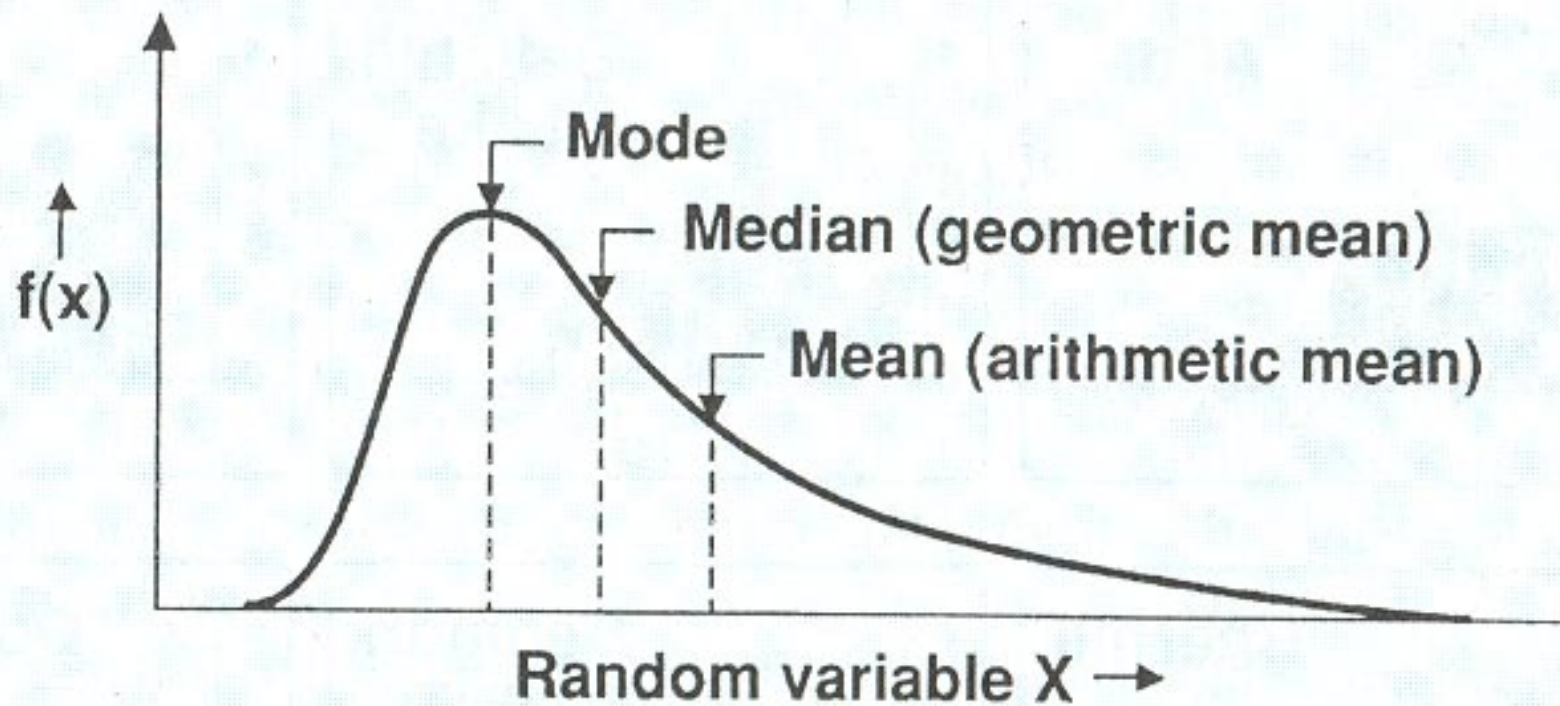
...All show classic "lognormal" distributions, but with different statistical parameters...



Comparison of PIF Distributions,

by
Field
"Type"

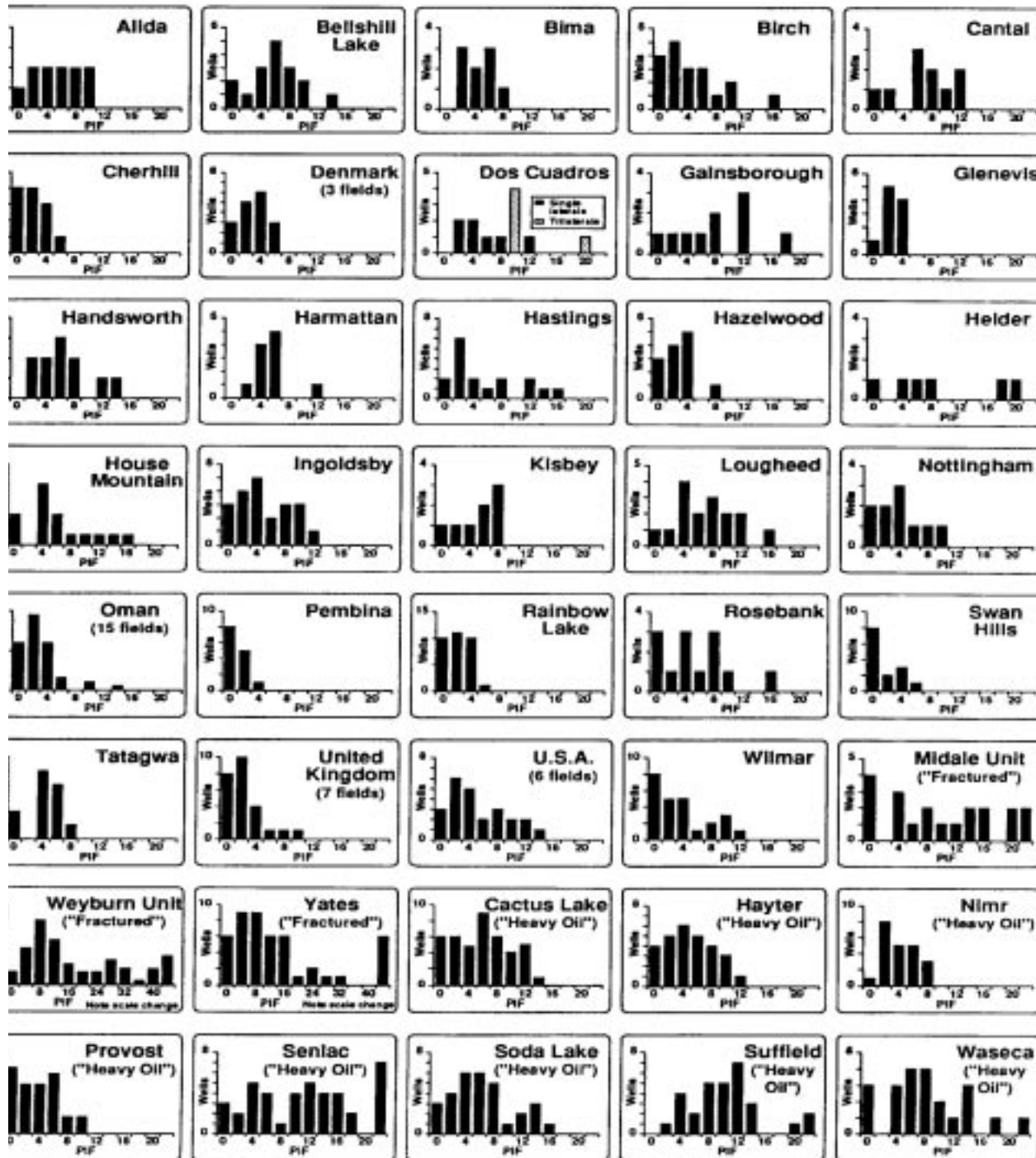




...the biggest technical contribution made by my paper was to reinforce the basics of this plot...



What do actual, but incomplete log-normal distributions look like?



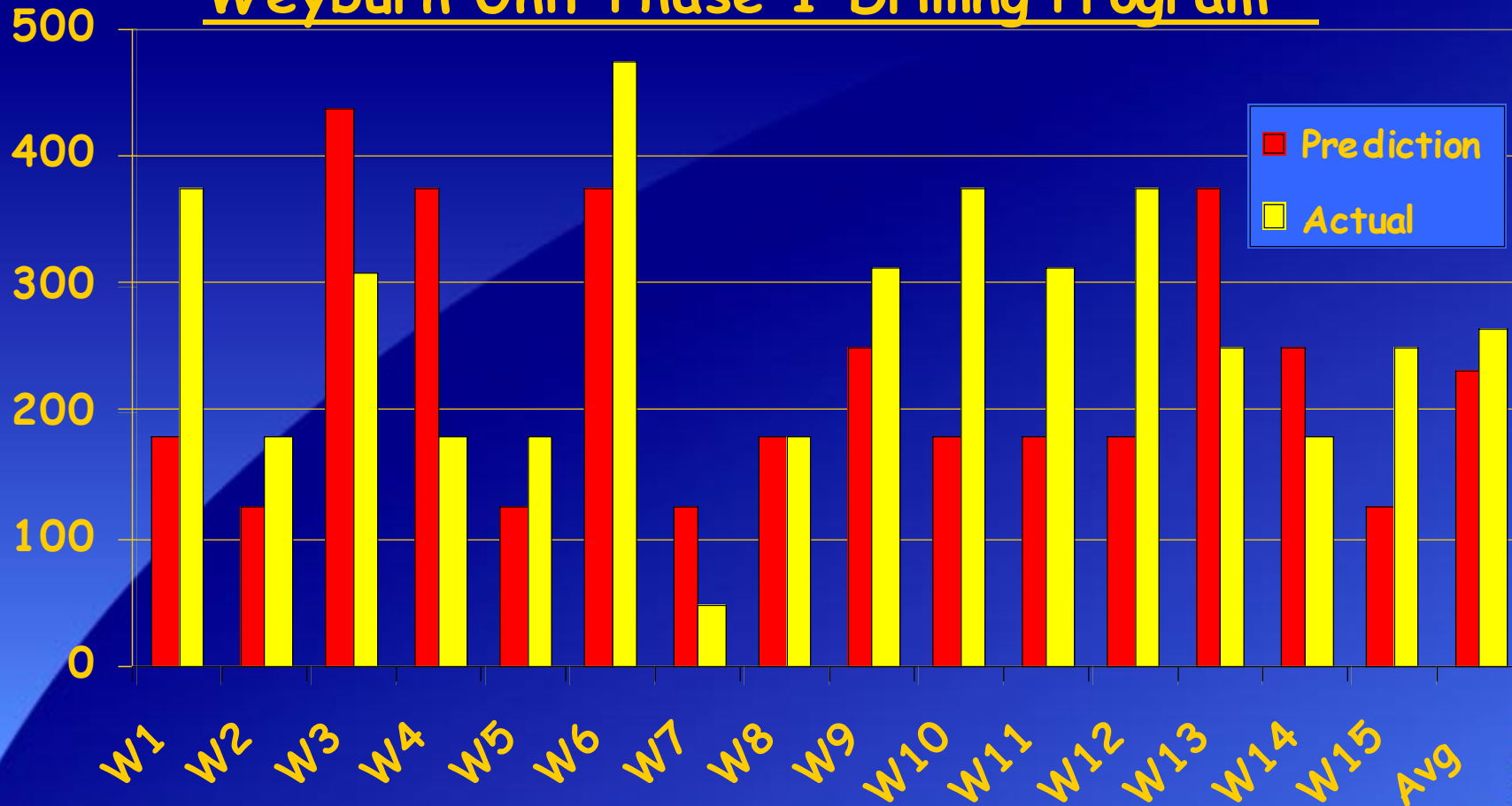
Predicted vs. Actual PIFs for Individual Wells

...this data is much harder to find in the public domain...

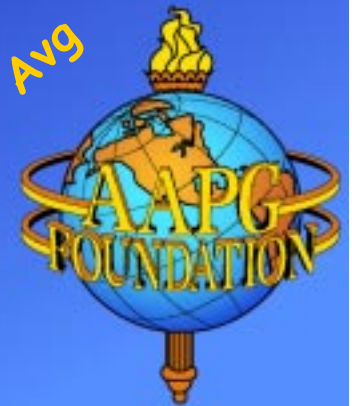
...most of us like to talk about how "good"
our predictions are...



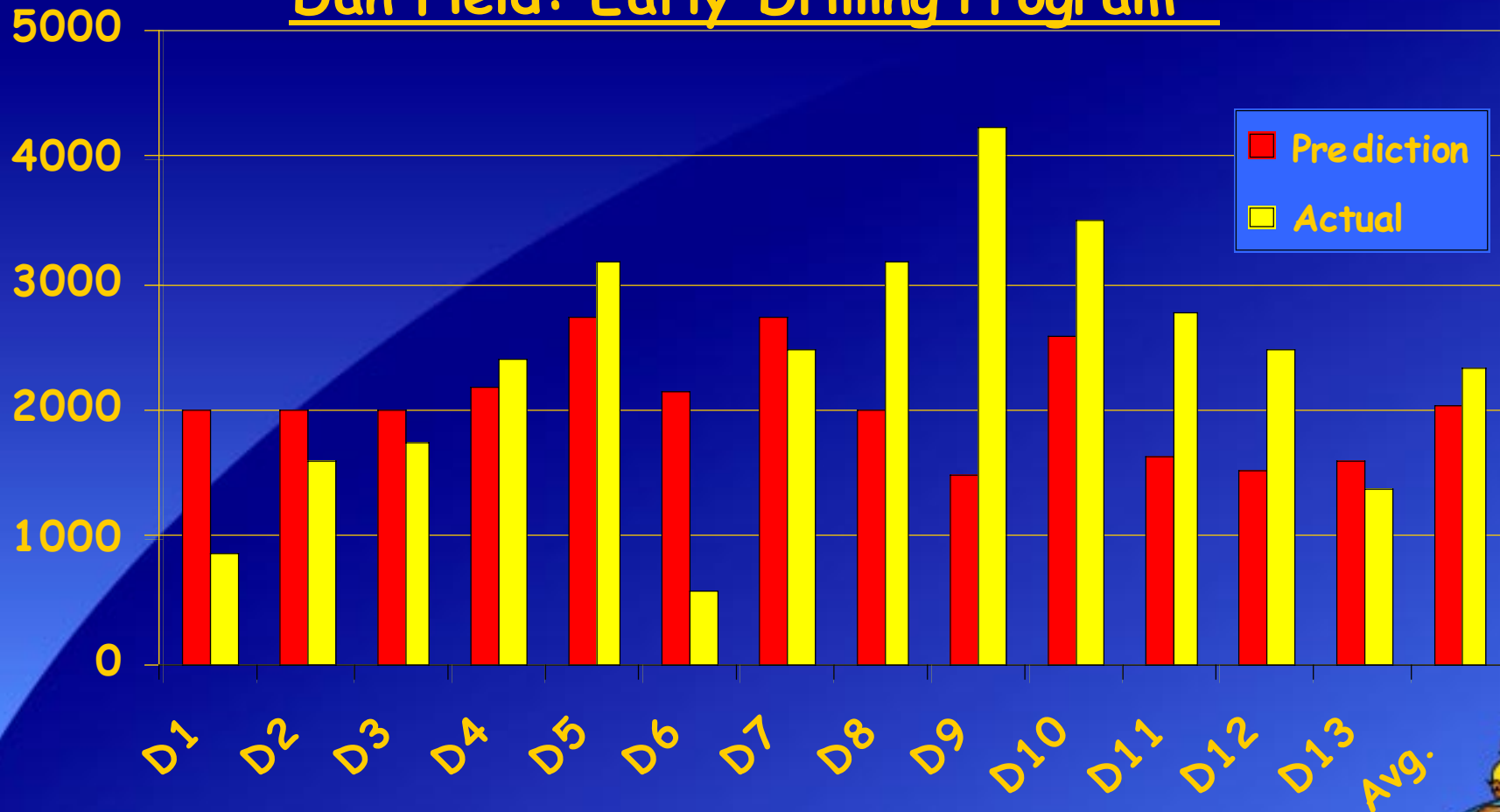
Weyburn Unit Phase 1 Drilling Program



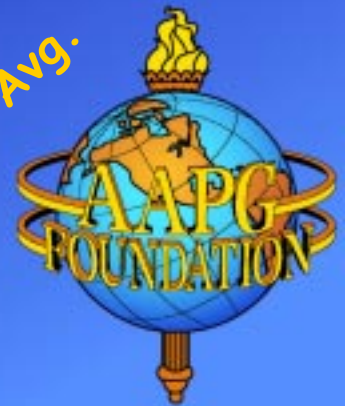
PIF Distributions
for Individual Wells (1)



Dan Field: Early Drilling Program



PIF Distributions for Individual Wells (2)



Predicted vs. Actual PIFs for Individual Wells

...the average error bar on reservoir engineering predictions of rate is $\pm 50\%$ of forecast...

...about half the wells fall within $\pm 50\%$ of forecast...

...many reservoir engineers like to talk about how "good" our predictions are...

...I like telling how bad mine are...



"Heterogeneity":

- Composed of unrelated or unlike elements or parts, varied, miscellaneous.
- Characteristic of a medium or field of force which signifies that the medium has properties that vary with position within it.
- Differing in kind; having unlike qualities; possessed of different characteristics.
- ...however, many other real-life things could be lumped into the definition, as well...



Heterogeneity: a new "definition"

- composed of unrelated or unlike elements or parts; a property that varies with position; differing in kind; etc.
- *anything that impacts the flow properties or "expected performance" of a producing reservoir.*



"Heterogeneity"

could encompass many effects:

Permeability

Saturations

Continuity

Pressure

Skins

Fluid Type

Fractures/Faults

Near-wellbore physics

Multi-phase effects (WOR, GOR, k_r , etc)

"Effective" Length

Measurement Errors

Interpretation Errors

Bad Data Records

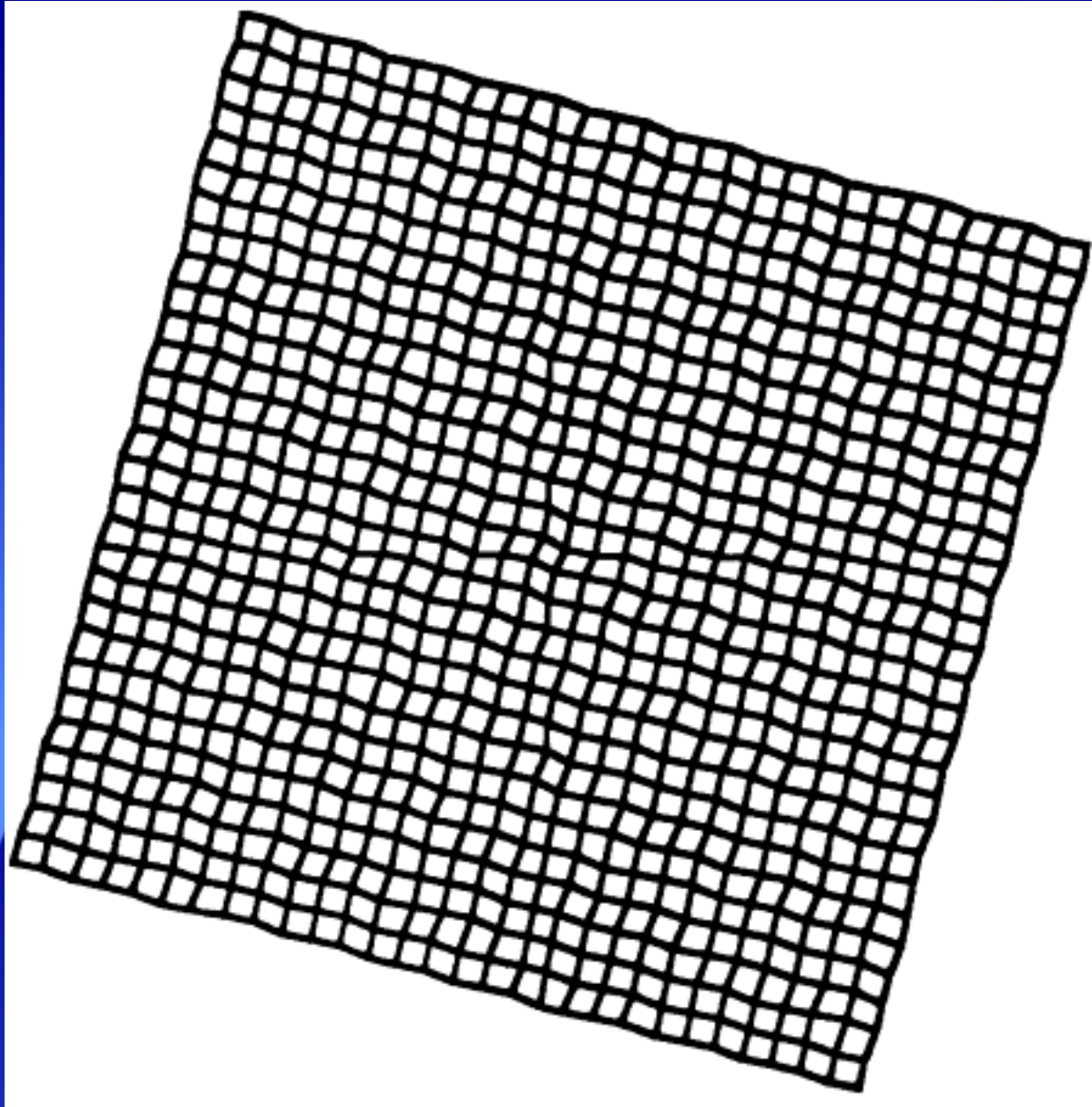
...& things you may

find somewhat

bizarre...



...2D map view...

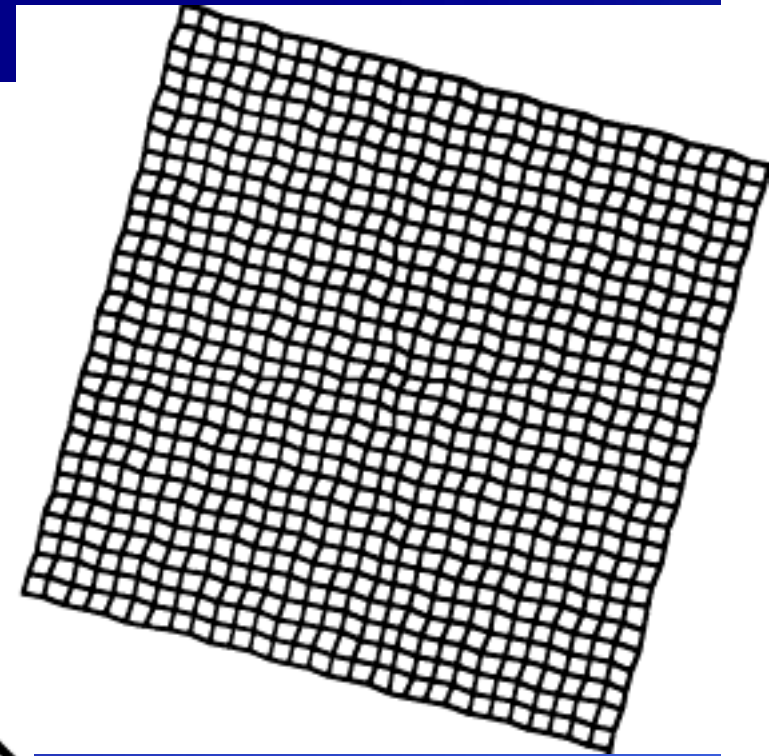
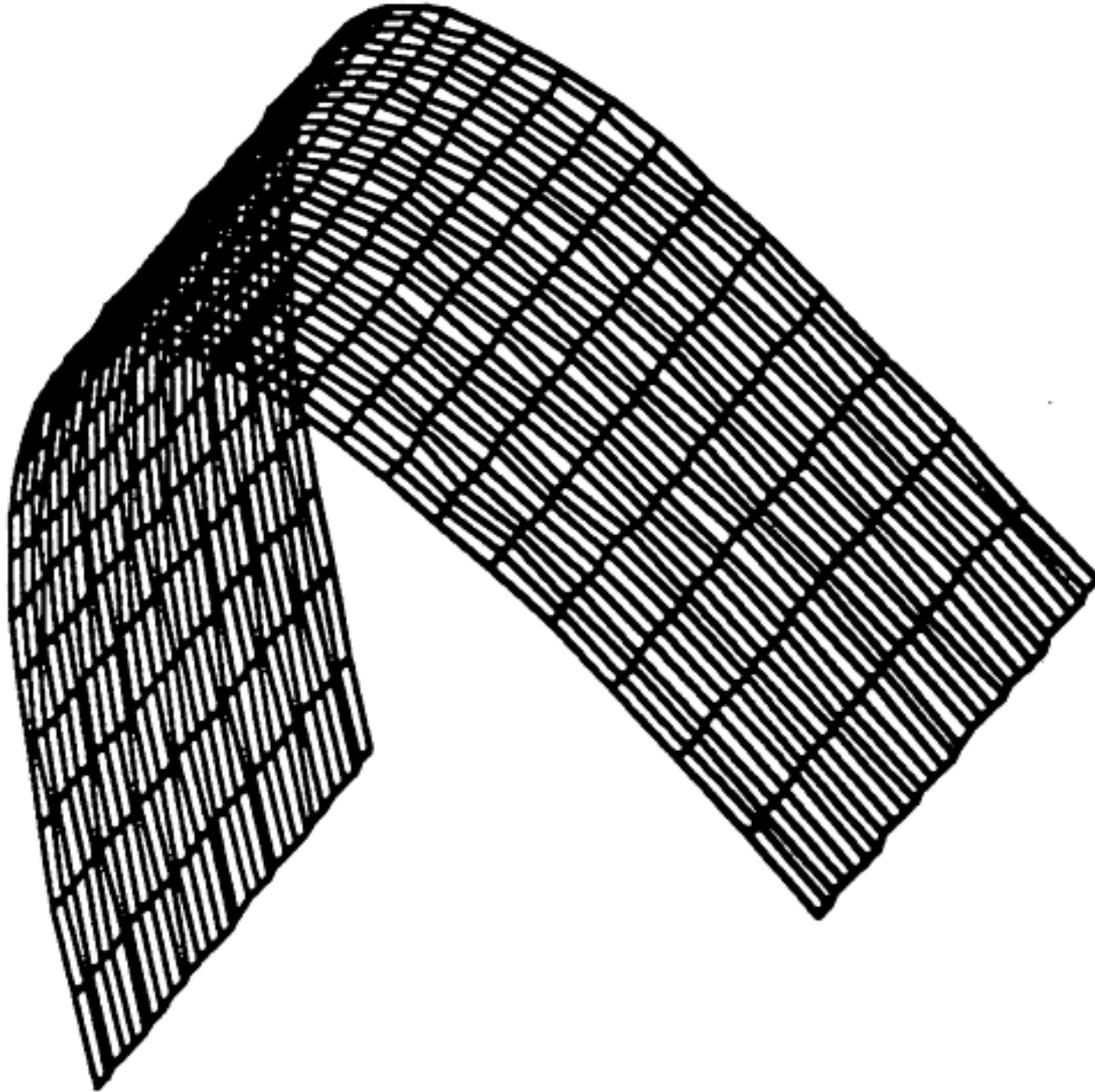


What is
Object #1?

What do you
see?



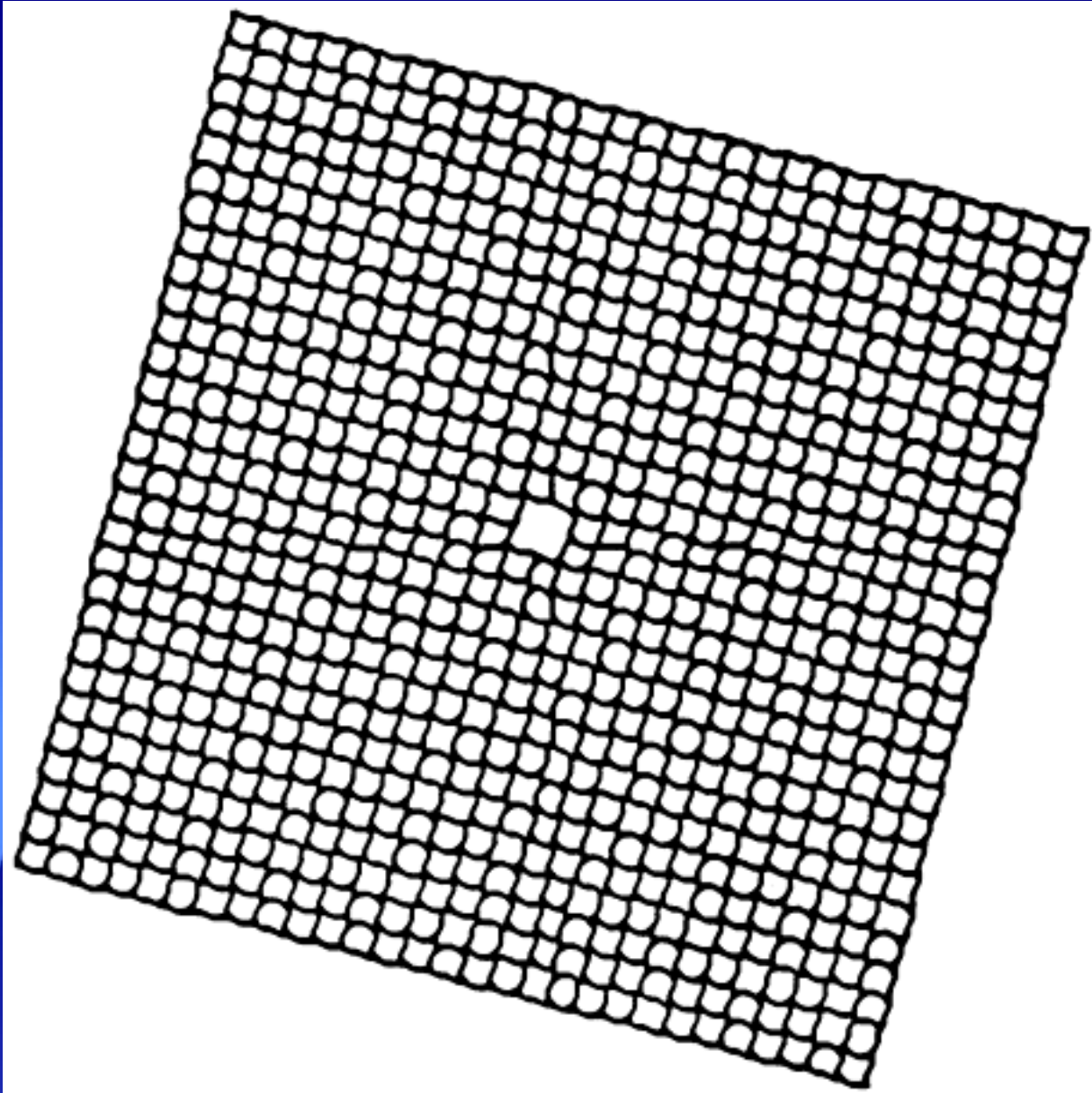
...Actual Object #1...



...2D map view...



...2D map view...

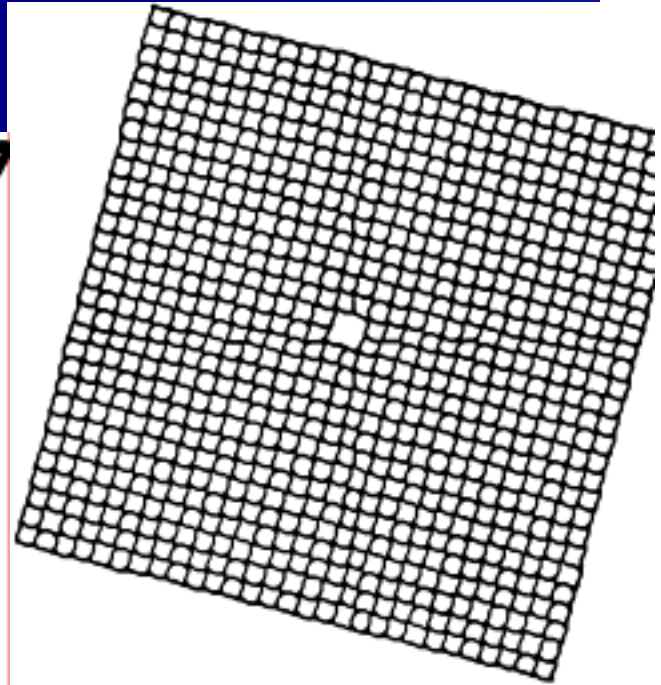
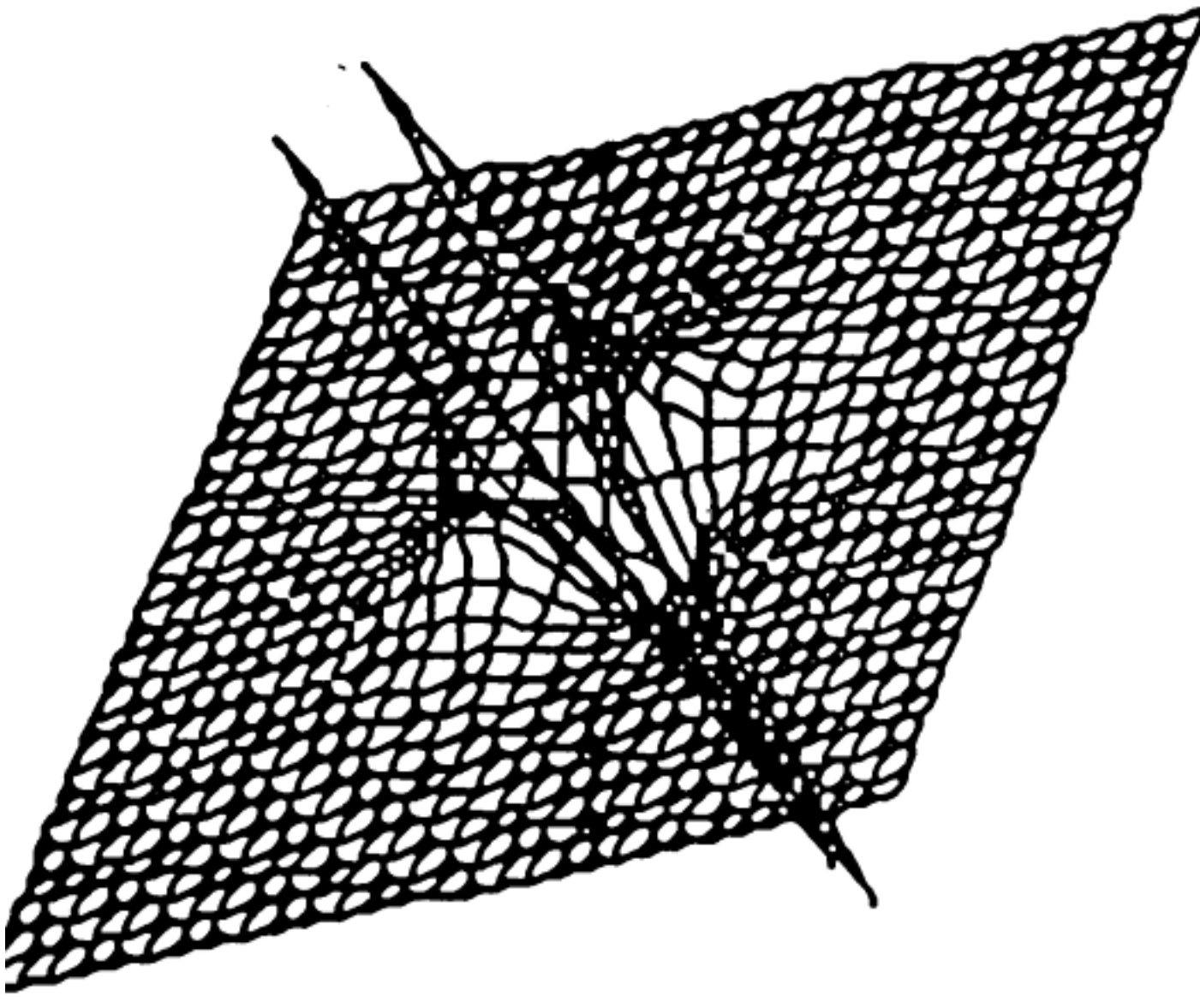


What is
Object #2?

...we have a little
bit more "signal"
to work with...



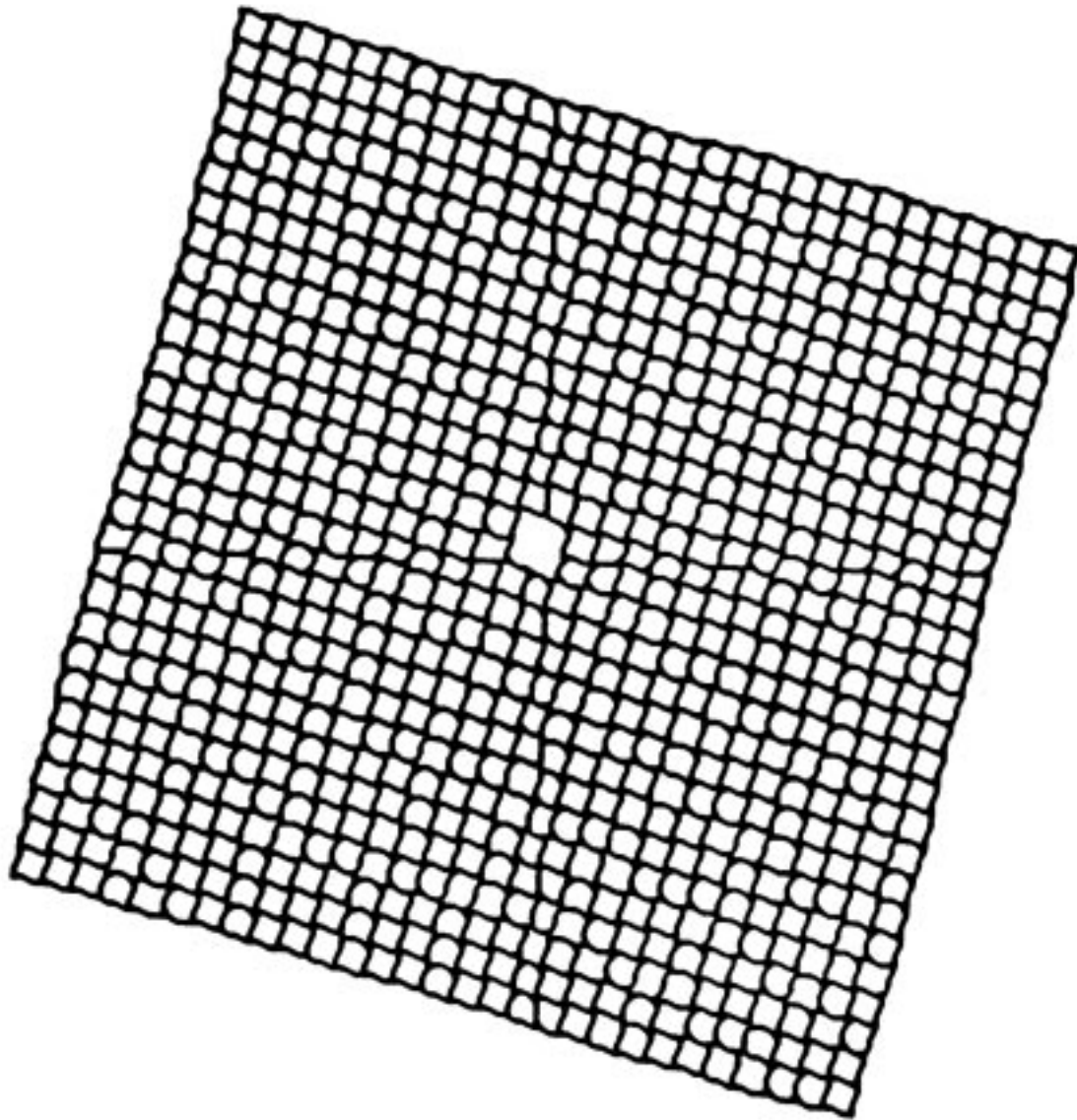
...Actual Object #2...



...2D map view...



...2D map view...

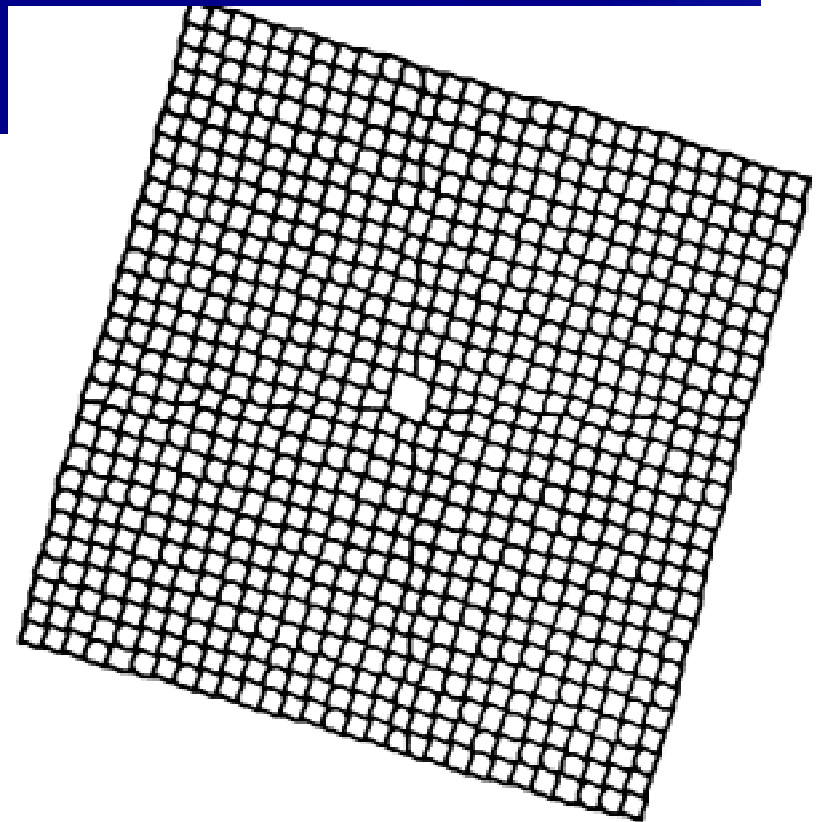
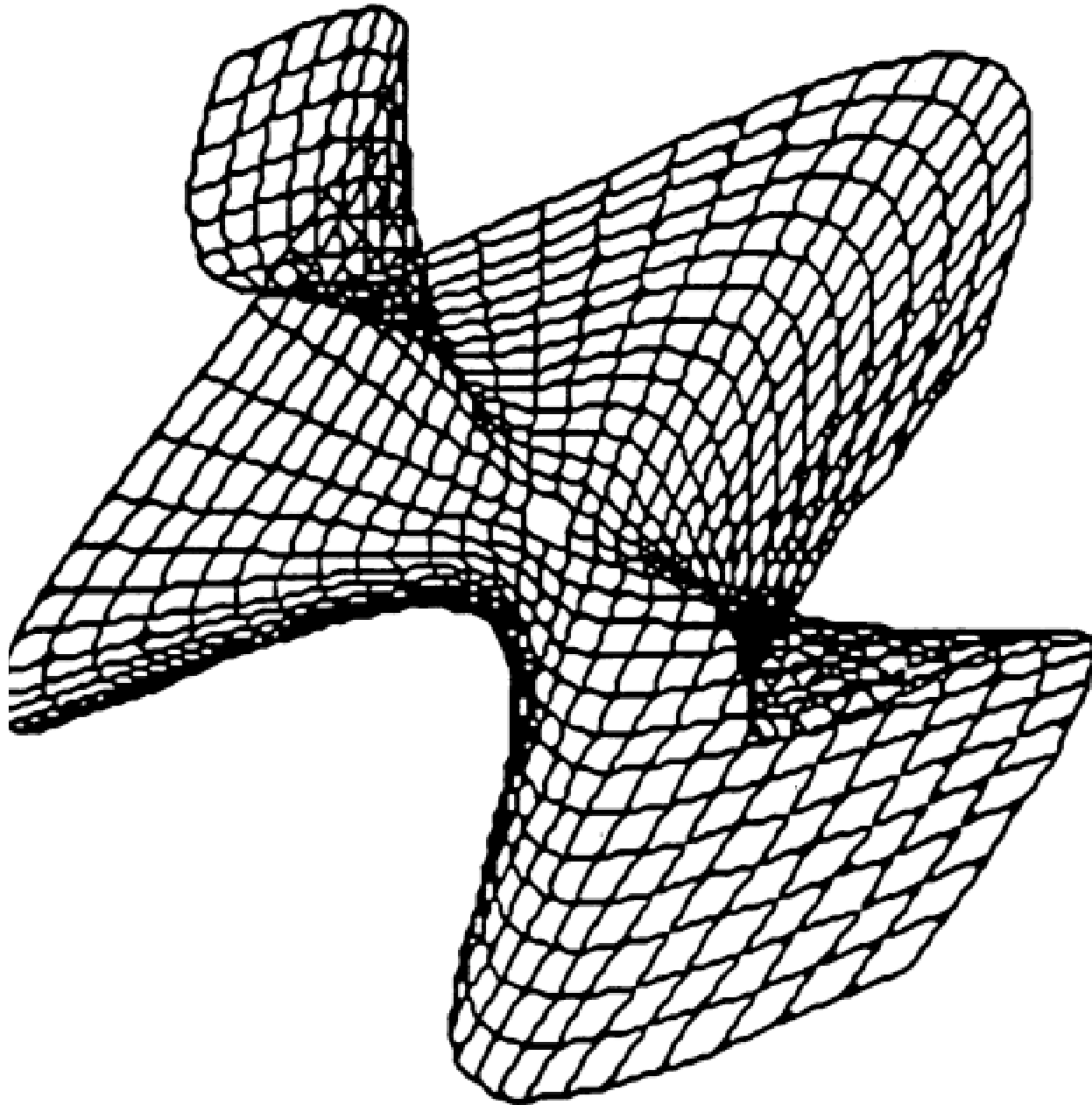


What is
Object #3?

...again, we have
a little bit more
"signal" to work
with...



...Actual Object #3...



...2D map view...



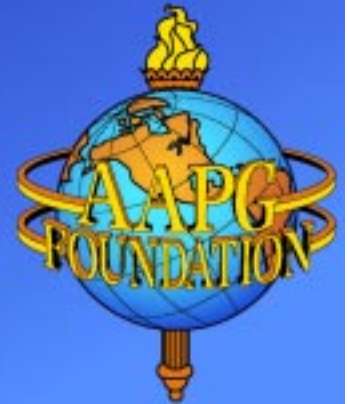
Uncertainty:

Who-What-When-Where-How(Much)?

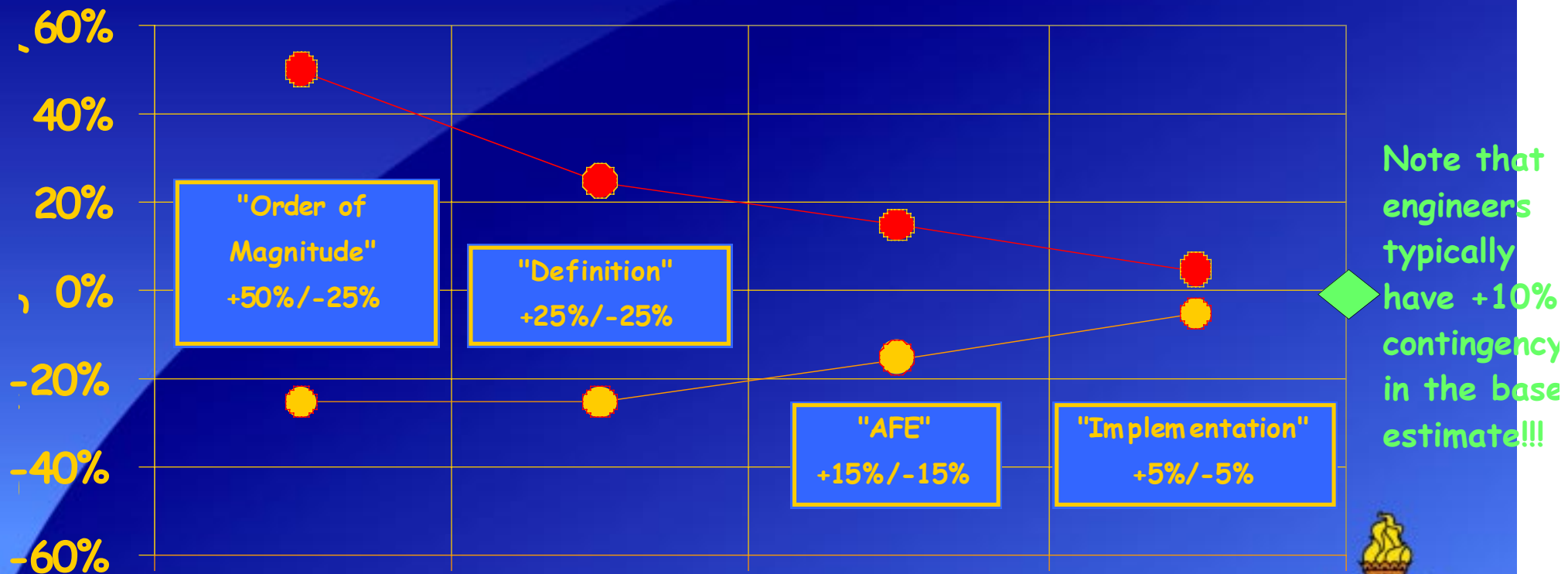
- Geophysics
- Exploration Geology
- Development Geology
- Petrophysics
- Reservoir Engineering
- Drilling Engineering
- Production Engineering
- Facilities Engineering



Increasing
uncertainty
in data and
analyses



Eng/Construction Cost Uncertainties



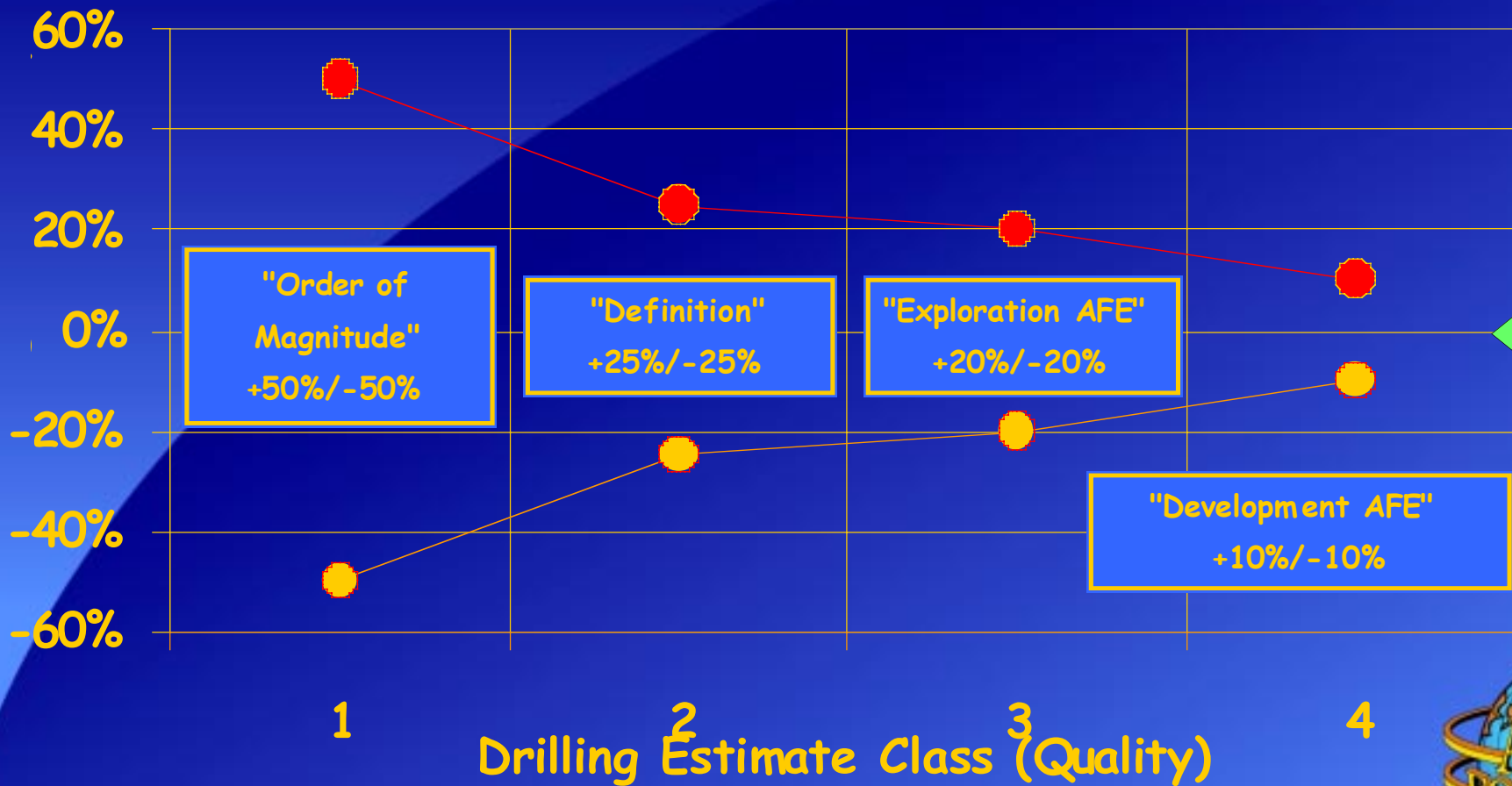
Note that engineers typically have +10% contingency in the base estimate!!!

1 Eng/Construction Estimate Class (Quality) 4

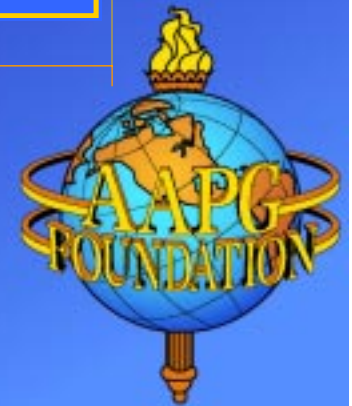
...from a typical major oil company...



Drilling Cost Uncertainties



Note that our drillers have a +10%/+20% contingency in the base estimates!!!



...from a typical major oil company...

What about AFE uncertainty?

Geophysics: ???

Geology: ???

Reservoir: $\pm 50\%$ uncertainty (rates).

Expl. Drilling: 20% contingency $\pm 20\%$ uncertainty.

Dev. Drilling: 10% contingency $\pm 10\%$ uncertainty.

Facilities: 5% contingency $\pm 15\%$ uncertainty.

Increasing
uncertainty
in data and
analyses



What about AFE uncertainty?

Increasing
uncertainty
in data and
analyses

Geophysics: more than the geologists!!

Geology: more than the engineers!

Reservoir: $\pm 50\%$ uncertainty (rates).

Expl. Drilling: 20% contingency $\pm 20\%$ uncertainty.

Dev. Drilling: 10% contingency $\pm 10\%$ uncertainty.

Facilities: 5% contingency $\pm 15\%$ uncertainty.



Universal Analytical H-Well PIF Simulator™

CAPABILITIES:

(Geo) statistics

Single, dual, and triple porosity (frac'd) reservoirs

Primary, secondary, and tertiary recovery

Heavy oil (primary, secondary, thermal)

Coning (gas, oil, water)

Multi-phase flow ($0 < "n" < 20$)

Darcy and non-darcy flow

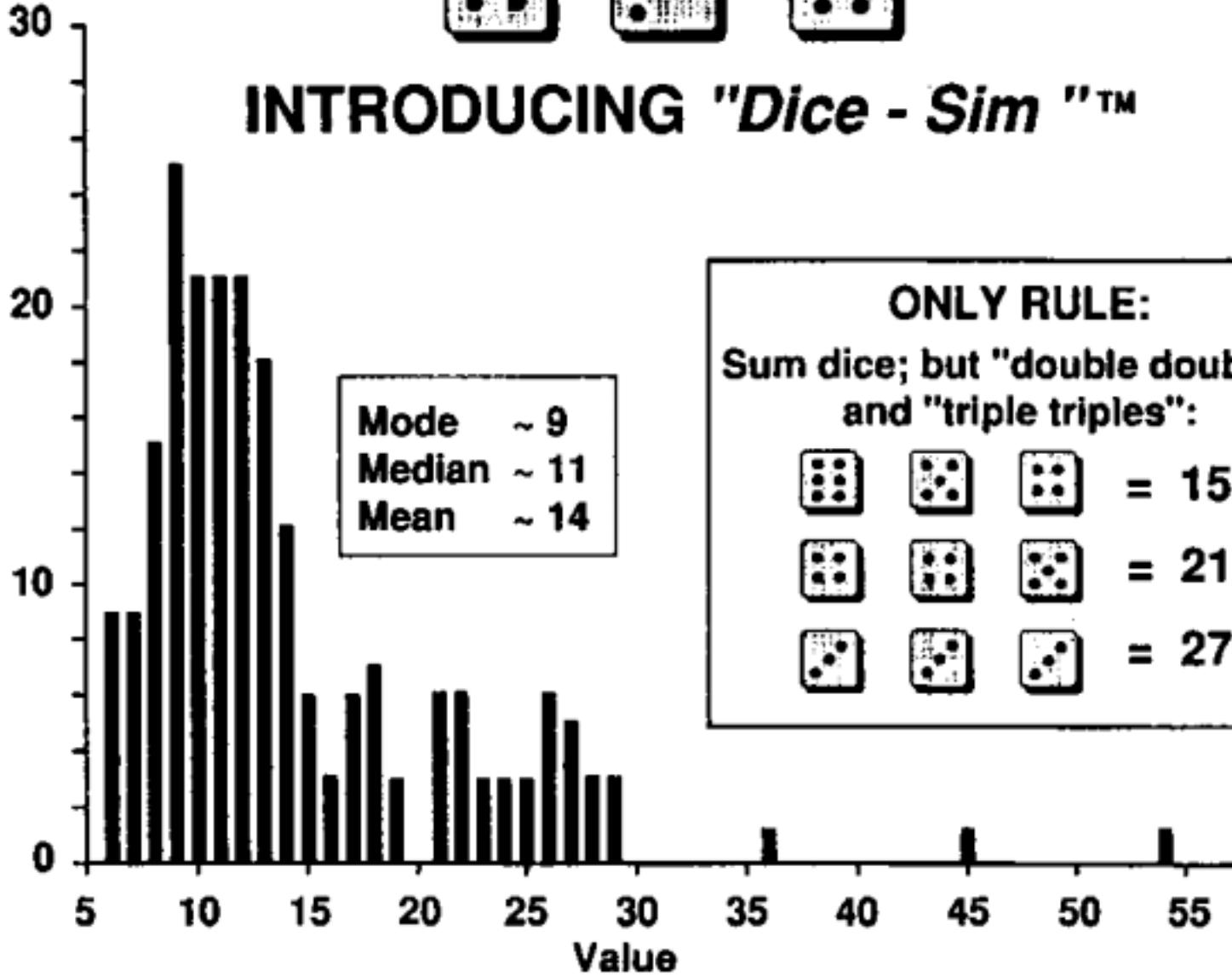
Coalbed methane





INTRODUCING "Dice - Sim"™

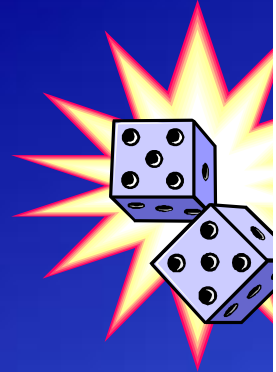
Number of Occurrences



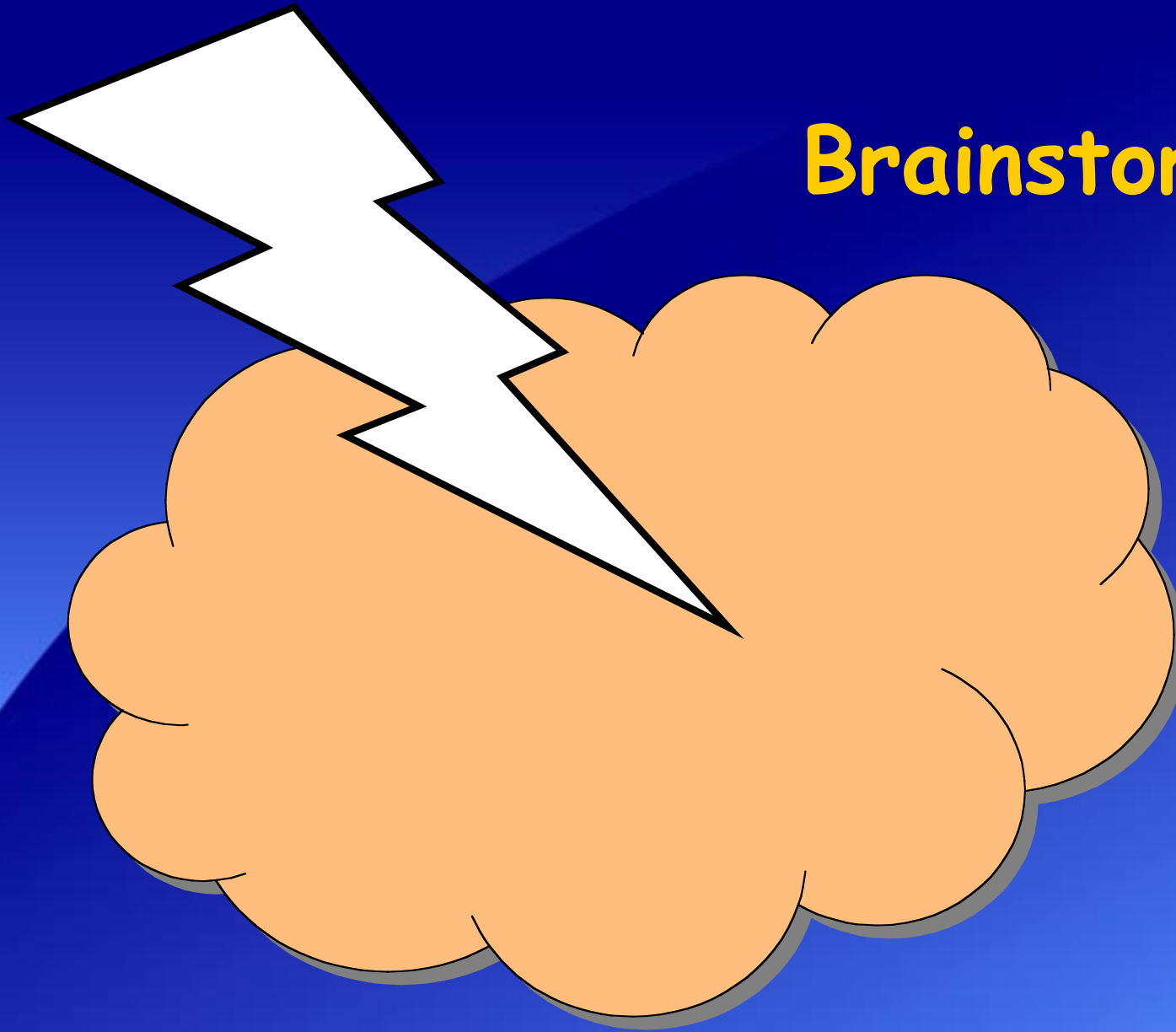
Mode ~ 9
 Median ~ 11
 Mean ~ 14

ONLY RULE:
 Sum dice; but "double doubles"
 and "triple triples":

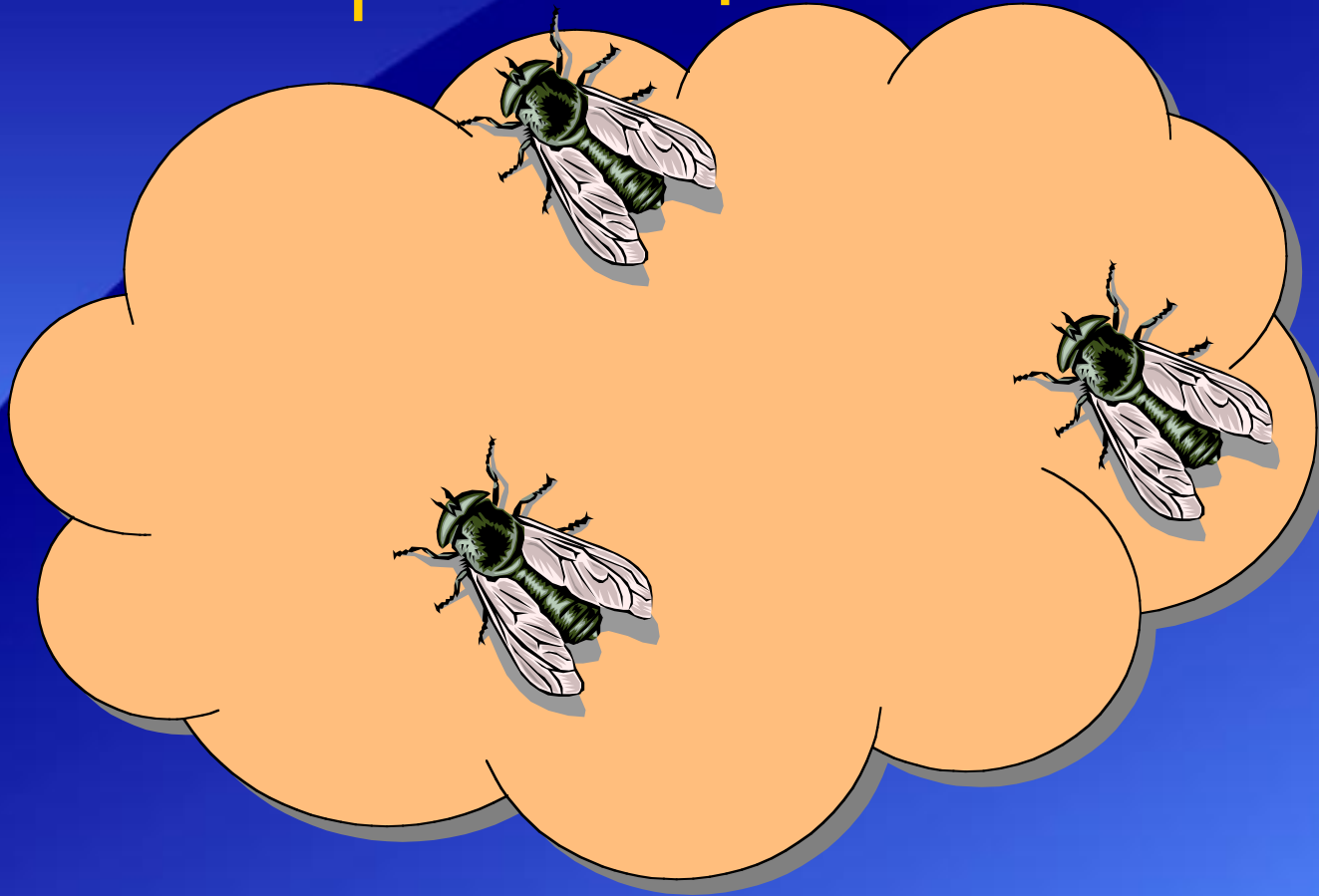
| | |
|--|------|
| | = 15 |
| | = 21 |
| | = 27 |



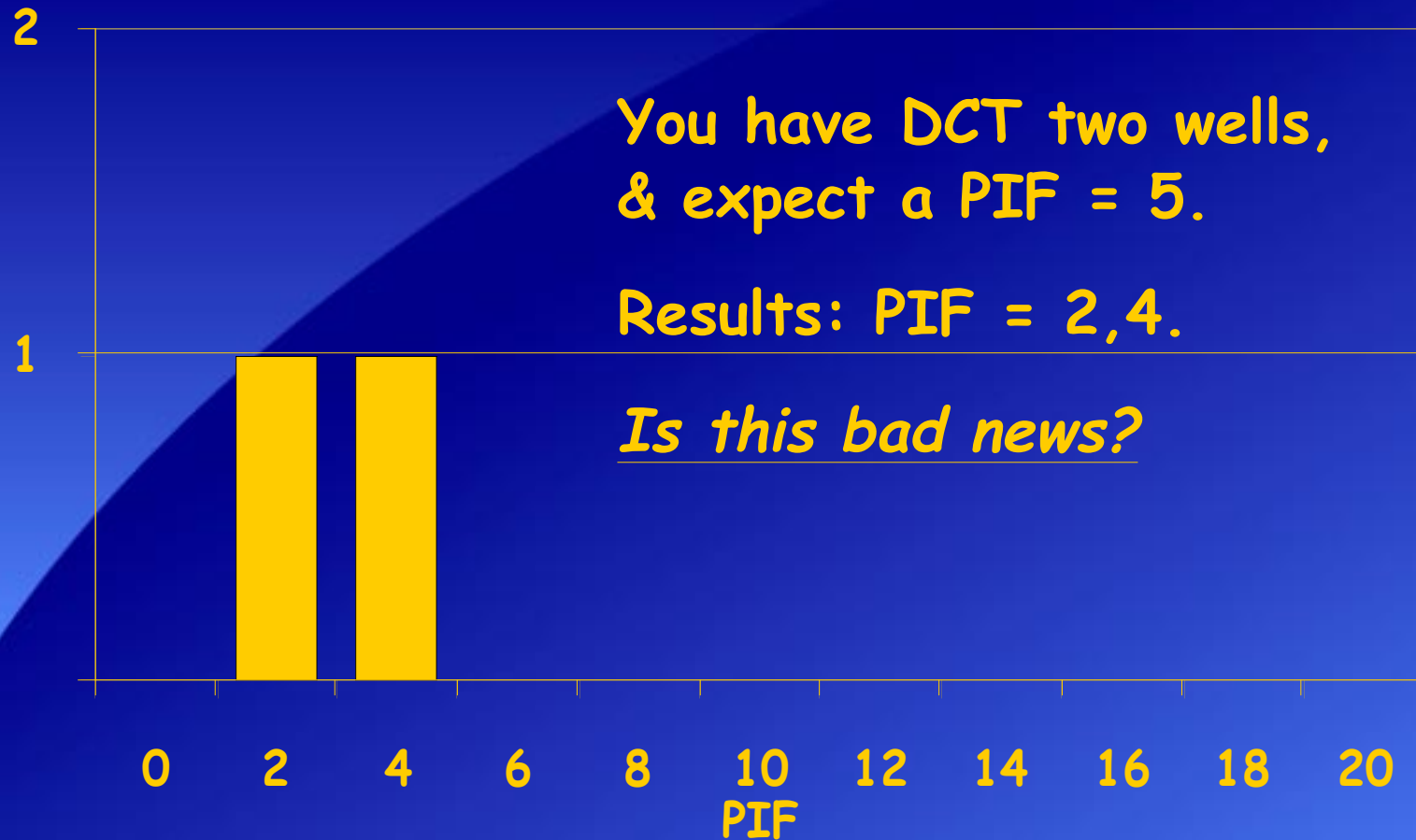
Brainstorm (BS) Session



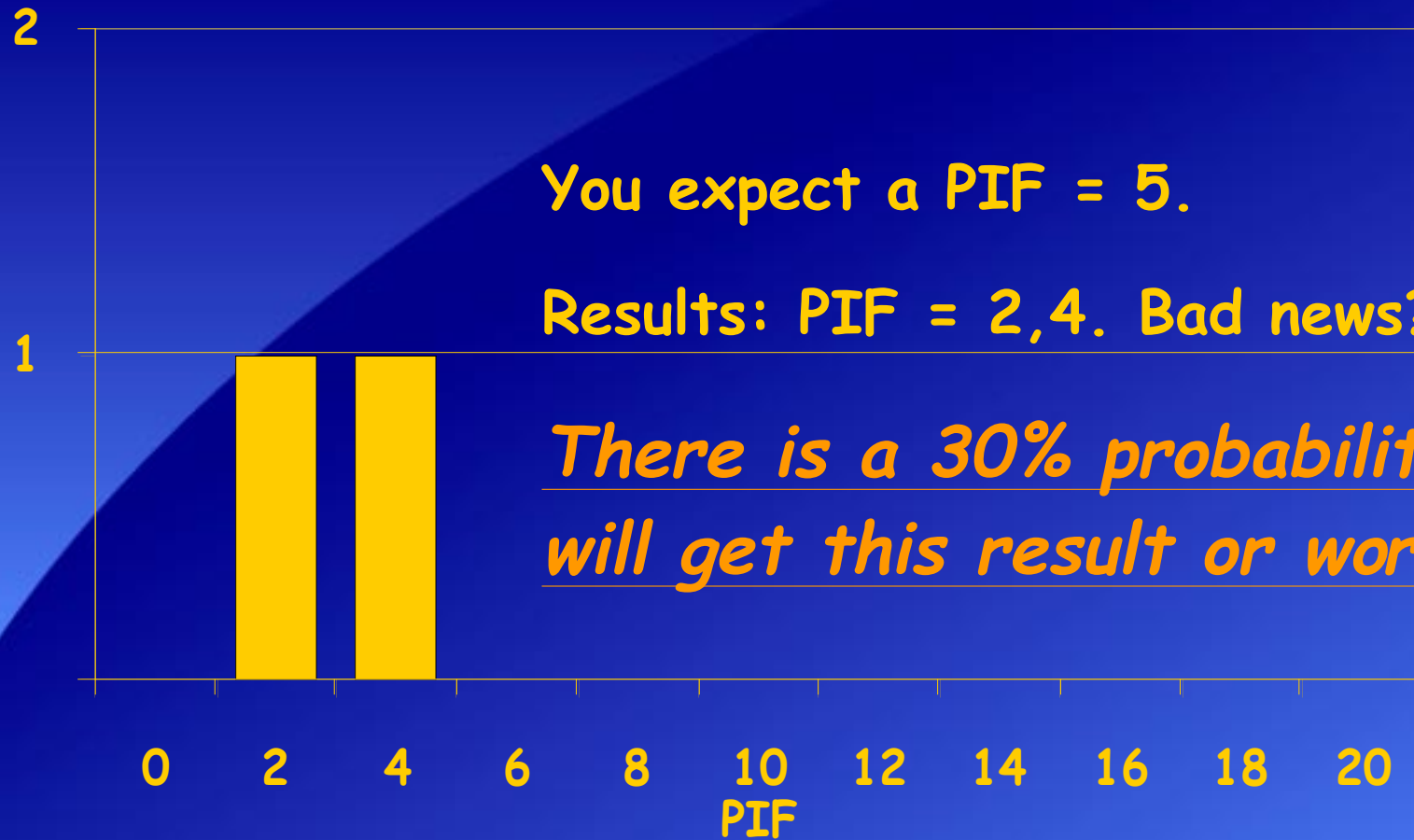
Brainstorm (BS) Session



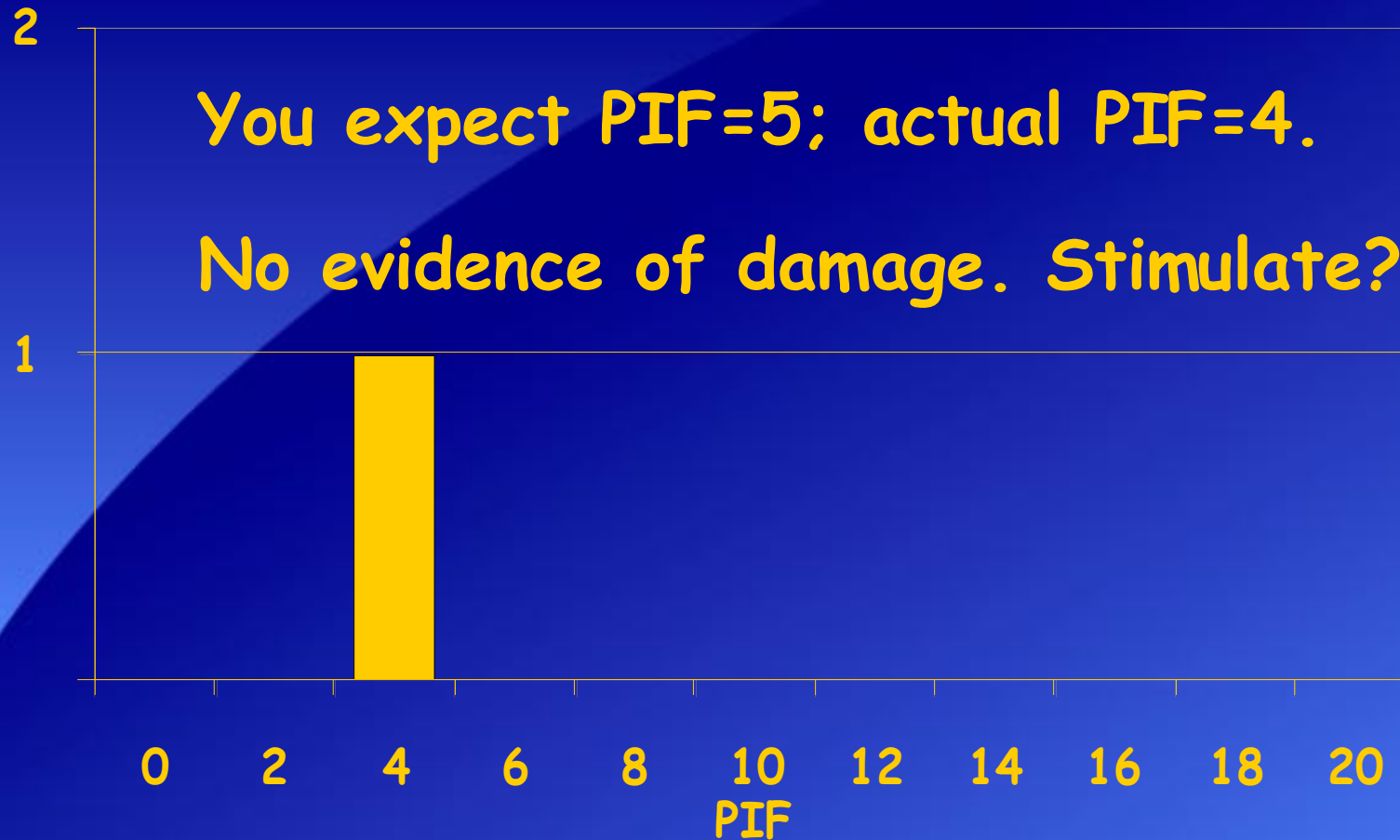
PIF Distributions BS:



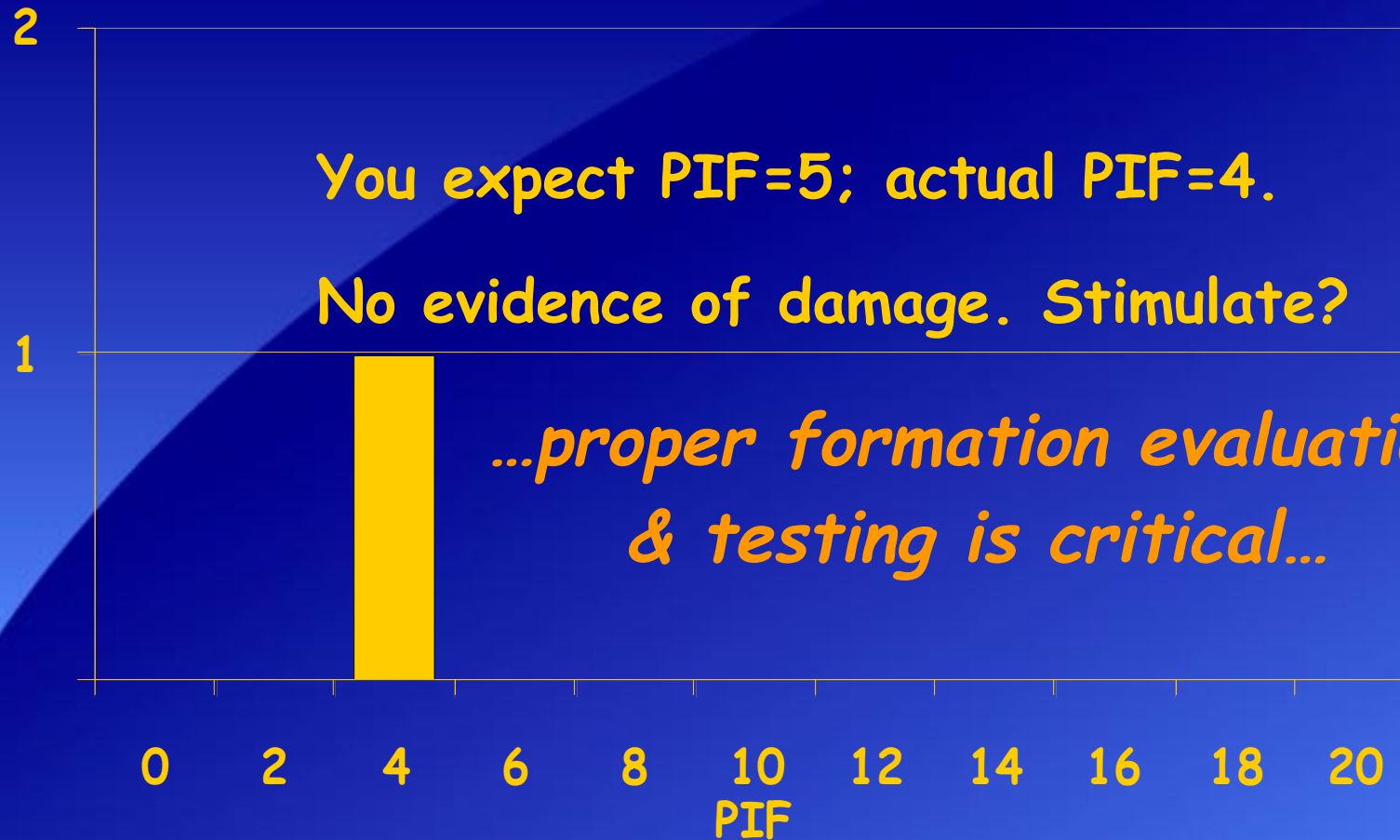
PIF Distributions BS:



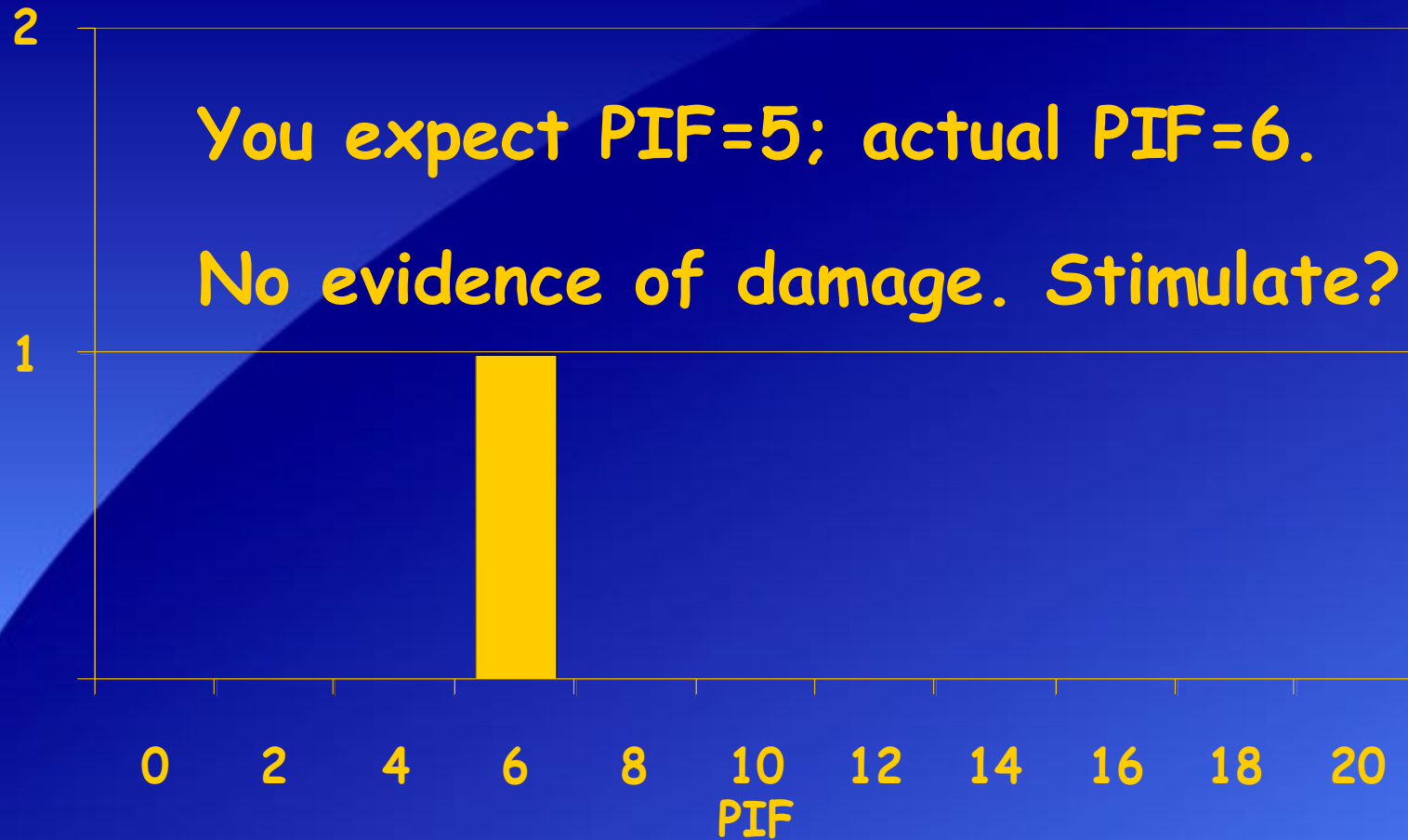
PIF Distributions BS:



PIF Distributions BS:



PIF Distributions BS:



"The level of detail is what separates the delusion of the Gambler from the wealth of the Casino Owner...

The *Gambler* tries to predict the individual spins of the roulette wheel, while the *Ca\$\$\$\$ino Owner* is only concerned with the quite predictable average results..."

From "The Known, the Unknown, and the Unknowable", R.E. Gomery



Summary:

- Horizontal PIFs are log-normally distributed due to natural heterogeneities.
- A mode PIF=3, median PIF=4, & mean PIF=5.
- Horizontal prediction methods are accurate for multi-well programs; however...
- Error bars on individual well rate predictions are at least $\pm 50\%$; and less than half the wells fell within $\pm 50\%$ of their forecast.
- *Don't be surprised about being surprised!*



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•For a copy of the original SPE JPT article, go to www.epiccs.com; external publication #52.

•Thanks for asking an engineer to talk about rather vague stuff to you folks who make a living dealing with this vague stuff...

...dennis and the Epic Team...

