Inference to the Best Geologic Explanation and Error Types in Reservoir Characterization and Modeling*

Y. Zee Ma[1] and Ernie Gomez[1]

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[1]DCS, Schlumberger, Greenwood Village, CO (mailto:yma2@slb.com)
[1]DCS, Schlumberger, Greenwood Village, CO

Abstract

Reservoir characterization and modeling almost always faces a problem of lack of data, as core and well-log data are limited. This problem, while serious, can be often mitigated by using a geologic conceptual model interpreted from 3D seismic data, outcrop analogues, comparison with contemporary sedimentation and choosing appropriate methods to reconcile the inconsistencies in the available data and to realistically predict reservoir properties. This is called inference to the best explanation or abductive reasoning by science philosophers. However, with the lack of the direct information of the subsurface, even the best geologic inference contains uncertainty, which explains why uncertainty and risk analysis has received significant attention of geoscientists in the last decade or so.

Uncertainty analysis and reservoir modeling involves many disciplines, including geology, geophysics, petrophysics and reservoir engineering. In this paper, error types associated with uncertainty analysis in reservoir characterization and modeling will be discussed, including Type I error or false positives (such as drilling dry holes), Type II error or false negatives (such as underestimations of subsurface resources, and farming out a prolific reservoir), Type III error or correct positives for the wrong reason (such as correct estimate of resources by overestimating pore space and underestimating hydrocarbon saturation) and Type IV error or correct negatives for the wrong reason. Examples for these error types will be given, and their analysis will provide insights for better uncertainty evaluation in reservoir characterization and modeling.

Inference to the Best Geologic Explanation and Error Types in Reservoir Characterization and Modeling

Y. Zee Ma and Ernie Gomez

Schlumberger - DCS

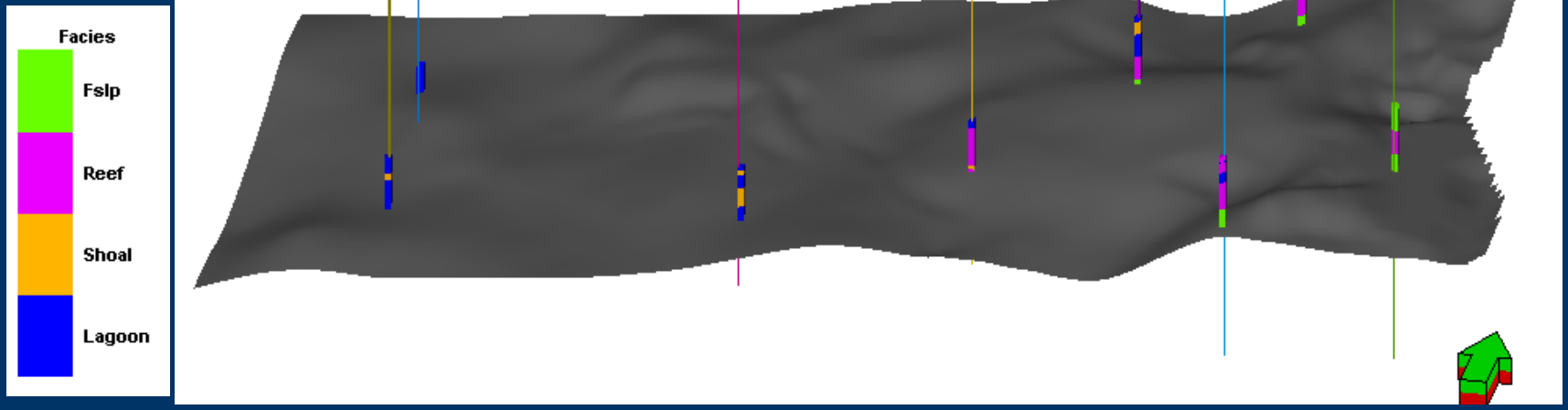
Denver, Colorado

Schlumberger

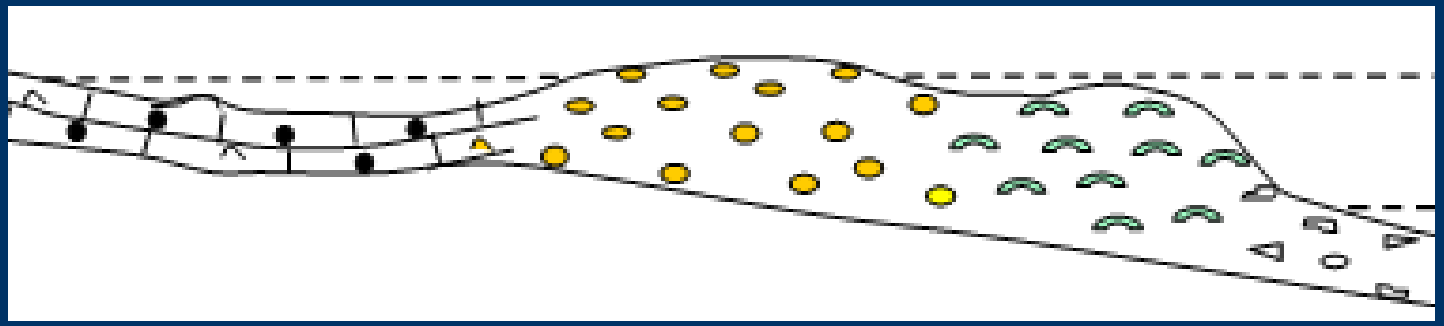
Outline

- **Abductive Inference in Reservoir Characterization**
  - **Example**
  - **Necessity**
- **Prediction and Uncertainty Analysis**
- **Error Types: Data Error vs. Inference Error**
- **Error Types: False Positive, False Negative.**
- **Simpson's Paradox in Reservoir Characterization.**

What is Inference to the Best Geologic Explanation?

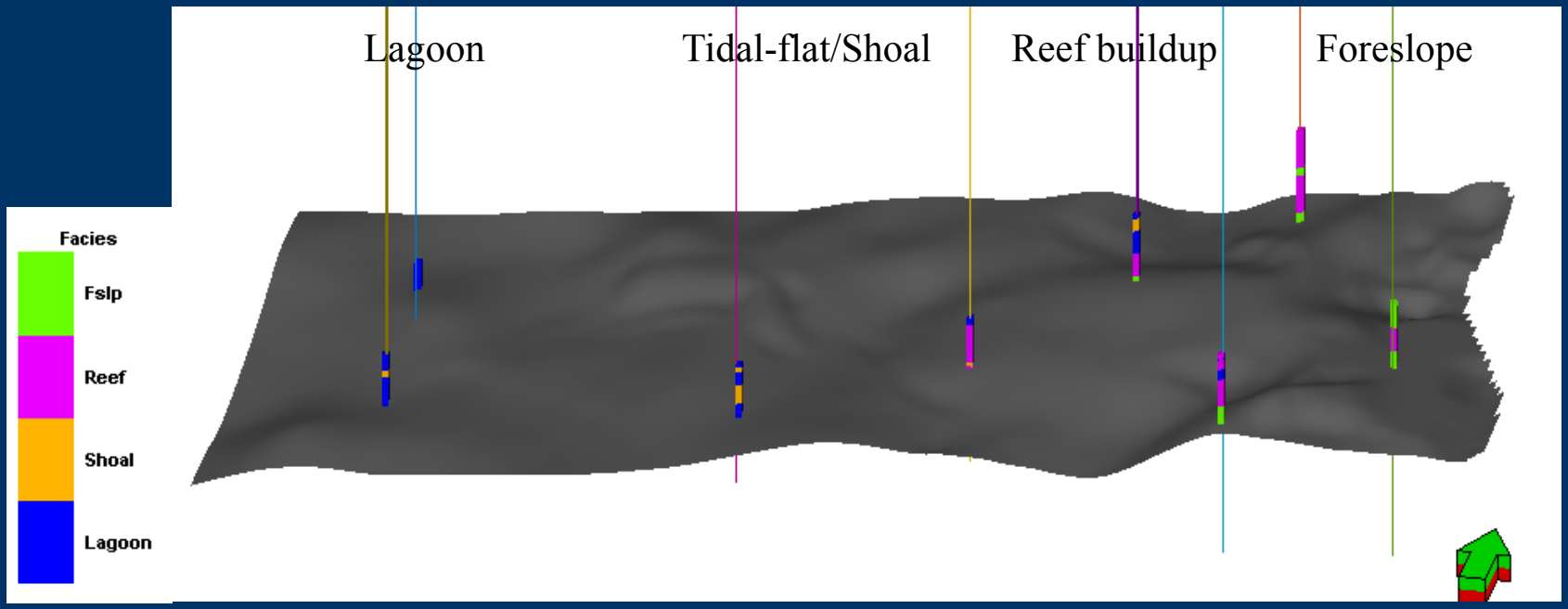


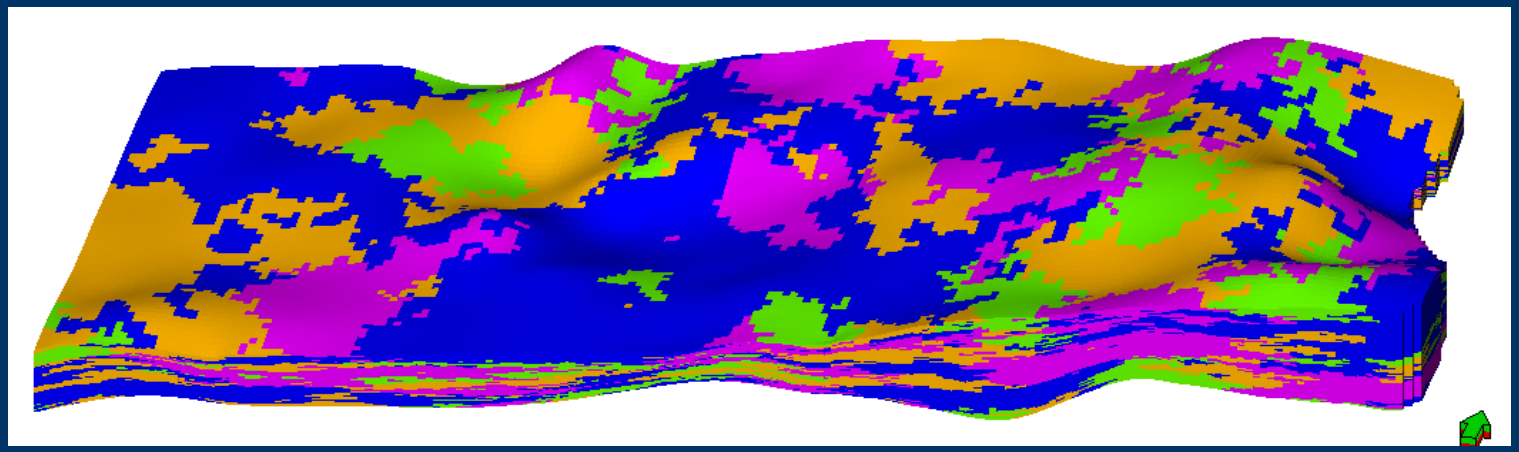
Lagoon | Tidal-flat/Shoal | Reef buildup | Foreslope =>Basin



Carbonate Rimmed-reef Shelf (modified from Wilson 1975)

Why Use Inference to the Best Geologic Explanation?





- **Geostatistical model with no depositional facies constraint**
- **All the data at the wells are honored**

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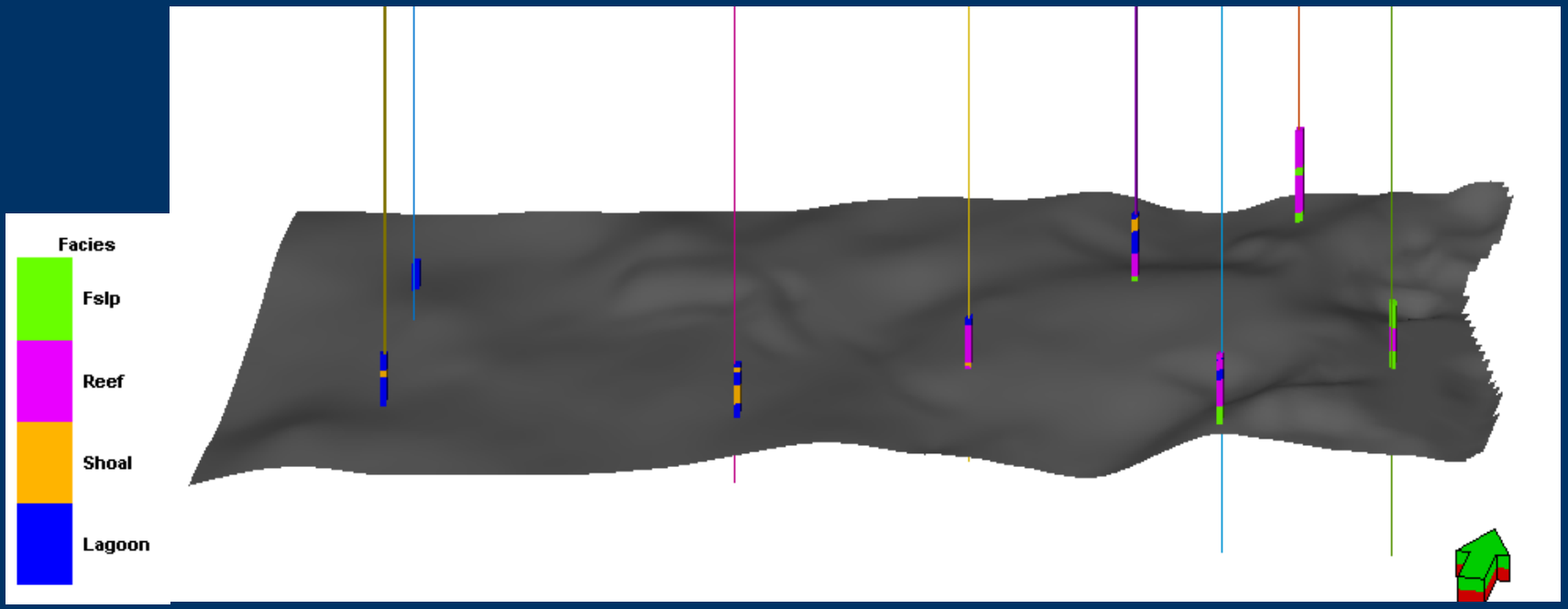
Is Inference to the Best Geologic Explanation Enough?



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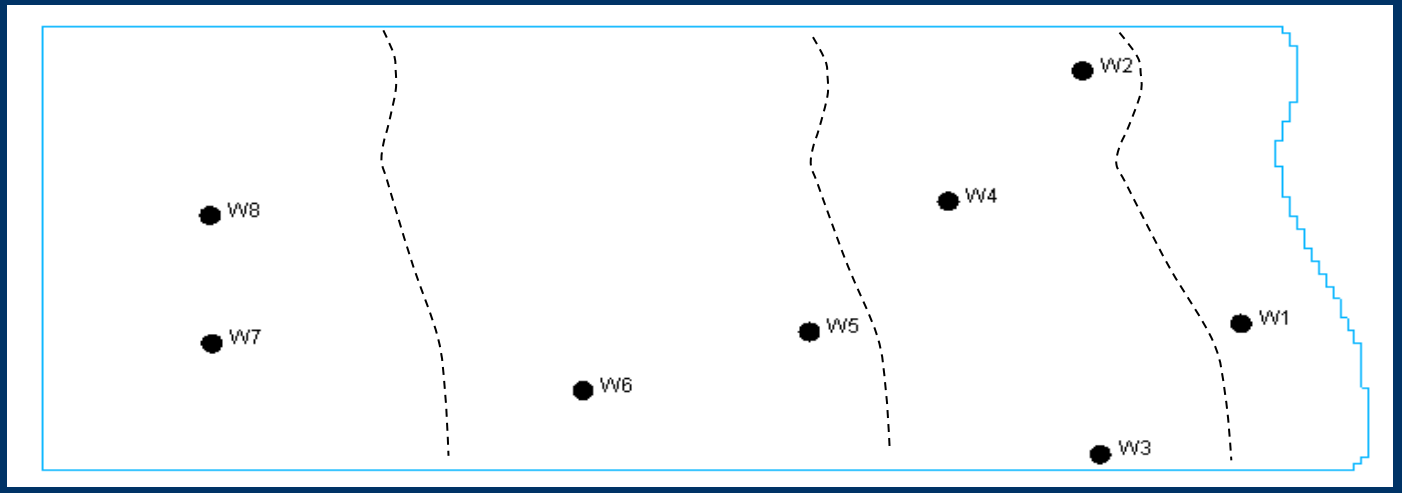

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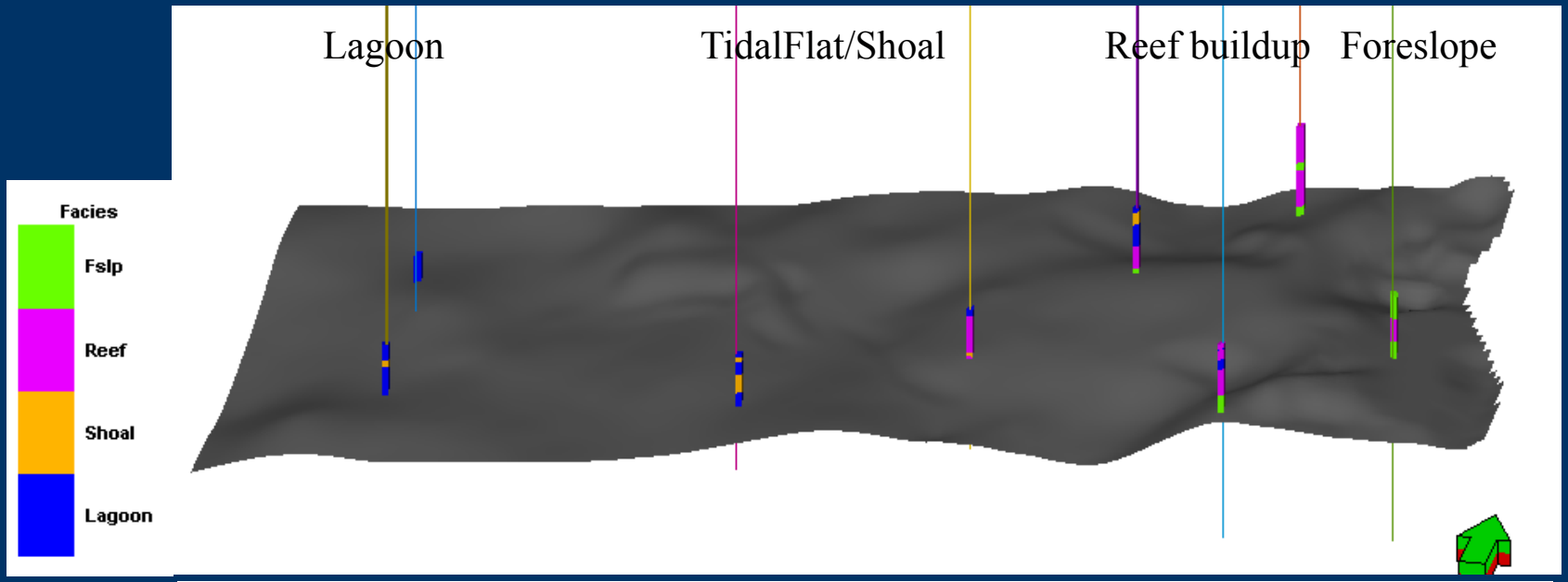
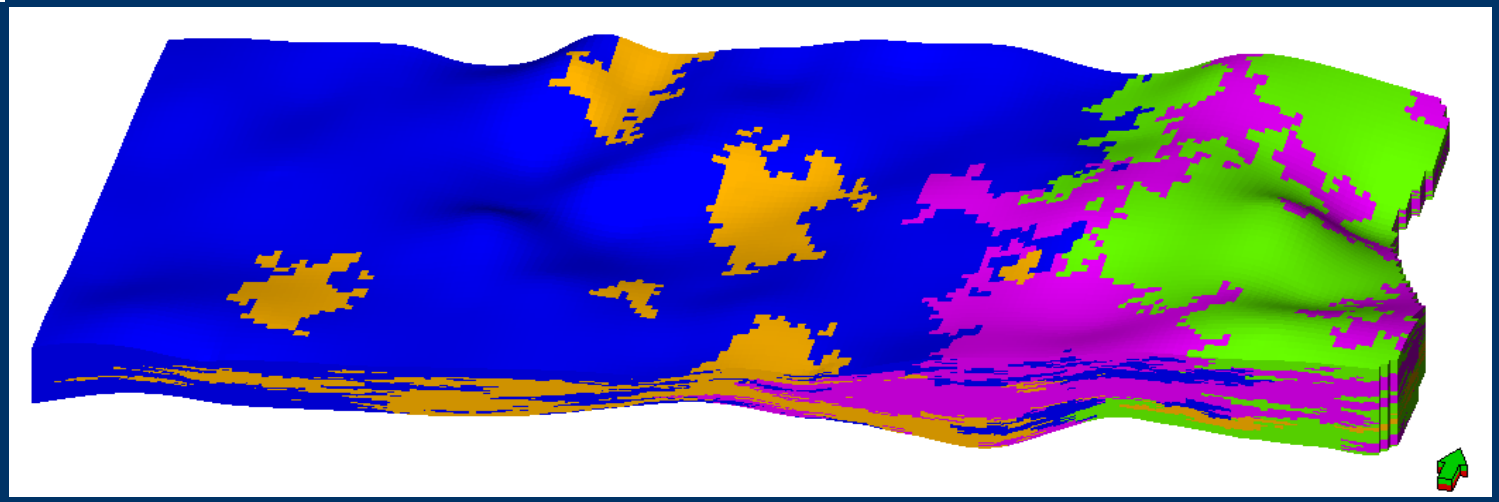
Inference to the Best Geologic Explanation & Honoring Data





- **Geostatistical model constrained with carbonate rimmed-reef shelf model**
- **All the data at the wells are honored**

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Fundamental Problem in Prediction

Height example: Brian > Charles , Andrew > Brian
Therefore, Andrew > Charles

- **Deductive logic: No error! (Dates back to Aristotle)**
- **But, No Prediction either!**

However, <u>Prediction is needed everywhere!</u>

Modeling, Uncertainty Analysis, Optimization, Planning, …

"The **Clairvoyant** Club of London won't meet next Tuesday because of **unforeseen** circumstances." - Ad in Financial Time.

- **Induction: Formulate laws based on limited observations of recurring phenomenal patterns.**
- **<u>Abduction:</u> Inference to the Best Explanation**

Types and Causes of Errors

- **Garbage in, Garbage out ⇔ Data problem**
- **Data in, Garbage out ⇔ Inference problem**

- **Garbage in, model out? (Magic inference?)**
- **Data in, Useful model out! (Correct inference)**

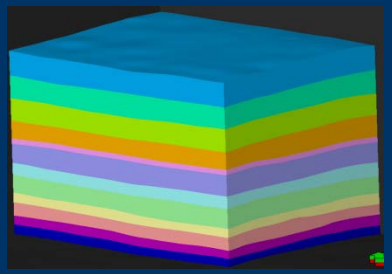
- **Measurement error**
- **Data handling error**
- **Inference errors:**

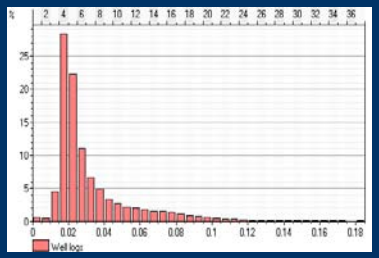
Human judgment /interpretation errors, generally due to limited data

- **Geologic**
- **Seismic**
- **Log interpretations**
- **Modeling parameters**
- **Modeling methods**
- **…**

Winning Reservoir Characterization 'Powerball'

3D Grid with 6 million cells





Example of porosity model:

Even if we use 1 decimal number, there would be more than 1 billion of possible realizations!

Science/Technology

- Geology
- Petrophysics/well-logs
- Seismic
- Reservoir engineering

Science and Tech, Help me find a Big Gusher!

Powerball: 80M possibilities in 2001:

$$\frac{(49-5)!\ *5!}{49!} \times \frac{1}{42} \approx \frac{1}{80M}$$

Winning numbers in a May-2001 Draw (at about $300Million):

(25) (10) 17 12 40 20

If you were able to play after the 1st 2 drawings:

$$\frac{(47-3)!\ *\ 3!}{47!} \times \frac{1}{42} \approx \frac{1}{680K}$$

Data, Data, Help me to reduce the range!

Geologic Inference Example

Example of Simpson's paradox in early well-to-well formation evaluation using NTG ratio

	Well 1 (Ref.)	Well 2	
Formation A	20%	16%	Lower
Formation B	30%	29%	Lower
Aggregate	25%	26%	Higher

Comparison: Clinical example of Simpson's paradox or 'Miracle' Drug!

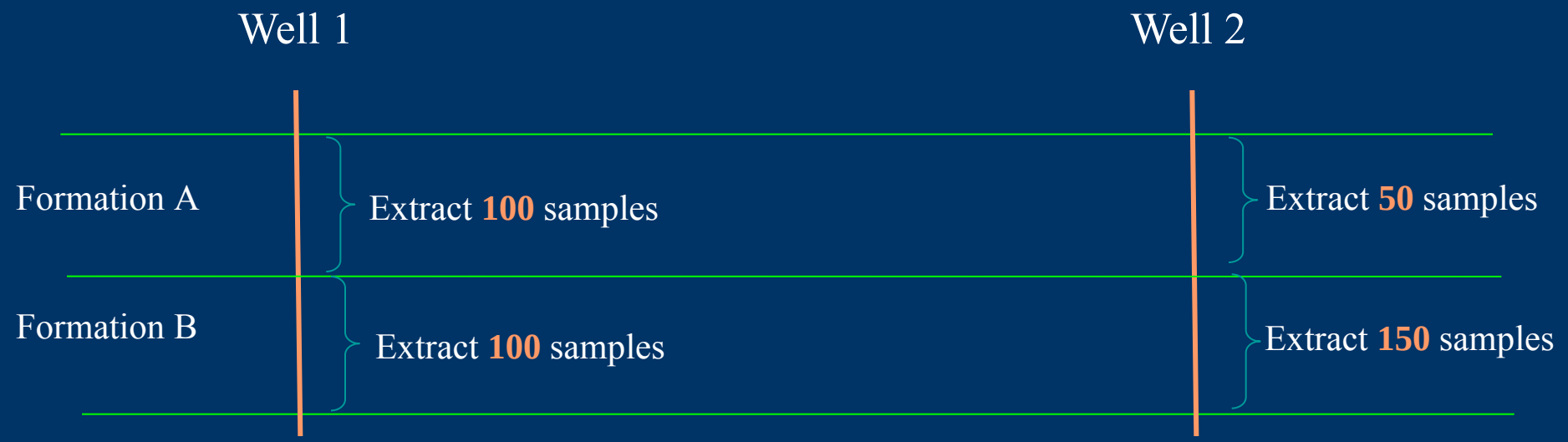
	Placebo	Drug	
Men	36% (32/90)	34% (12/35)	Bad
Women	80% (32/40)	76% (72/95)	Bad
People	49% (64/130)	65% (84/130)	Good

Effectiveness of drug vs. Placebo

From Ma, 2009, Math Geosciences 41, p. 193-213.

Error Due to Sampling Bias

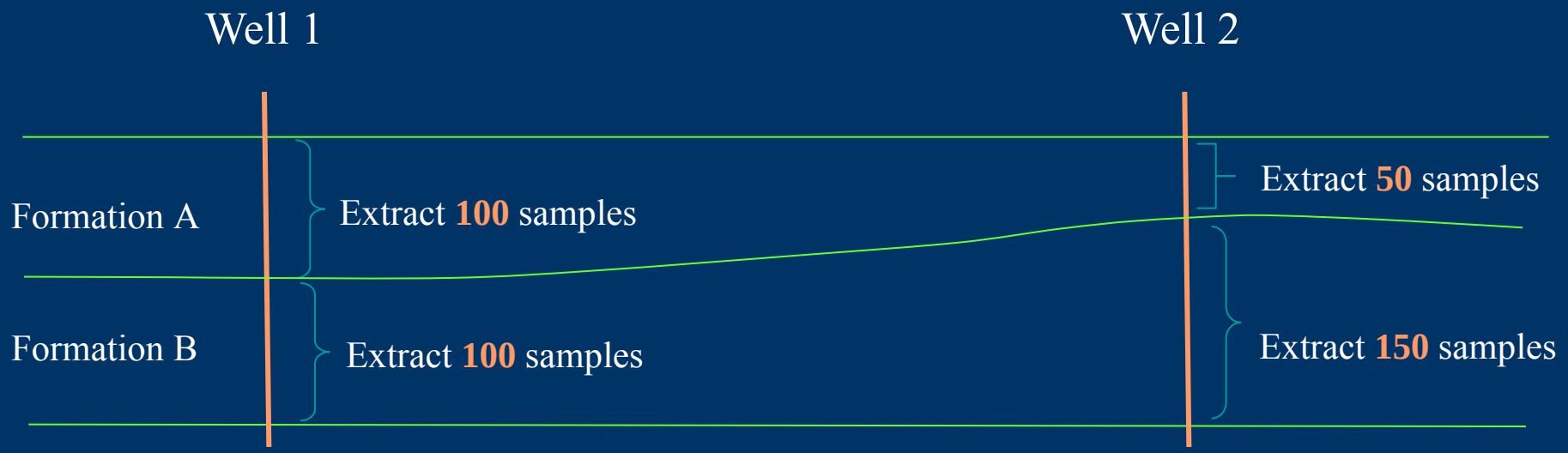
	Well 1	Well 2
Formation A	**20% (20/100)**	**16% (8/50)**
Formation B	**30% (30/100)**	**29% (44/150)**
Aggregate	**25% (50/200)**	**26% (52/200)**



- **Sampling bias can cause a "statistical ploy" …**

From Ma, 2009, Math Geosciences 41, p. 193-213.

But, This May Not be an Error, but due to Geology!



	Well 1	Well 2
Formation A	20% (20/100)	16% (8/50)
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Aggregate	25% (50/200)	26% (52/200)

- Understanding geology can be critical.
- Simpson's paradox has a geologic meaning.

From Ma, 2009, Math Geosciences 41, p. 193-213.

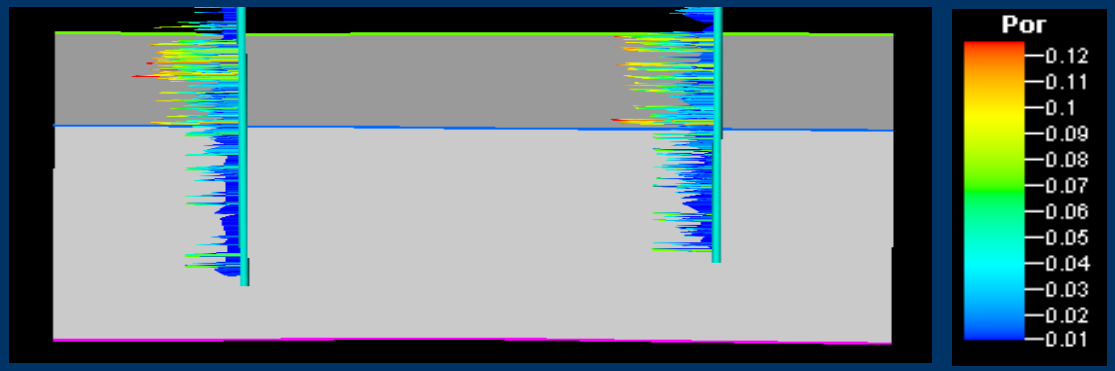
Error Types based on Results

	Did	Did not
Should	Good But …	False Negative / Under-estimate (Type II)
Should Not	False Positive / Over-estimate (Type I)	Good But …

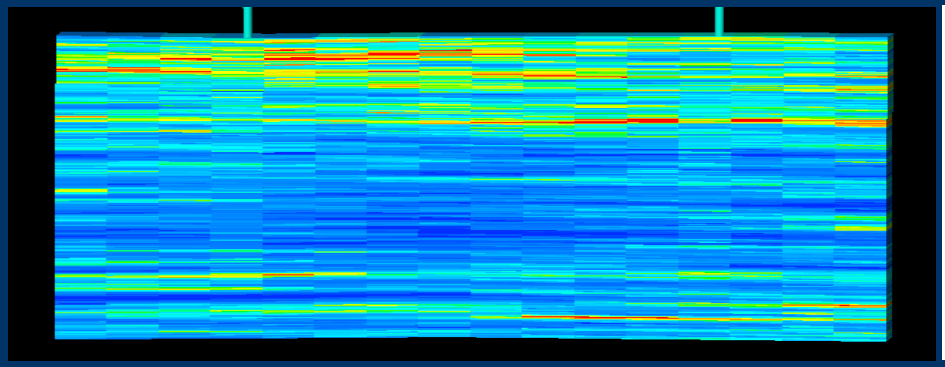
- False Positive / False Optimism / Overestimate — Type I
- False Negative / Too Pessimistic / Underestimate — Type II
- Correct Positive for a Wrong Reason — Type III
- Correct Negative for a Wrong Reason — Type IV

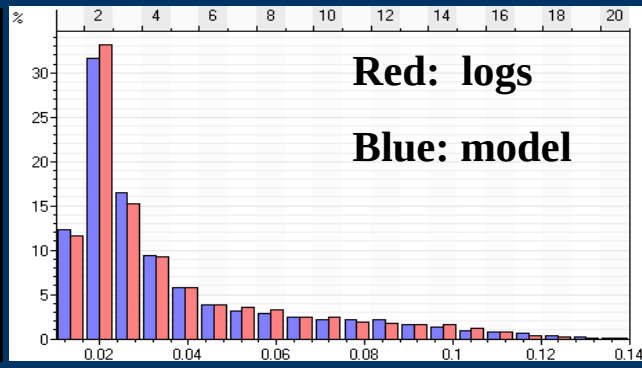
Geologic/Petrophysical Modeling Example

Porosity Logs



Porosity Model





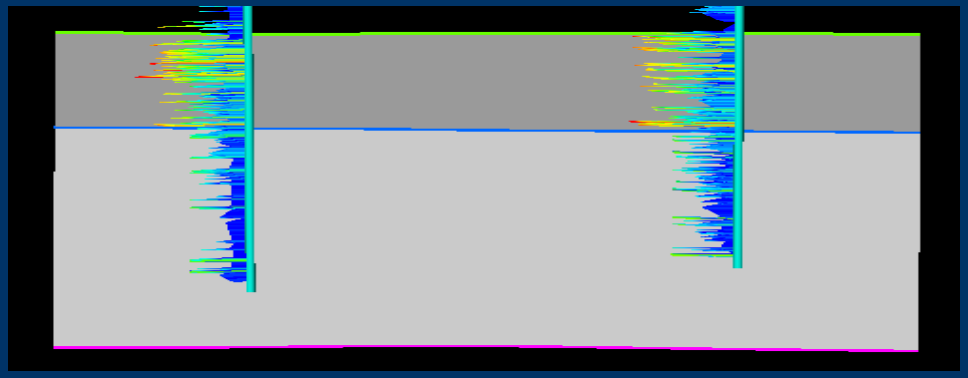
Average porosities

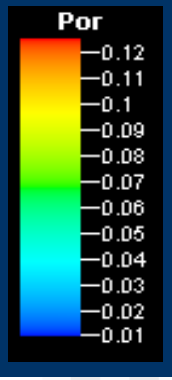
	Well log	3D model	Comparison
Upper formation	4.86%	5.34%	9.9% higher*
Lower formation	2.52%	2.67%	6.0% higher
Aggregate	3.49%	3.48%	Matched

Note: (0.0534-0.0486)/0.0486 = 9.9%. From Ma, 2009, Math Geosciences 41, p. 193-213.

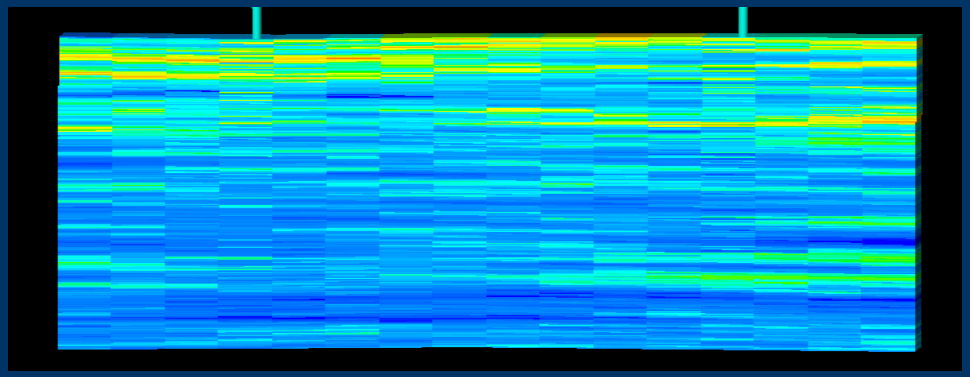
Geologic/Petrophysical Modeling Example

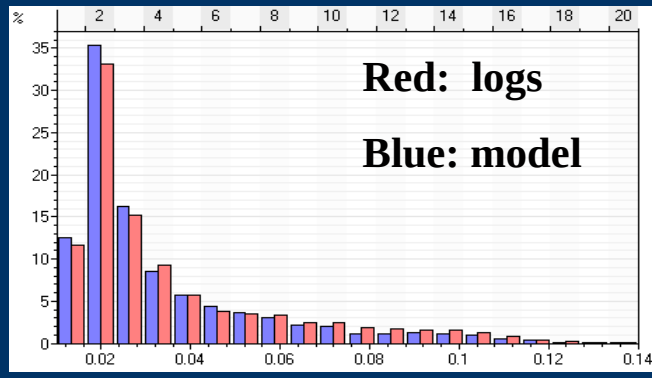
Porosity Logs





Porosity Model



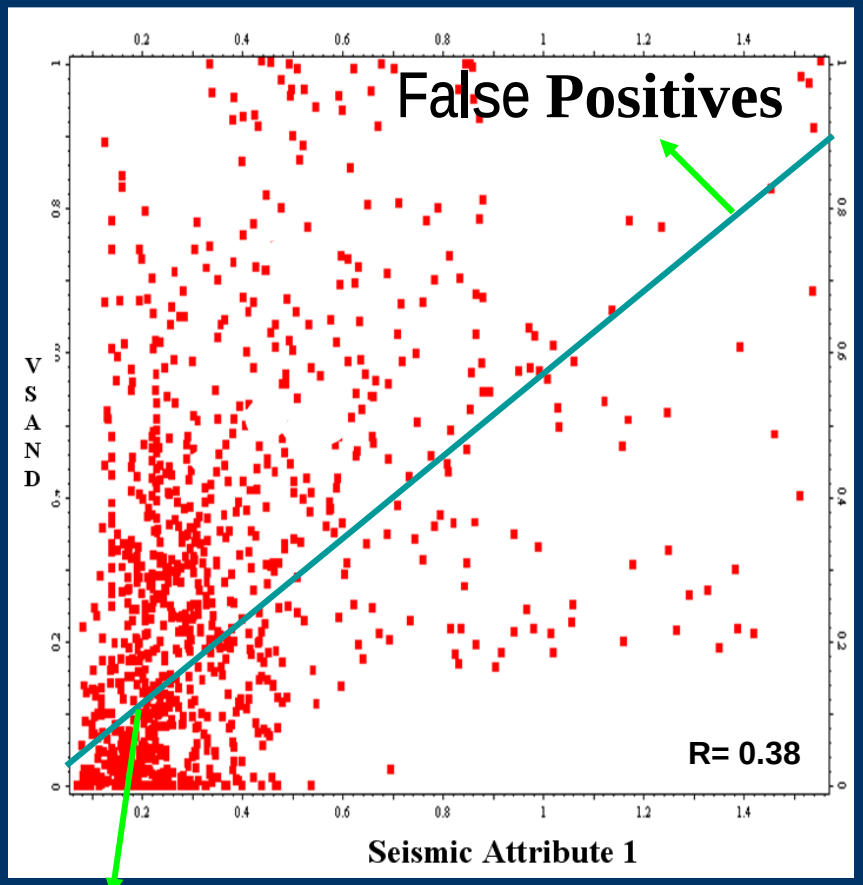


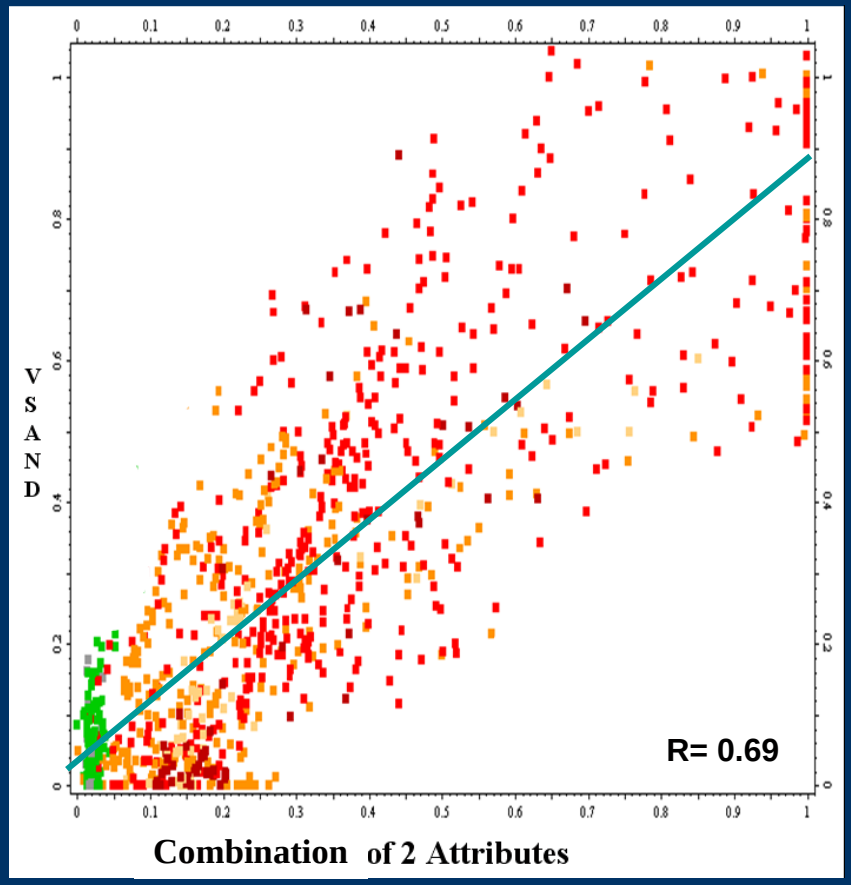
Average porosities

	Well log	3D model	Comparison
Upper formation	4.86%	4.88%	Matched
Lower formation	2.52%	2.53%	Matched
Aggregate	3.49%	3.24%	7.2% lower

Analogous to Berkeley Graduate Admission Case, 1975, Science 187: p. 398-404.

2 Error Types at the Same Time & Possible Reduction





- The seismic can guide, but can also misguide if not used gingerly!
- Analogue may be good, but can be dangerous if too speculative/abusive!

AAPG 2009, Ma and Gomez

Examples of Error Type III or IV

- **Correct estimate of OOIP by under-estimating Porosity and *Sw* (Over-estimate S_h) - Type III**
  - **3D Model-based HCPV:**

$$OOIP = \sum_{i=1}^{N} V_i * NTG_i * \Phi_i * (1 - Sw_i)$$

- **Farmed in a so-so reservoir because of over-estimating the reserve, but oil price went up (Type III)**
- **Did not farm in a prolific reservoir because of underestimating the reserve, but oil price came down (Type IV)**

Summary

- **Abductive Inference or Inference to the Best Geologic Explanation is necessary in Reservoir Characterization.**
- **Study of Error Types is an outstanding process of mitigating errors!**
- **Legitimate and fallacious Simpson's paradoxes**
- **Impact of drilling schemes to resource evaluation.**
- **It is critical to scrutinize data, otherwise GIGO.**
- **To achieve DIMO, use more data & correct inference.**
- **Integrated approach is necessary to reduce errors in Reservoir Characterization.**

“Nothing is concluded unless errors are excluded, at least unless the uncertainty is mitigated.”

Anonymous

References

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Ma, Y.Z., 2009, Simpson's paradox in natural resource evaluation: Mathematical Geosciences, v. 41/2, p. 193-213. DOI: 10.1007/s11004-008-9187-z

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