Selection of Geological Models for Uncertainty Assessment with a Novel Streamline Approach*

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Abstract

Exploration and appraisal efforts are progressively migrating to deeper and more poorly understood reservoir systems. Costs to assess commerciality alone can be extremely high. Consequently, the uncertainty space of geological features impacting in-place hydrocarbons and reservoir performance must be thoroughly evaluated for sound investment decisions.

Limited numbers of wells may be the only data source for pre-test reservoir characterization if seismic is of little use in mapping rock properties and architecture. The extremely small volume sampled by wells emphasizes the need to thoroughly investigate uncertainty distributions of reservoir properties. Numerous models may be required to fully capture geological uncertainty affecting economic evaluation. Available tools permit efficient batch running of many models once uncertainty ranges for input variables are established.

Our approach to dynamic ranking involves use of streamline simulation to characterize the spectrum of geological conditions influencing flow behavior. The simulations are simple single phase cases requiring minimal resources. Analysis of streamline data are performed with proprietary code. Results of the analysis include storage capacity, flow capacity and sweep efficiency vs. time for each model. Furthermore, a Lorenz coefficient (a standard measure of heterogeneity under dynamic conditions) is determined for each geological scenario. Models are ranked by the Lorenz coefficient, so that realistic distributions are included in economic uncertainty analysis.

Results are conditional to injector-producer schemes, net-to-gross, depositional architecture, facies relations and permeability-porosity structure. Consequently, a reasonable conceptual understanding of local depositional and diagenetic settings is necessary. Sensitivity of results to conditioning information is useful in discerning relative contributions of inputs and, if necessary, tuning the workflow.

We consider ranking the dynamic behavior of geological models as a recommended practice. Straightforward workflows provide effective distillation of large numbers of earth models to a select few for detailed flow simulation. Time consuming model recycling between simulation engineers and earth modelers is substantially reduced as well due to embedded quality control and a priori knowledge of flow characteristics.

References

Pyrcz, M.J., M. Sullivan, N.J. Drinkwater, J. Clark, A. Fildani, and T. McHargue, 2006, Event-base models as a quantitative laboratory for testing quantitative rules associated with deepwater distributary lobes: *in* R.M. Slatt, M. Bowman, J. Castagna, T. Good, J. Grace, R. Latimer, B. Loucks, M. Scheihing, R. Smith, (editors), Proceedings, Reservoir Characterization: Integrating Technology and Business Practices: Gulf Coast Section-SEPM Twenty-Sixth Annual Research Conference, Houston, TX, Gulf Coast Section SEPM 26th Annual Research Conference, CD-Rom, p. 923-950

Shook, G.M. and K.M. Mitchell, 2009, A robust measure of heterogeneity for ranking earth models: The F-PHI curve and dynamic Lorenz Coefficient: SPE 124625, 2009 SPE Annual Technical Conference, New Orleans, LA, Web accessed 16 July 2010, http://www.onepetro.org/mslib/app/Preview.do?paperNumber=SPE-124625-MS&societyCode=SPE

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Objectives of Our Approach

- Provide appropriate end-member depositional architectures relative to a deterministic base case to adequately span the uncertainty space of possible geological conditions.

- Provide a basis for dynamic ranking performance of reservoir (geological) models prior to significant time investment by reservoir (simulation) engineers.

- Increase the efficiency of the "static" modeling workflow by ranking architecture-based heterogeneity prior to detailed modeling of petrophysical properties.

- Eliminate the "hey! …your low case is too connected…" concern of simulation engineers by having in-hand quantitative connectivity assessment.

Reasons for Our Approach

Shook and Mitchell (2009) demonstrated the dynamic Lorenz coefficient to be the most robust of 5 studied measures for ranking models by dynamic heterogeneity. Their evaluation included 450 simulation cases and their results demonstrate heterogeneity is a very good predictor of project economics (figure below).

Advances in modeling of depositional settings (e.g., Pyrcz, et al., 2006) allow for the construction of detailed expert-driven rule-based architectures which together with permeability govern heterogeneity
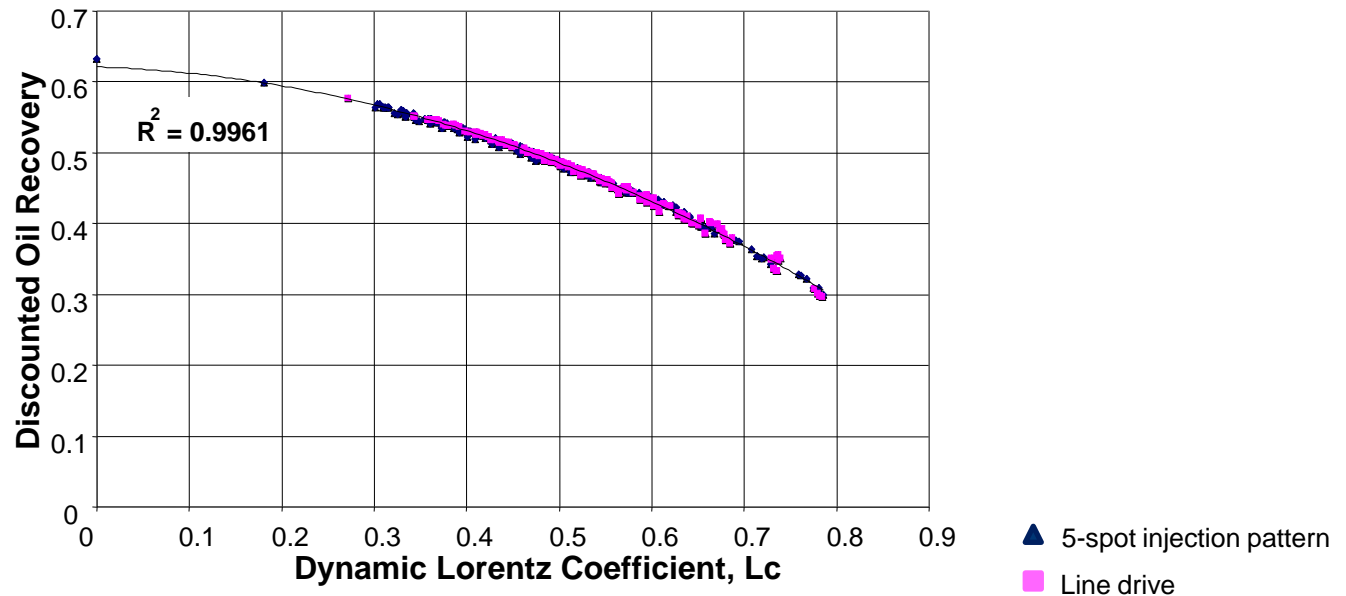
Shook, G, Michael, and K. M. Mitchell, 2009, A Robust Measure of Heterogeneity for Ranking Earth Models: The F-PHI Curve and Dynamic Lorenz Coefficient: SPE 124625, 2009 SPE Ann. Technical Conference, New Orleans, LA.

Pyrcz, M.J., et al., 2006, Event-base Models as a Quantitative Laboratory for Testing Quantitative Rules associated with Deepwater Distributary Lobes: Gulf Coast Section SEPM 26th Ann. Research Conference, pp. 923-950.
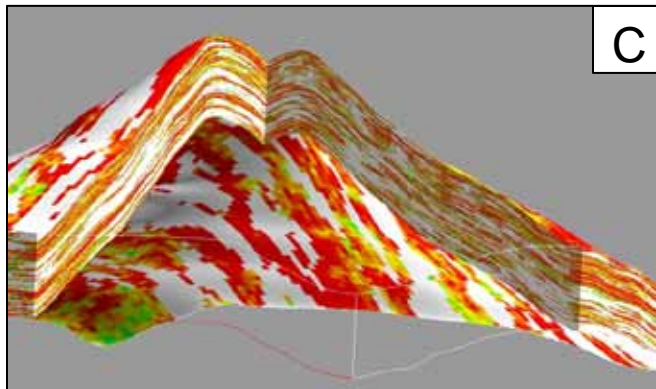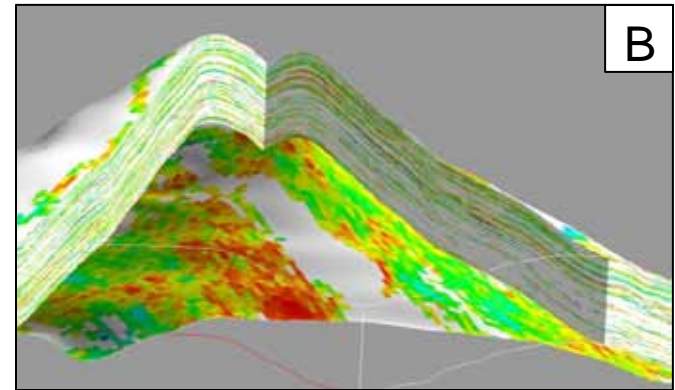
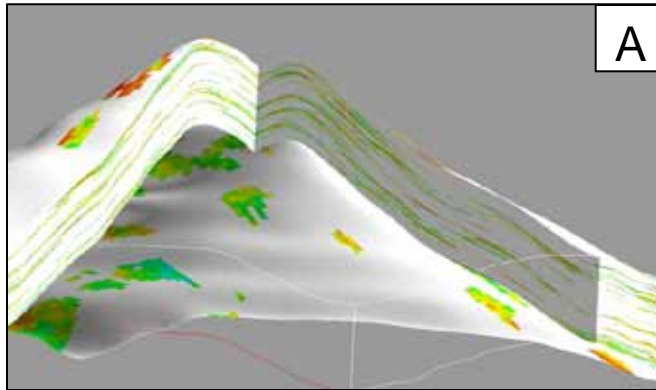# Process of Dynamic Heterogeneity Assessment

Earth model construction

Dynamic analysis leading to forecasts and economic models
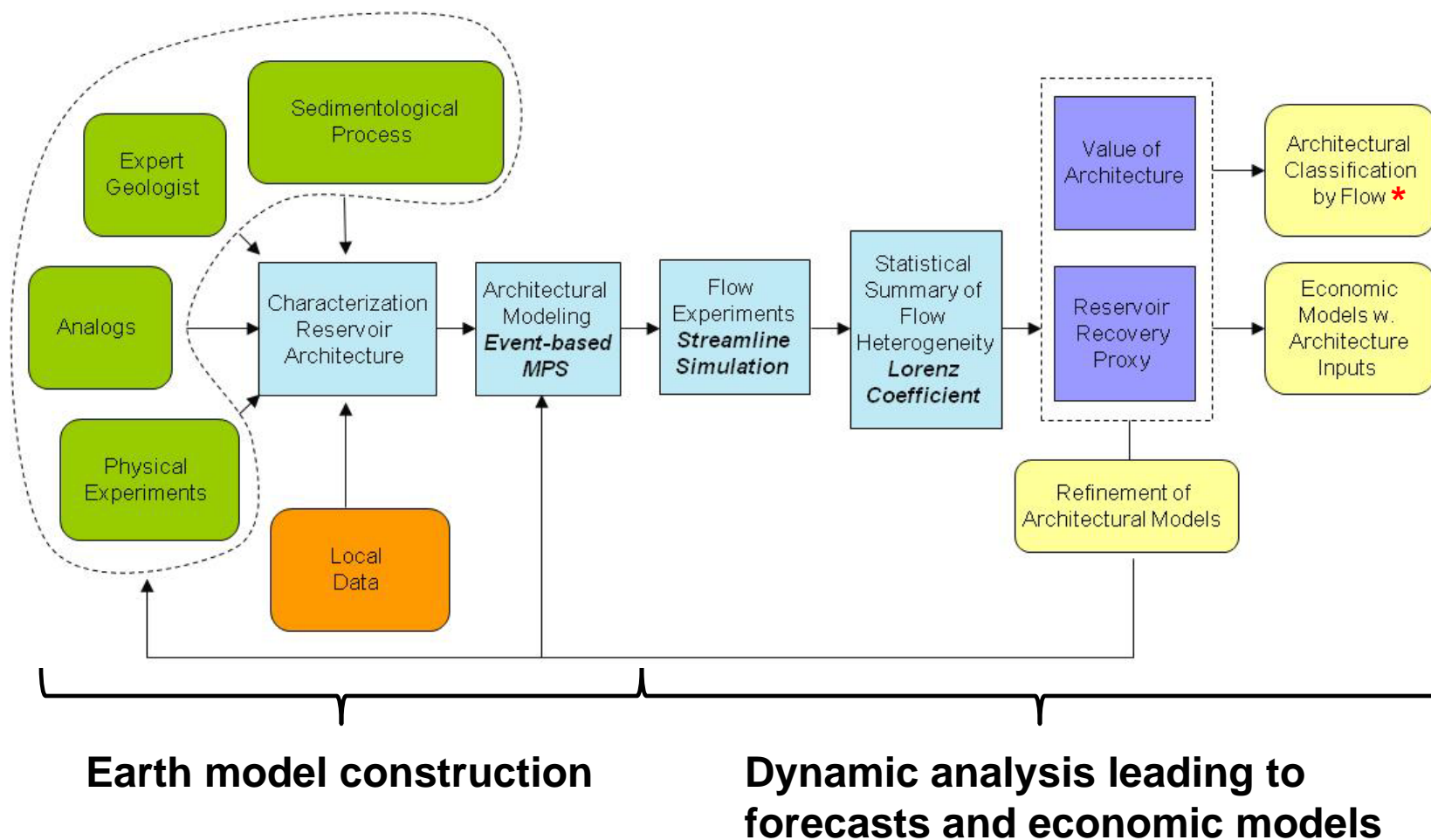
Key Words

n Architecture

n F – PHI curve

n Dynamic Lorenz coefficient
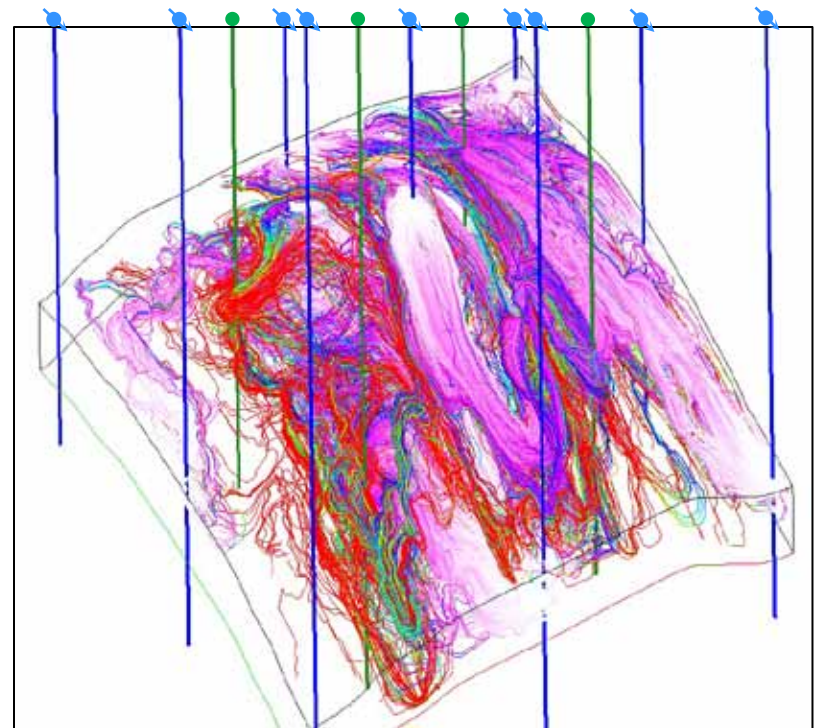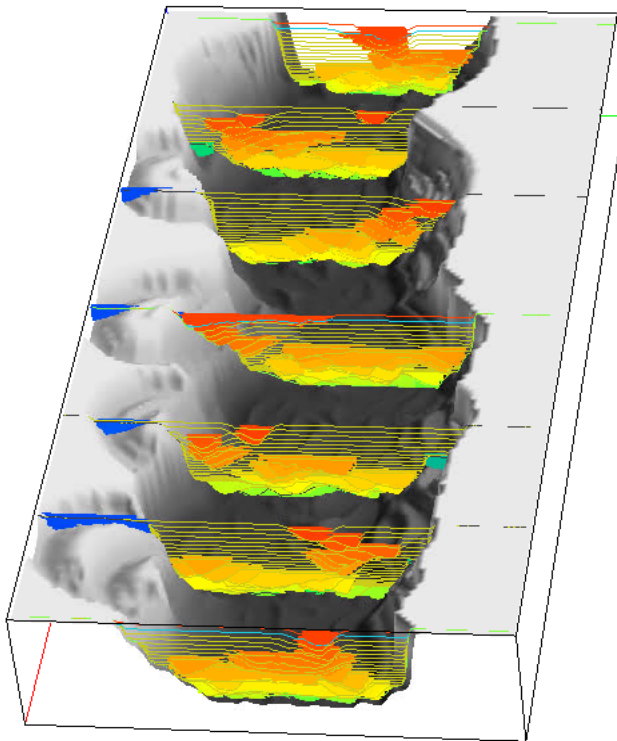
Factors Affecting Streamline Based Heterogeneity
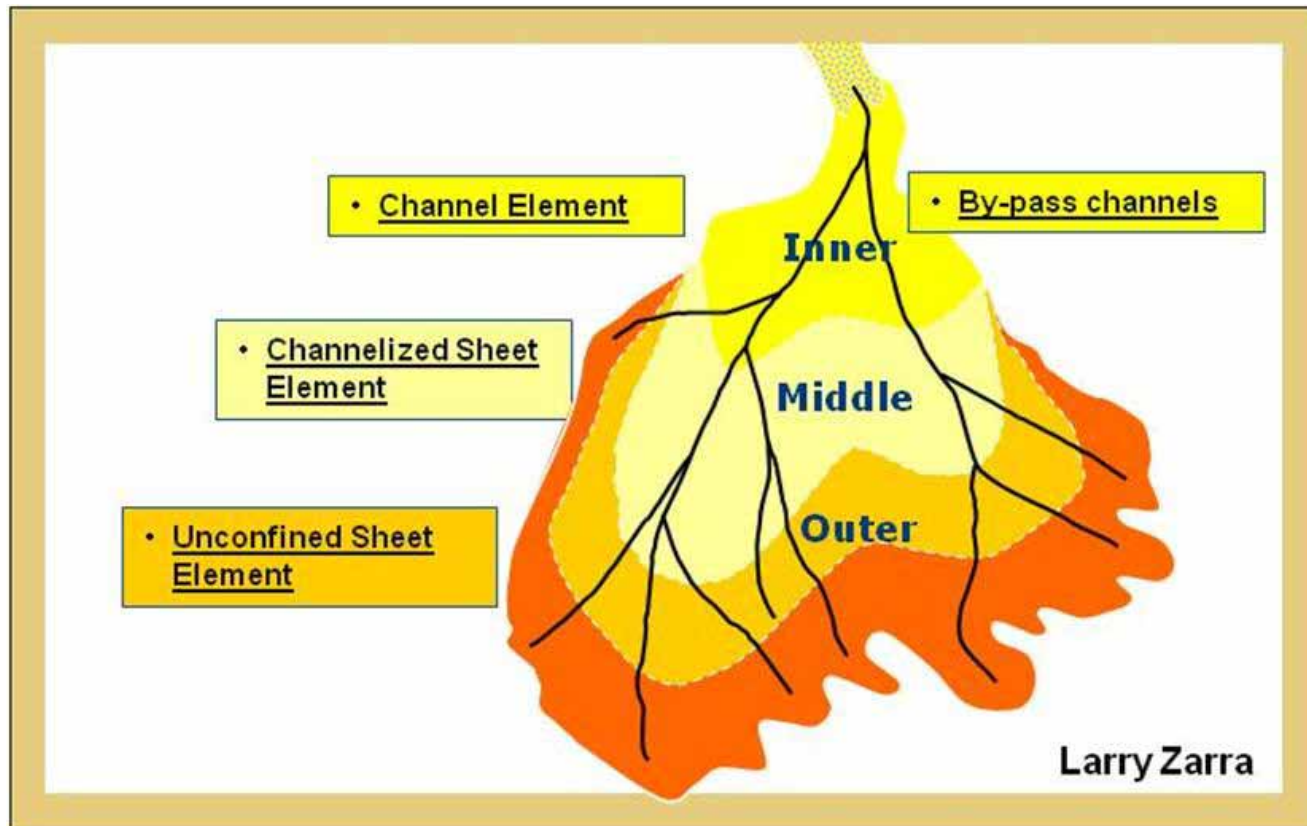

A

B

C

permeability

0.001   100

- Examples of depositional architecture, net-to-gross, and permeability affecting heterogeneity described by the <u>Dynamic Lorentz coefficient</u>.

Image	Fan Position	Predominant Architectural Element	Net-to-Gross	Permeability	Lorentz Coefficient Swept PHI	Lorentz Coefficient Total PHI
A	distal	sheet	10	low	0.62	0.74
B	mid	ch. sheet	30	low	0.52	0.59
C	proximal	channel	50	high	0.39	0.42

Model Architecture Construction

- Populate architectural framework with sand /non-sand lithology, permeability

- Establish appropriate depositional setting of reservoir

4. Property Distributions

1. Generic Depositional Model

3. Model Architecture

2. Analogs

- Construct model architecture based on depositional setting and geometrical constraints

- Compile geometrical information of selected depositional setting

Establish Depositional Setting

- Channel Element
- By-pass channels
- Channelized Sheet Element
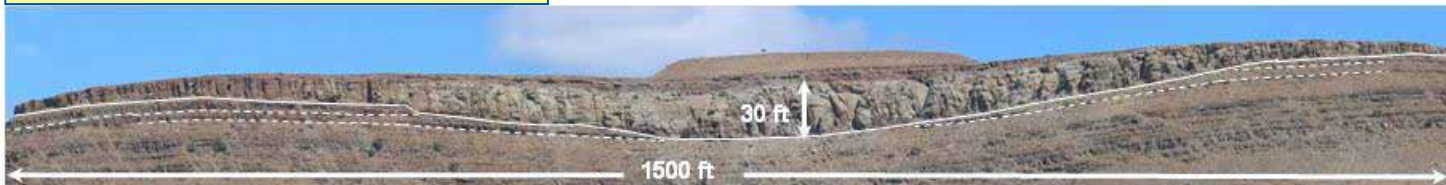- Unconfined Sheet Element

Inner
Middle
Outer

Larry Zarra

- **n** A submarine fan depositional setting was selected to model architecture.

- **n** The depositional setting of each case was constant areally.

- **n** Evaluated a continuum of inner-to-distal fan architectural models.

Architecture Analogs: Skoorsteenburg Fm., Tanqua Karoo Basin, South Africa

- **Channel Element**

60 ft
1000 ft

- **Channelized Sheet Element**

30 ft
1500 ft

- **Channelized Sheet Element**
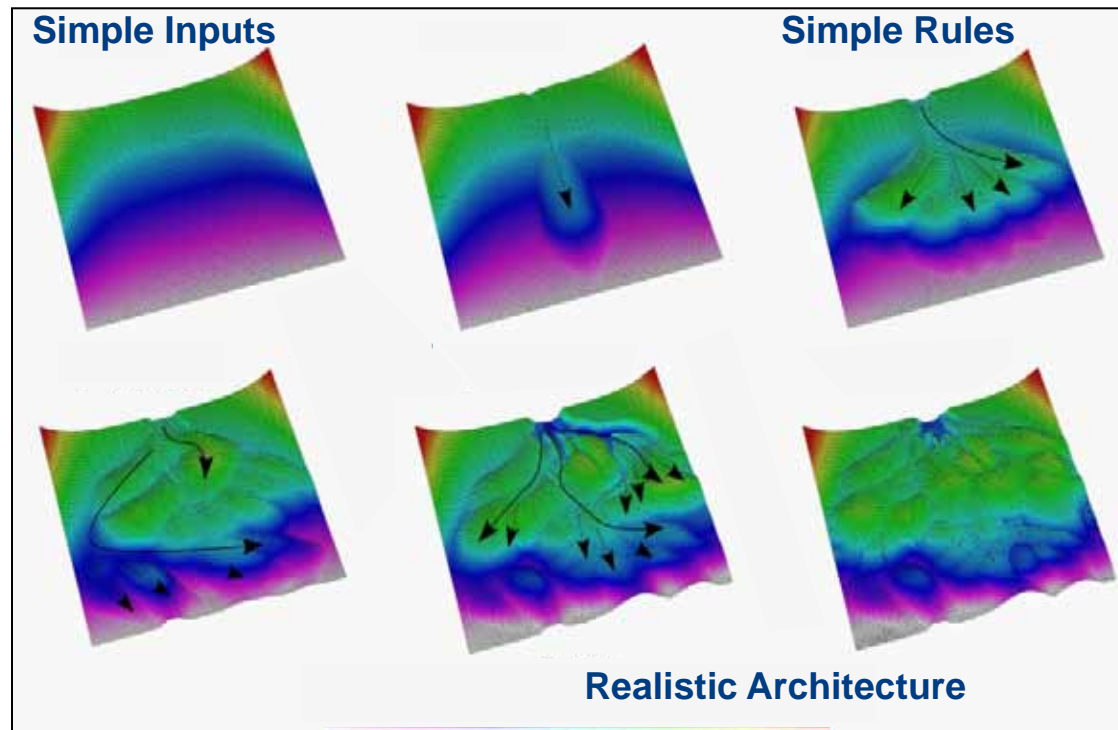

60 ft
1600 ft

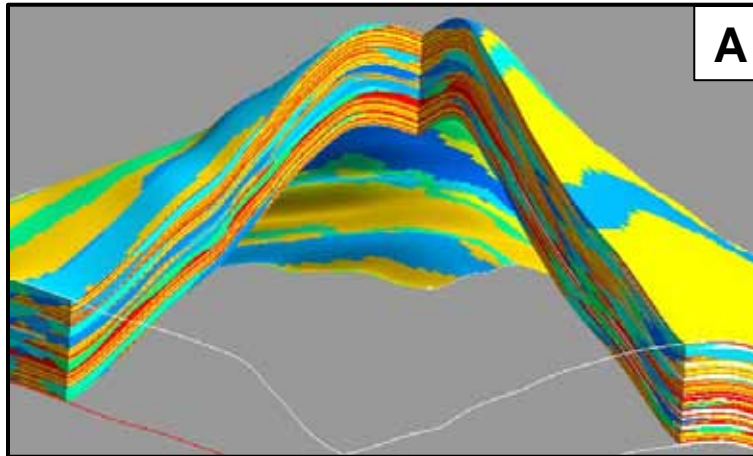- **Unconfined Sheet Element**

70 ft
2500 ft

Construction of Model Architecture

n   Event-based models – realistic architectures, by a rule-based forward geostatistical method developed in Chevron.
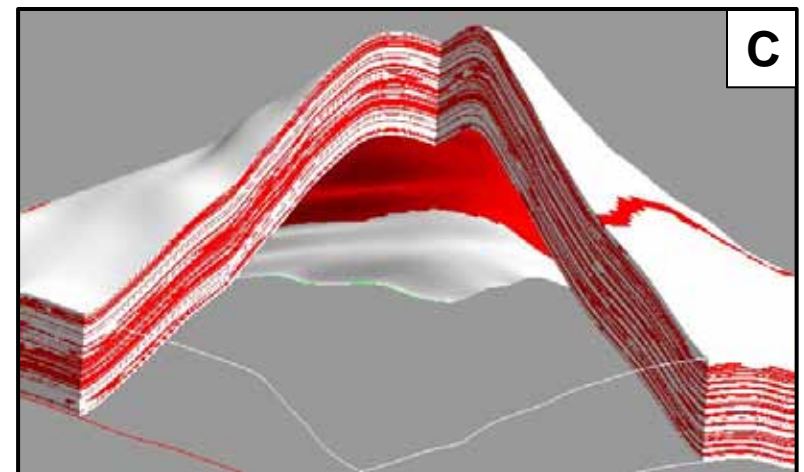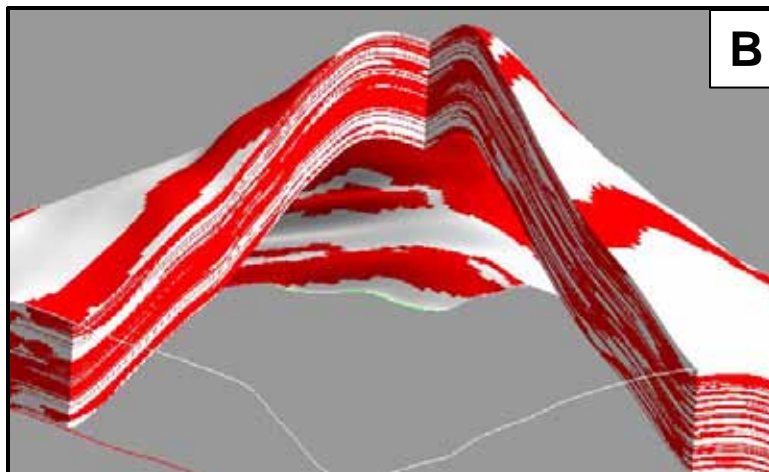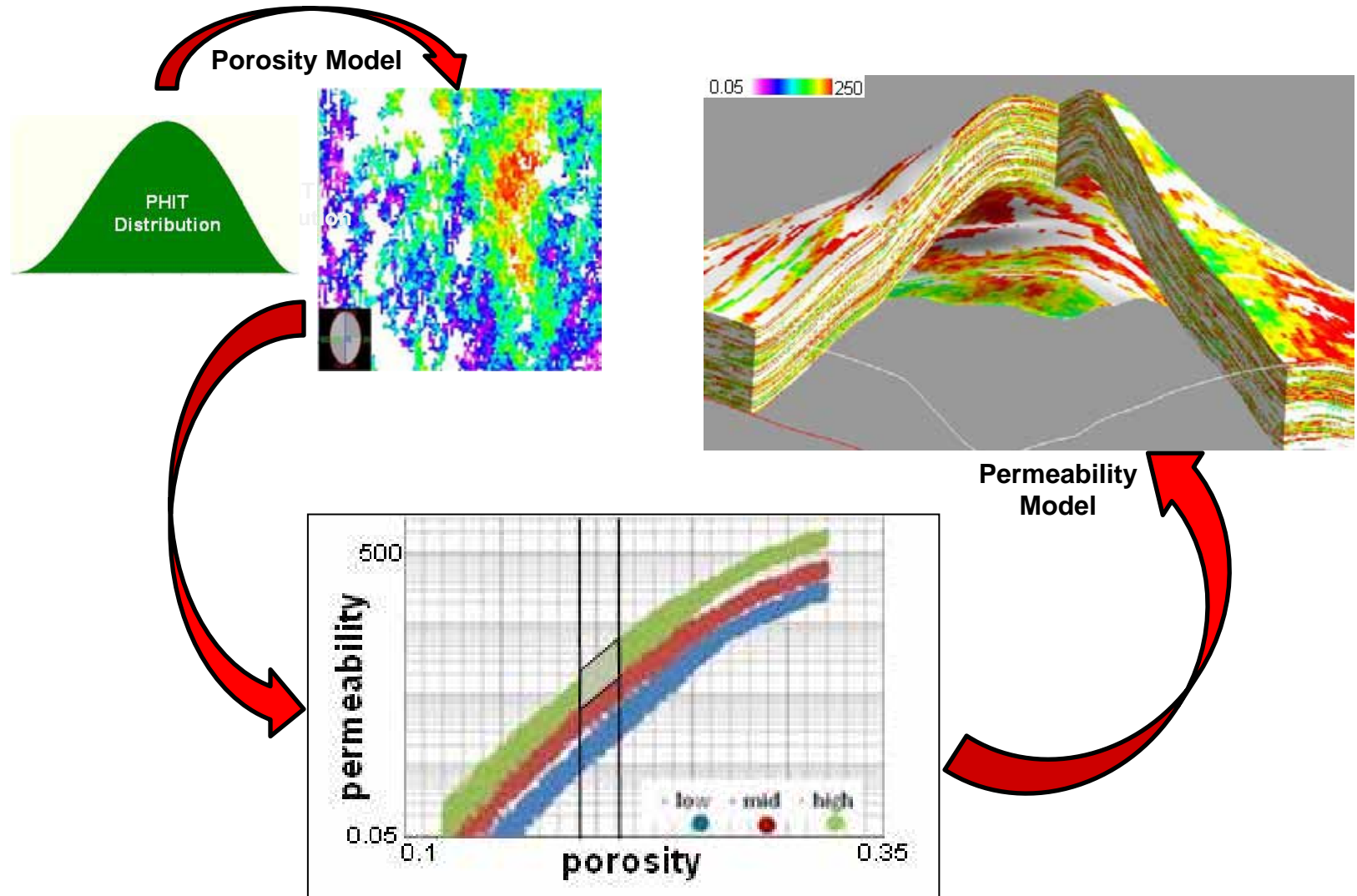

(Pyrcz et al., 2006)

Sand – No-sand Training Images Derived from Architecture Models

- **A**. Architecture model having channel (blue-green) and sheet elements (orange-red) in submarine fan setting.

- **B**. Channel-dominant training image for sand – no-sand modeling in proximal fan settings.

- **C**. Sheet dominant training imaged for sand – no-sand modeling in more distal fan settings.
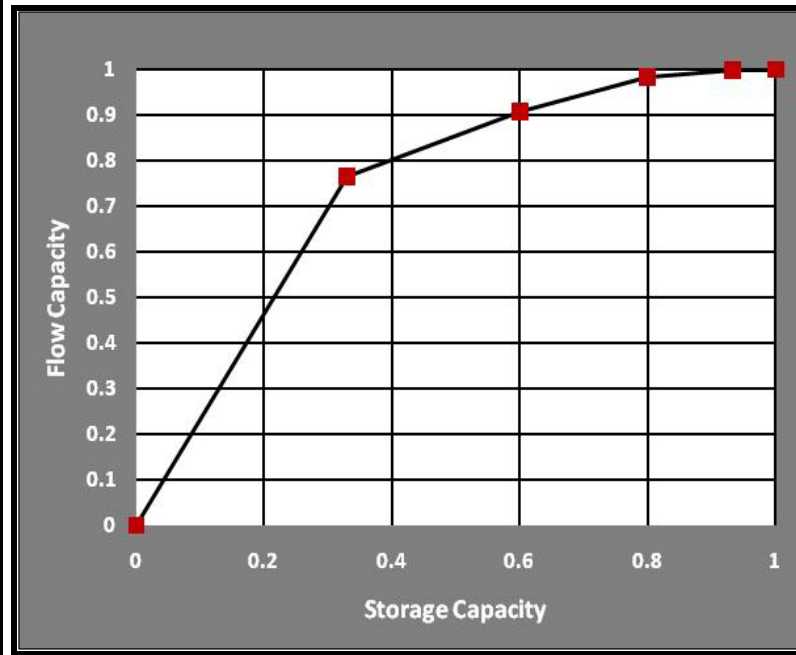
Petrophysical Properties

Porosity Model

Permeability Model

PHIT Distribution

0.05 — 250

permeability — porosity
500 — 0.05
0.1 — 0.35
low · mid · high

Streamline simulation
Flow Capacity – Storage Capacity(F- PHI) and Lorenz Coefficient

Flow Capacity – Storage Capacity

h(ft)	K(md)	j	Kh	j h	F	C
					0	0
5	500	0.25	2500	1.25	0.7654	0.33
5	100	0.2	500	1	0.9077	0.6
5	50	0.25	250	0.75	0.9834	0.8
5	10	0.1	50	0.5	0.9985	0.933
5	1	0.05	5	0.25	1	1
			3305	3.75		

Lorenz Coefficient

$$Lc = 2 \left(\int_0^1 F\,dF \ - \ 0.5 \right)$$

Increasing heterogeneity

Lc = 0.98

Lc = 0.70

Lc = 0

homogeneous

Dynamic Lorentz coefficent – computed from streamline data

Flow Capacity, F

Storage Capacity, PHI

Flow Capacity

Storage Capacity
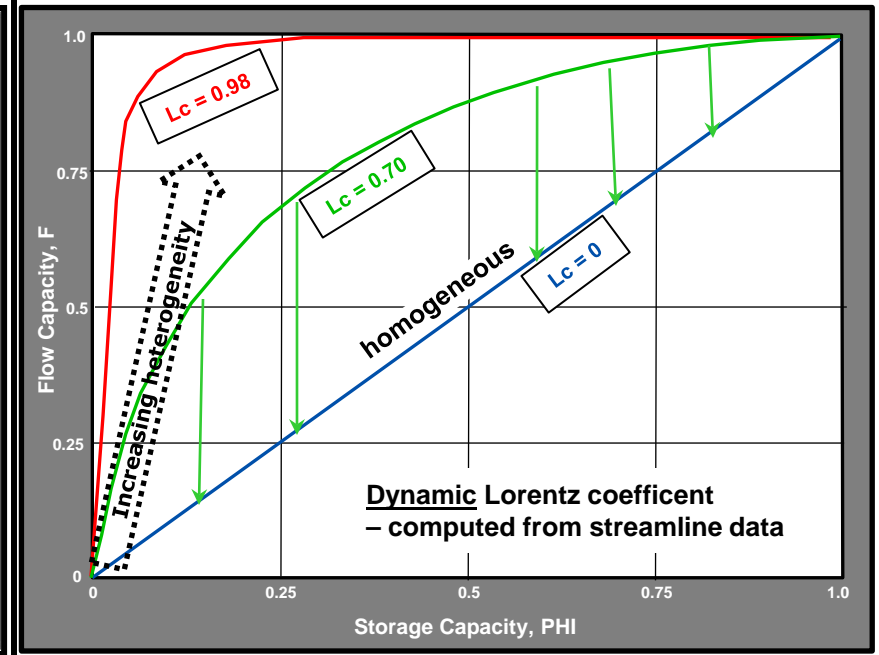
Modified from Shook and Mitchell, 2009, SPE 124625 and references therein

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Streamline Workflow

- Analyze streamline attributes and select appropriate models for detailed flow simulation

- Convert "static" property models to format required for streamline simulation

4. Compile Results and Select Models

1. Export Models to Simulator Format

3. Read Streamline Information

2. Run Streamline Simulations

- Read attributes pertinent to fluid flow from streamline data

- Run Streamline simulation on models at selected well patterns and spacing

Streamline Analytical Procedure

- **n** Generic simulation deck contains 3 include statements for property grid and well information.

- **n** Run a streamline simulation for a few time steps.
  - **n** No transients; steady state (volume replacement)

- **n** Read streamline volumetric flow rate and time of flight.

- **n** Compute pore volume represented by each streamline

- **n** Calculate Dynamic F-F curve and Lorenz coefficient (heterogeneity indicator; Shook and Mitchell, 2009)

Abbreviations

Lc – dynamic Lorenz coefficient.

Lc1 – dynamic Lorenz coefficient computed from swept pore volume.

Lc2 – dynamic Lorenz coefficient computed from total pore volume.

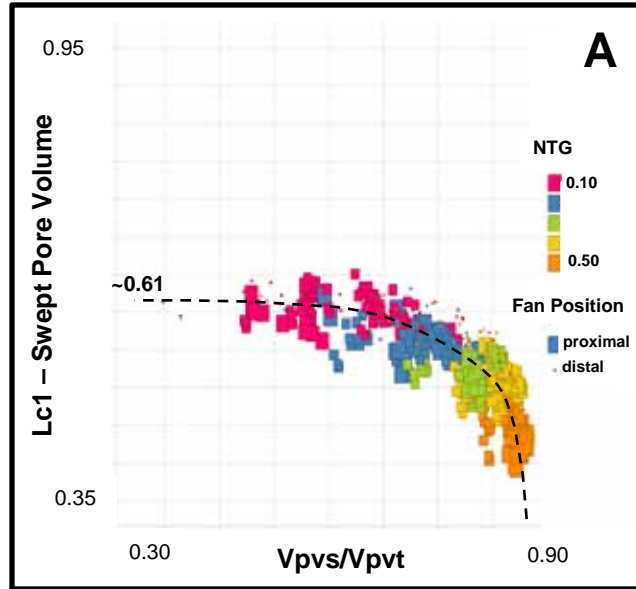**Vpvs** – swept pore volume. **Vpvt** – total pore volume. **PV** – pore volume.

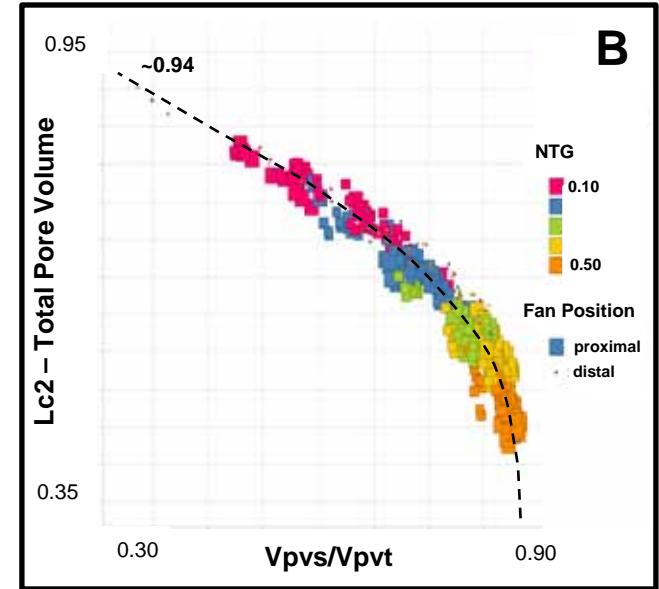# Two Storage Capacity – Flow Capacity Curves can be Computed

- **n** Blue curve (Lc1) describes heterogeneity for swept PV
- **n** Red curve (Lc2) describes heterogeneity for total PV
  - **§** 44% of PV is unswept
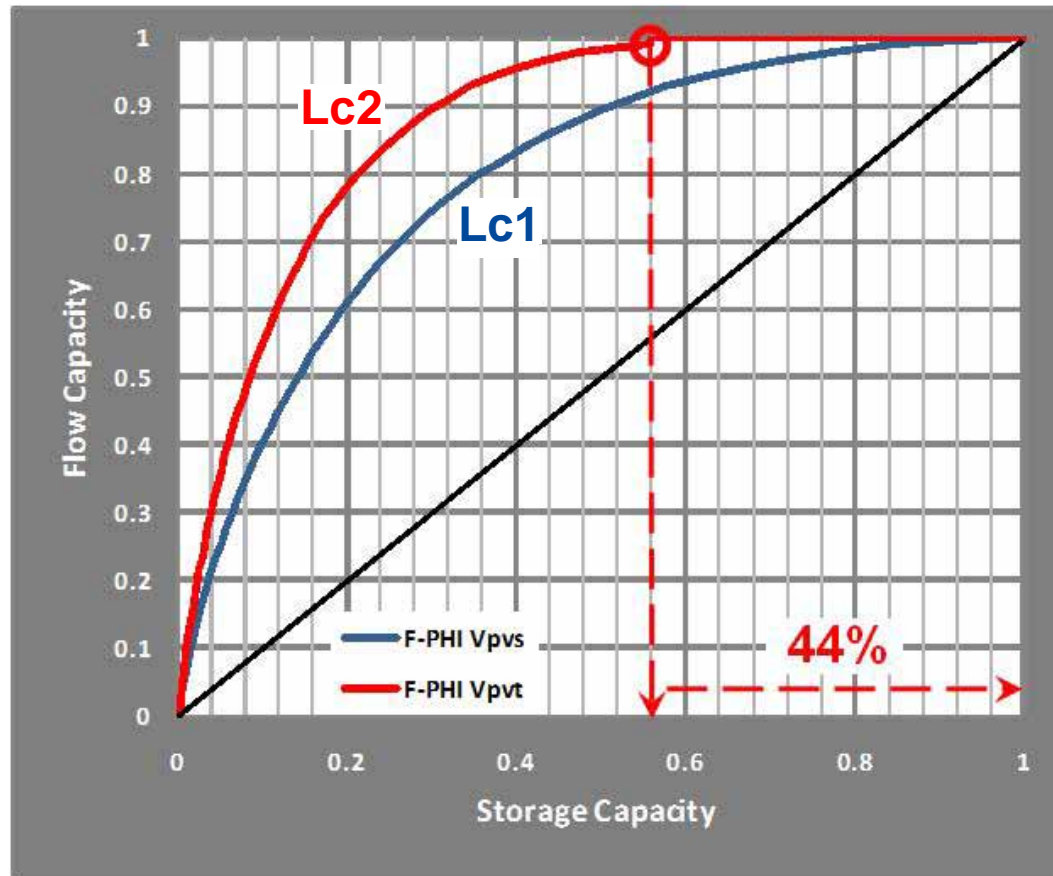
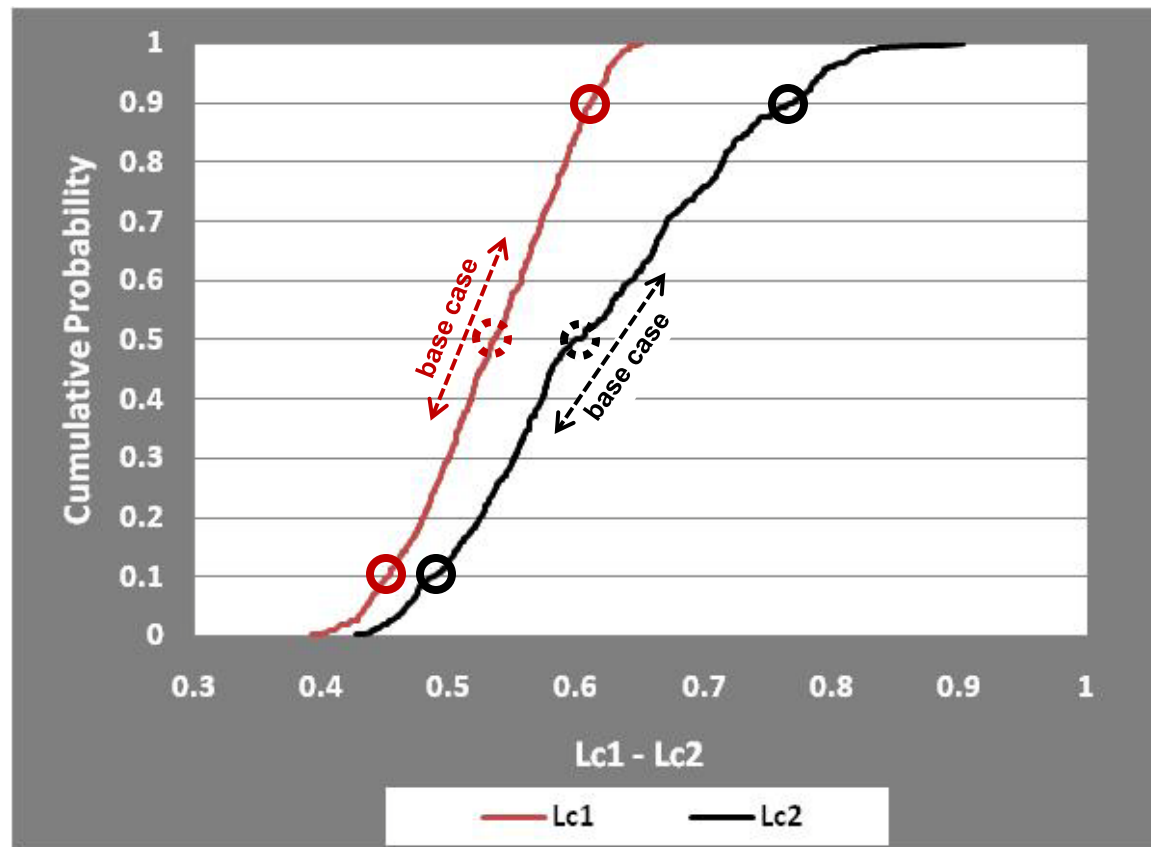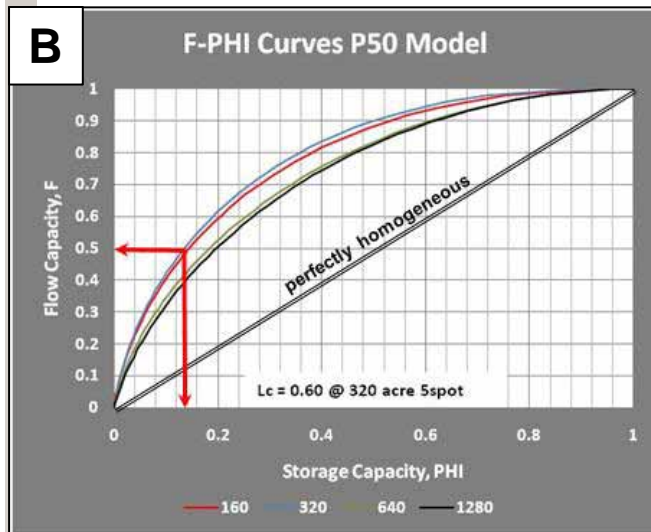# Lc1 and Lc2 (Lorenz Coefficients) Plotted vs. Swept/Total Pore Volume Ratio

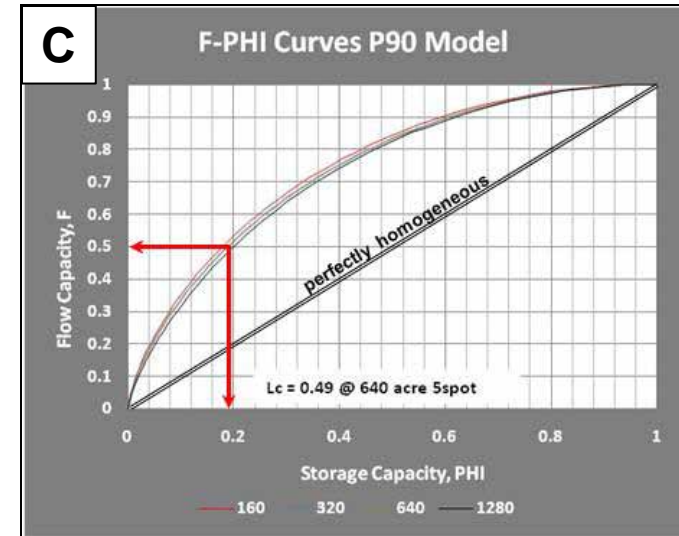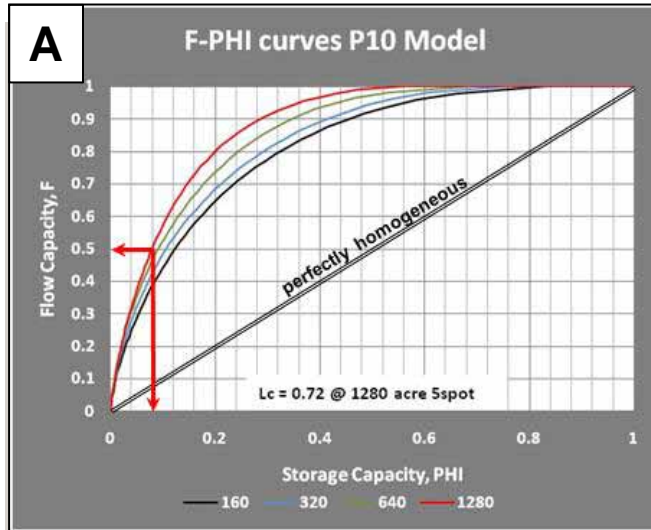- **A**. Crossplot of swept pore volume to total pore volume ratio vs. Lc computed from swept pore volume. NTG scale in color boxes. Increasing symbol size representing more proximal positions.
    - Lc1 plummets at 30% NTG and 0.85 Vpvs/Vpvt.
    - Lc1 plateaus at 0.61.
    - Significant implications with respect to thief zones in secondary and tertiary recovery
- **B**. Crossplot of swept pore volume to total pore volume ratio vs. Lc2 computed from total pore volume. NTG scale in color boxes. Increasing symbol size representing more proximal positions.
    - Lc2 diminishes linearly until ~ 30% NTG and 0.80 Vpvs/Vpvt then plummets in similar fashion as Lc1.
    - More applicable to primary recovery.

Model selection: CDF ranking

- **n** **Order to rank Lc results and select streamline cases for detailed modeling.**

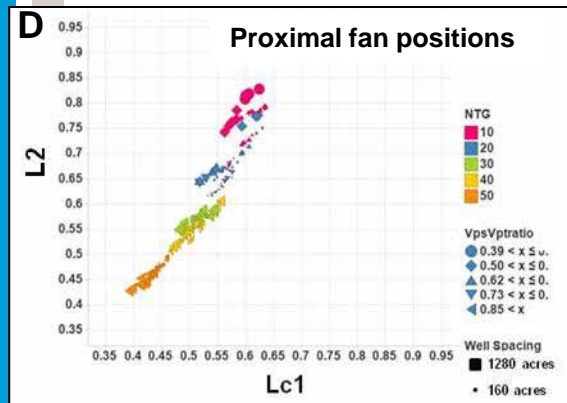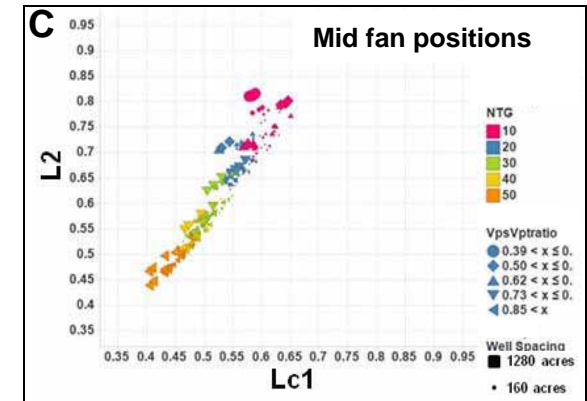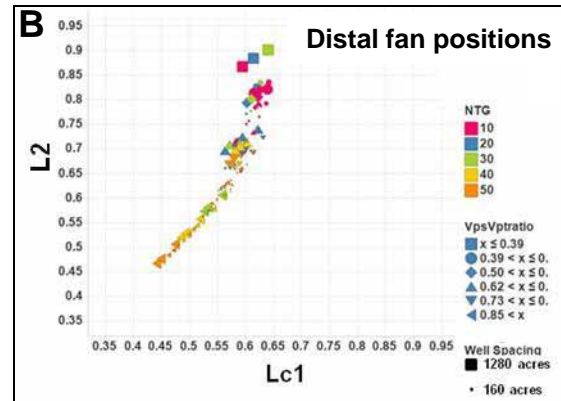- **n** **Compare associated ranked streamline results and select models based on balancing attributes of respective properties.**
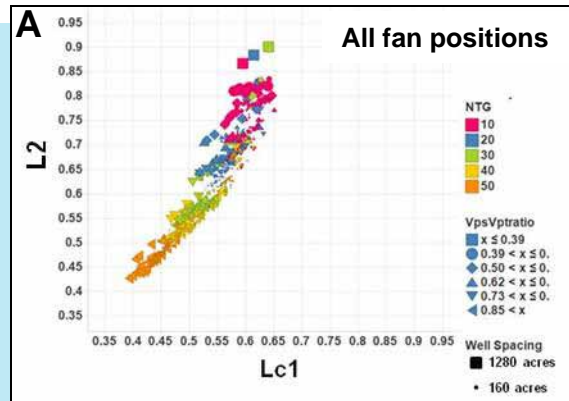
Model selection: CDF ranking

A — F-PHI curves P10 Model
Flow Capacity, F vs Storage Capacity, PHI
perfectly homogeneous
Lc = 0.72 @ 1280 acre 5spot
160 320 640 1280

C — F-PHI Curves P90 Model
Flow Capacity, F vs Storage Capacity, PHI
perfectly homogeneous
Lc = 0.49 @ 640 acre 5spot
160 320 640 1280

B — F-PHI Curves P50 Model
Flow Capacity, F vs Storage Capacity, PHI
perfectly homogeneous
Lc = 0.60 @ 320 acre 5spot
160 320 640 1280

- **Example of models selected by CDF ordering of Lc2 from previous slide.**
  - **Note that < 20% of total pore volume contributes to 50% flow capacity for all cases.**
- **A. 50% flow capacity from 8% PV.**
- **B. 50% flow capacity from 12% PV.**
- **C. 50% flow capacity from 19% PV.**

Model selection: Multivariate Analysis

- **n** Multivariate plots useful for selection of cases for detailed modeling.

- **n** Depending on level of confidence in depositional setting one may elect to rank models for detailed analysis using all depositional model cases (A), or rank models based on specific depositional positions (B, C, and D).

- **n** High-level understanding (expert opinion) of, e.g., development strategy (exploration/appraisal) dictates variable combinations appropriate for model ranking.

Displayed variables include:

Lc1 (x-axis)

Lc2 (y-axis)

net-to-gross (color box scale)

Vpvs – Vpvt ratio (plot symbol shape)

5-spot pattern size (plot symbol size)

Conclusions

- Expert guided rule-based depositional models provide detailed and conceptually accurate reservoir architecture essential to ascertain the uncertainty range of fluid-flow characteristics critical to economic analysis.

- The dynamic Lorentz coefficient provides a means of rapidly ranking earth models to capture the uncertainty space of subsurface geological conditions.

- Correlation of the dynamic Lorentz coefficient to key economic drivers may provide early insight into a projects financial viability.

- Early evaluation of heterogeneity enhances efficiency of the modeling workflow. Simulation engineers also receive earth models with a priori understanding of heterogeneity.

Thank you