Geostatistical Reservoir Models
me Unfit for Purpose
ys to avoid this)

Chev
Human E

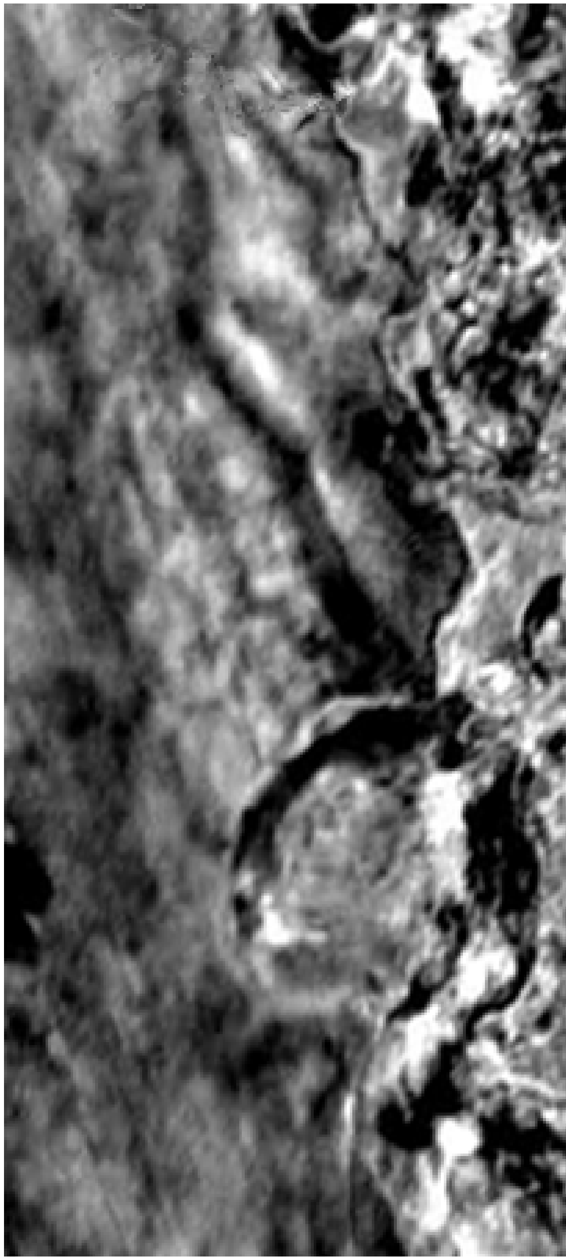
el J. Pyrcz
d P. Sech
ence R&D, Chevron Energy Technology Company
Texas, USA

orning Tech Talk, July 23rd, 2015

ction

cterizing the spatial
ution of reservoir
rties to support billion
nvestment decisions is a
challenge in the presence
cal subsurface datasets

e datasets are limited
 all of the scales that are
ented in reservoir models



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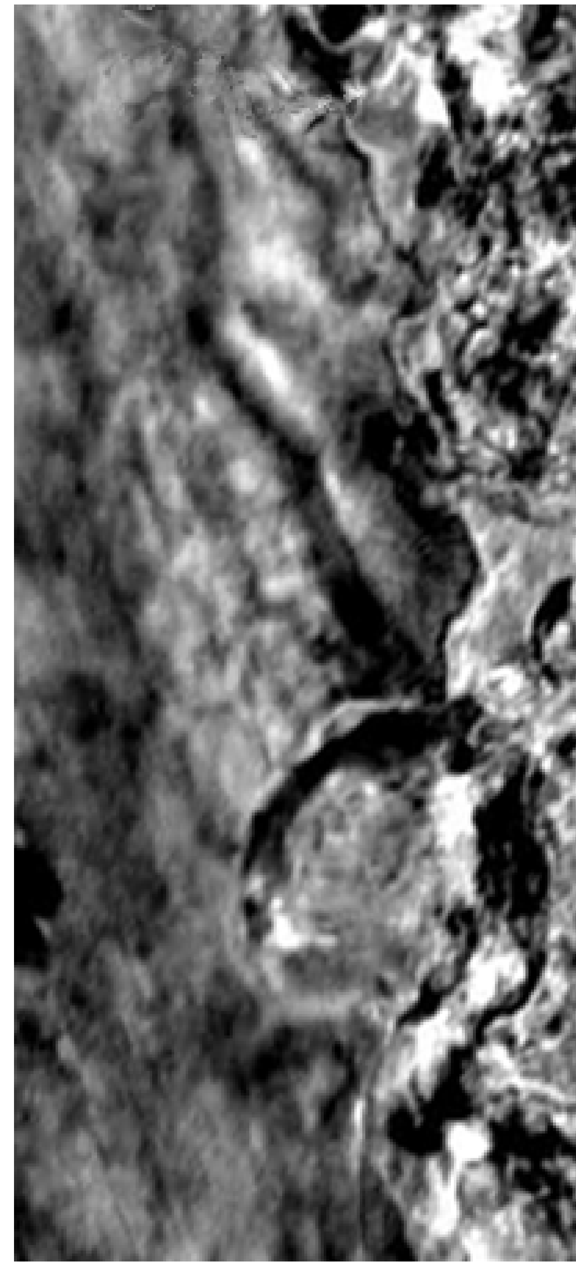

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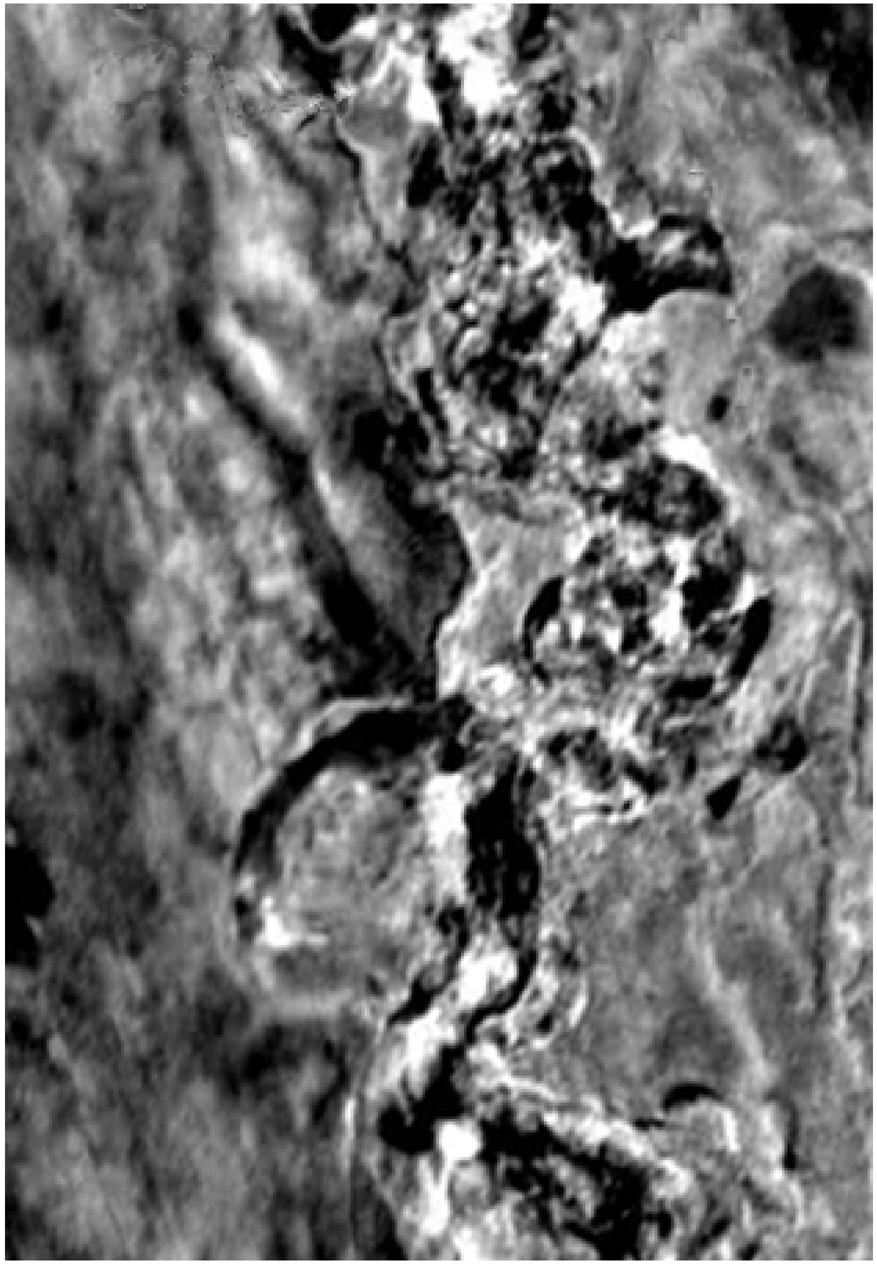

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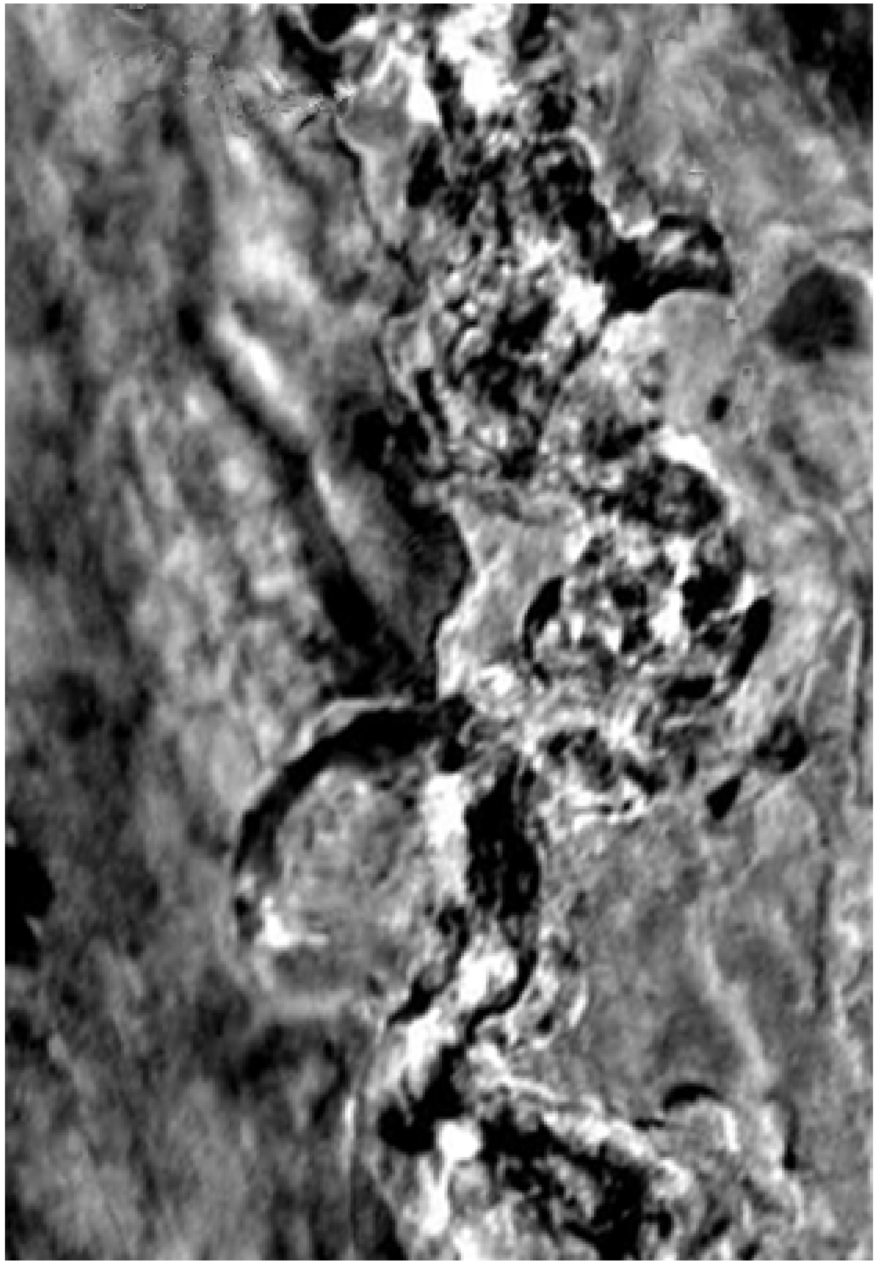

(*Fisk, 1944,* Mississippi River Cor

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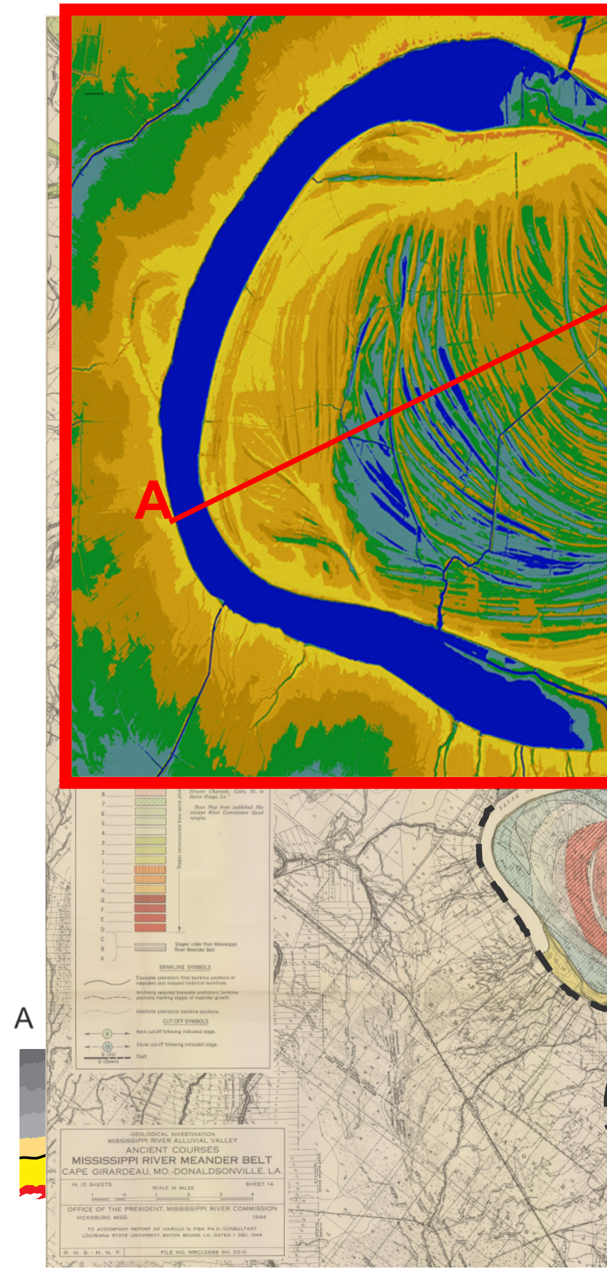


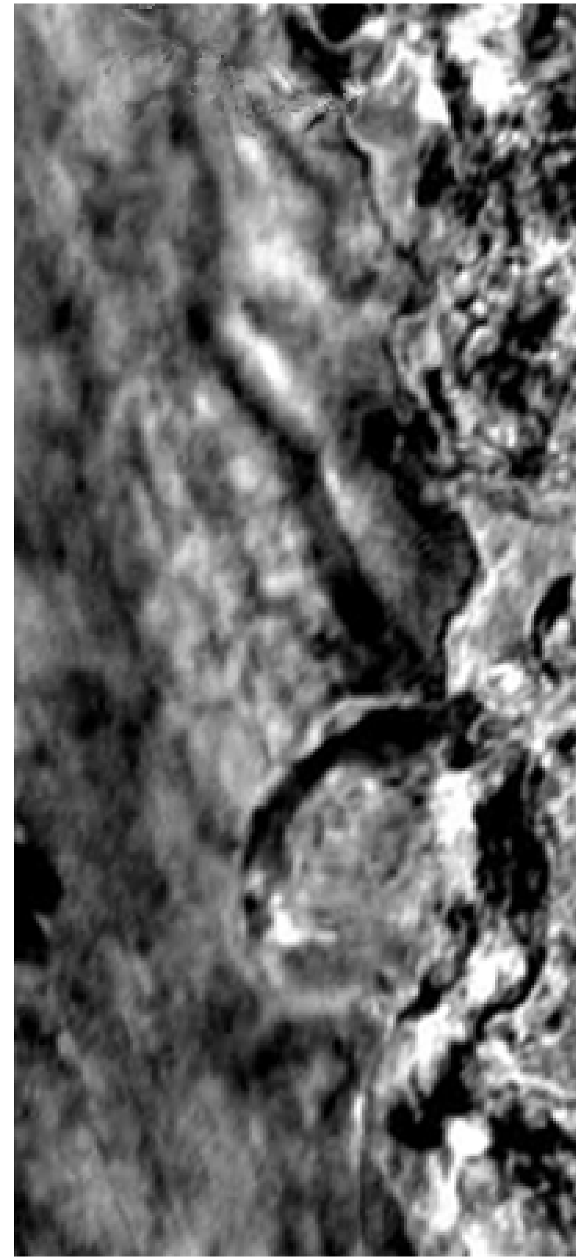
(Fisk, 1944, Mississippi River Commission Report)

ction

ved reservoir
cterization can have a
e impact on field
mics

ample, the cost of drilling
in the setting shown here
0 million

r, the development plan
s field assumes no water
ng capability



ction

cal reservoir model for
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odel offers a fine
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cs…but is it an
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geology…and does
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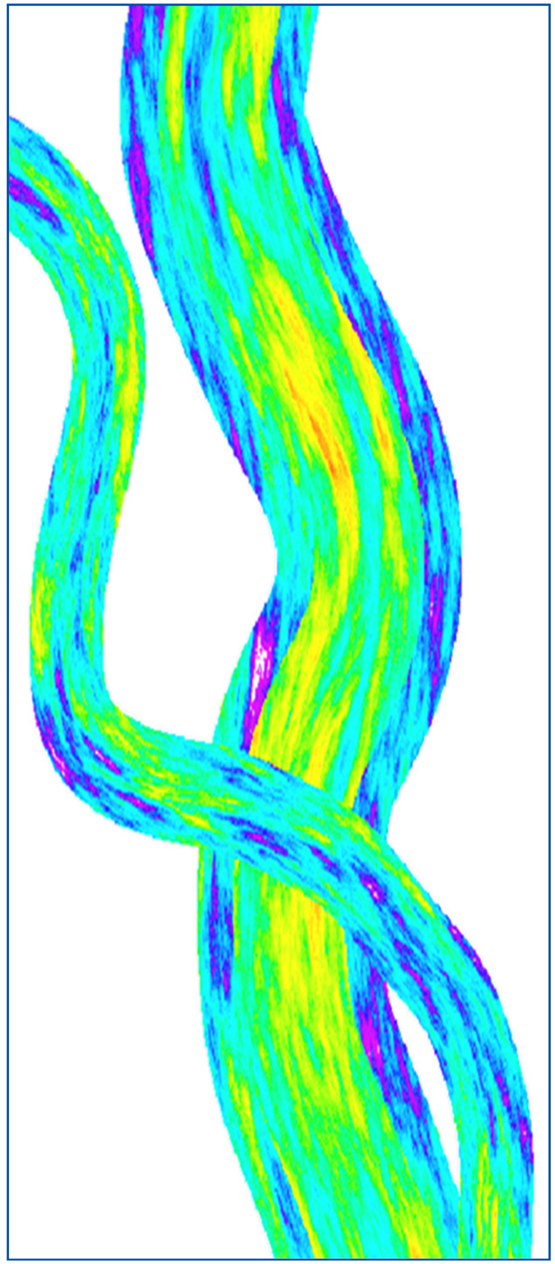
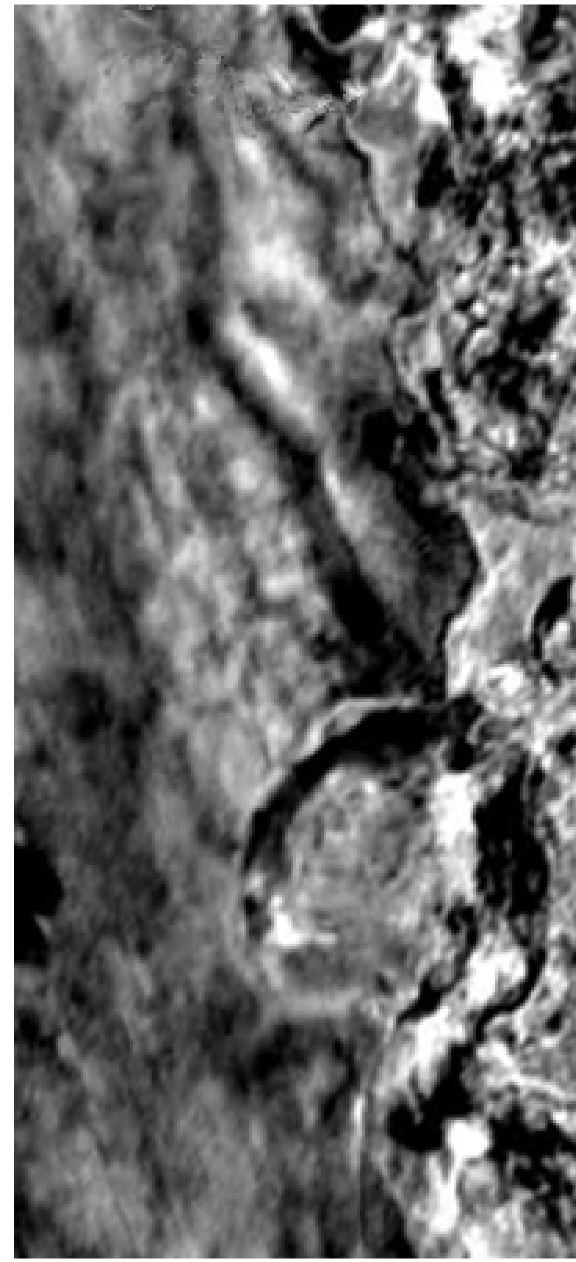




ent of the problem

atistical modeling is a fundamental tool for reservoir characteris
ver, we identify limitations to the use of geostatistics for the spe
se of reservoir modeling owing to the following reasons:

ing it wrong! abuse, misuse, and misunderstanding of the fundamen
nciples of geostatistics

reasonable expectations! arising from inadequate appreciation of th
tations of the technology

tead of geology! ignorance to the requirement for the integration of g
ological knowledge into the reservoir modeling process

lk will address why these issues arise, how they can be mitiga
irections research in geostatistical reservoir modeling is taking

tistical reservoir modeling - talk outline

orted uses

non abuses

derstandings

purpose

e research directions

tistical reservoir modeling - talk outline

orted uses

non abuses

derstandings

purpose

e research directions

– Numerical description of het
consistent with measured da

– Integration multiple data sou

– Accounting for scale

– Multiple realizations to mode
uncertainty

– Objectivity: repeatable, mea

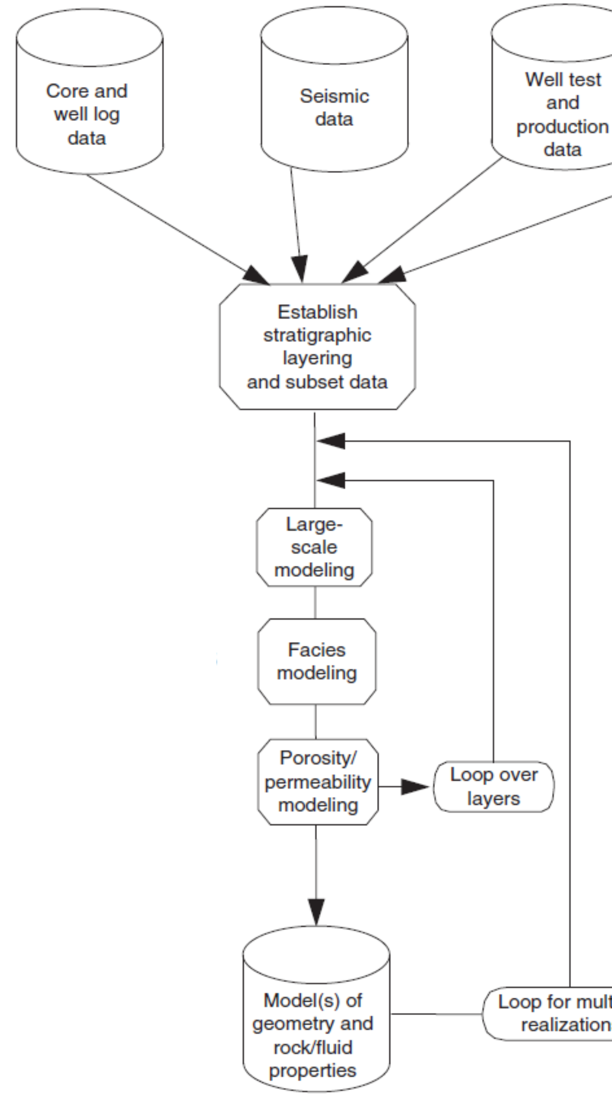
– Robust treatment of probab

– Practical: user friendly, intuit
tractable

tistical reservoir modeling is *the* practical choice fo ace geological characterization

- ve, transparent, repeatable
- le, conditional heterogeneity
- y available in vendor and academic are
- t in various academic institutions and nized in industry
- lth of published workflows and results
- orts optimum decision making
- way? Add it to the tool box…

(Pyrcz and Deutsch, 20



cal approach with theoretical underpinnings and demonstrated track r

tistical methods can account for scale variability in
ata

ng for Scale

statistical inputs have implicit volume support

persion variance is a generalized

ume-based variance

$$D^2(v,V) = \overline{\gamma}(V,V) - \overline{\gamma}(v,v$$

iging system is general, supports volume integrated variogram
r)

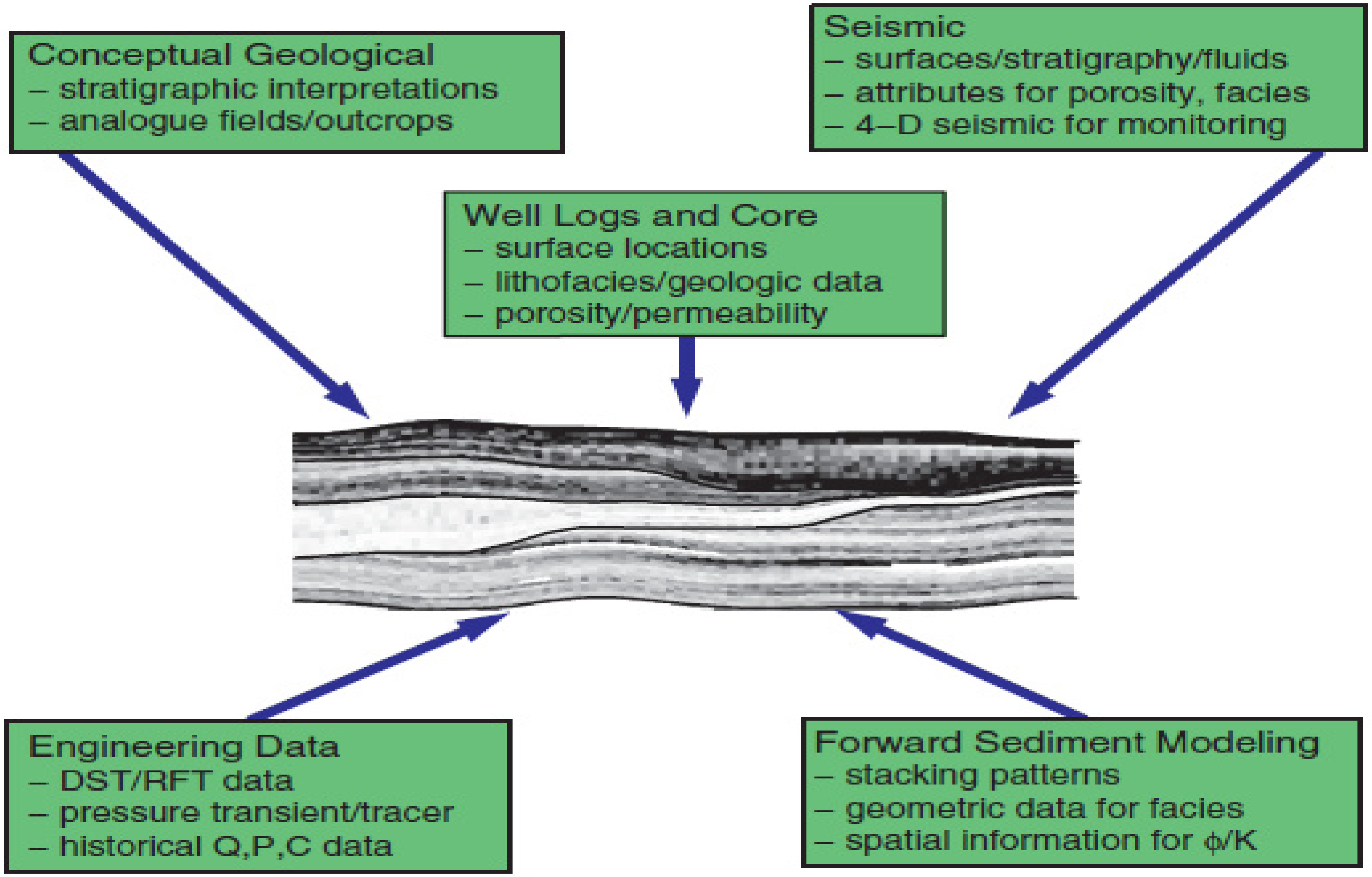
mma bars may be

plied directly

$$\overline{\gamma}\left(v(\mathbf{u}),V(\mathbf{u}')\right) = \frac{1}{v \cdot V}\int_{v(\mathbf{u})}\int_{V(\mathbf{u}')}\gamma$$

y of the estimation and simulation routines are general – support any

tistics can integrate multiple data sources



Various types of data that may be integrated into reservoir models (Pyrcz and Deutsch, 2014)

ablers: Conditional to soft and hard data, Bayesian approaches, multivariate rel
archical, explicit scale, inversion workflows

us updating, combination, merging and soft data approaches are ava

tistics allows for a quantitative description of geolo

ve Geology

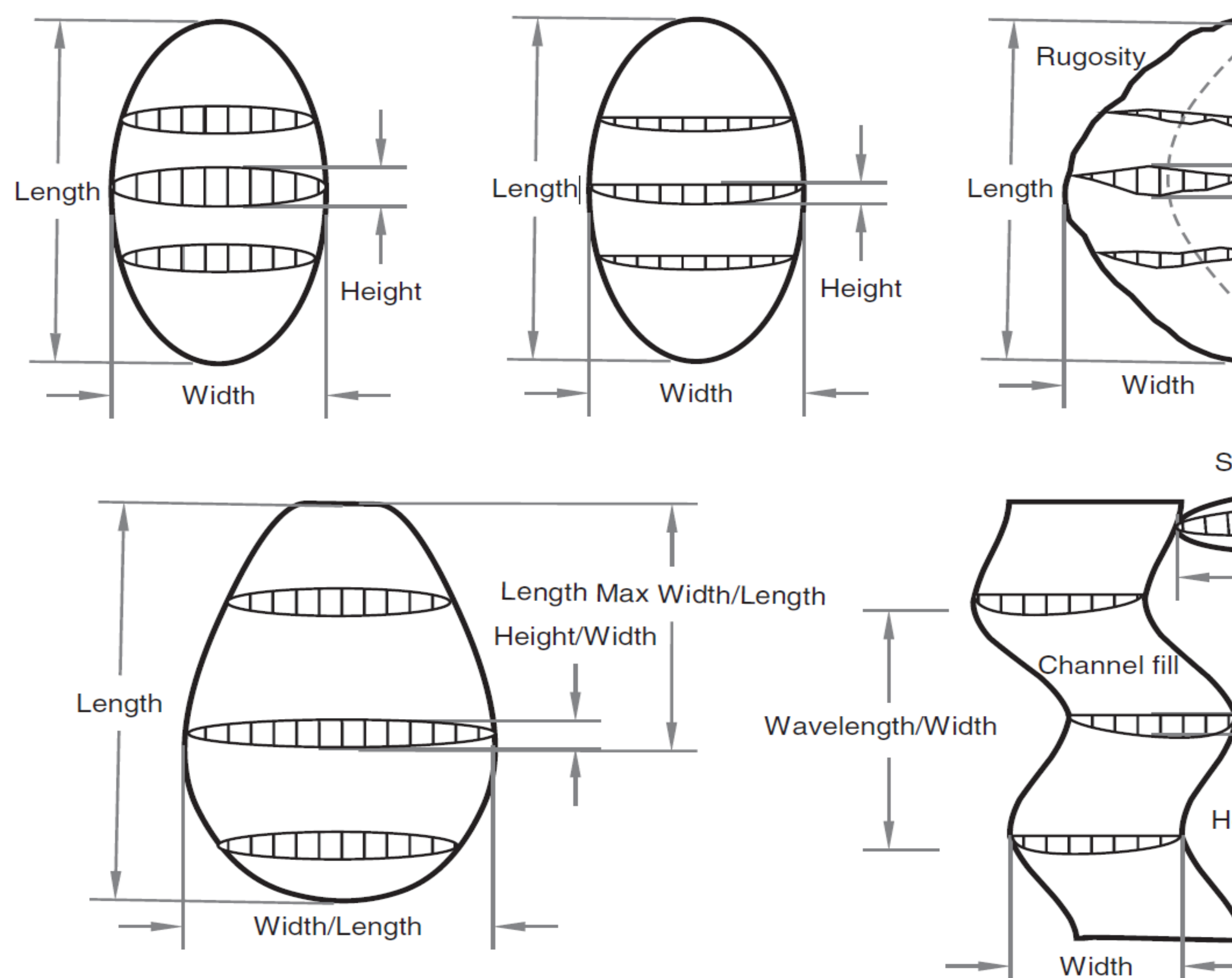
eatable

nsparent

endable

cterization

roduction



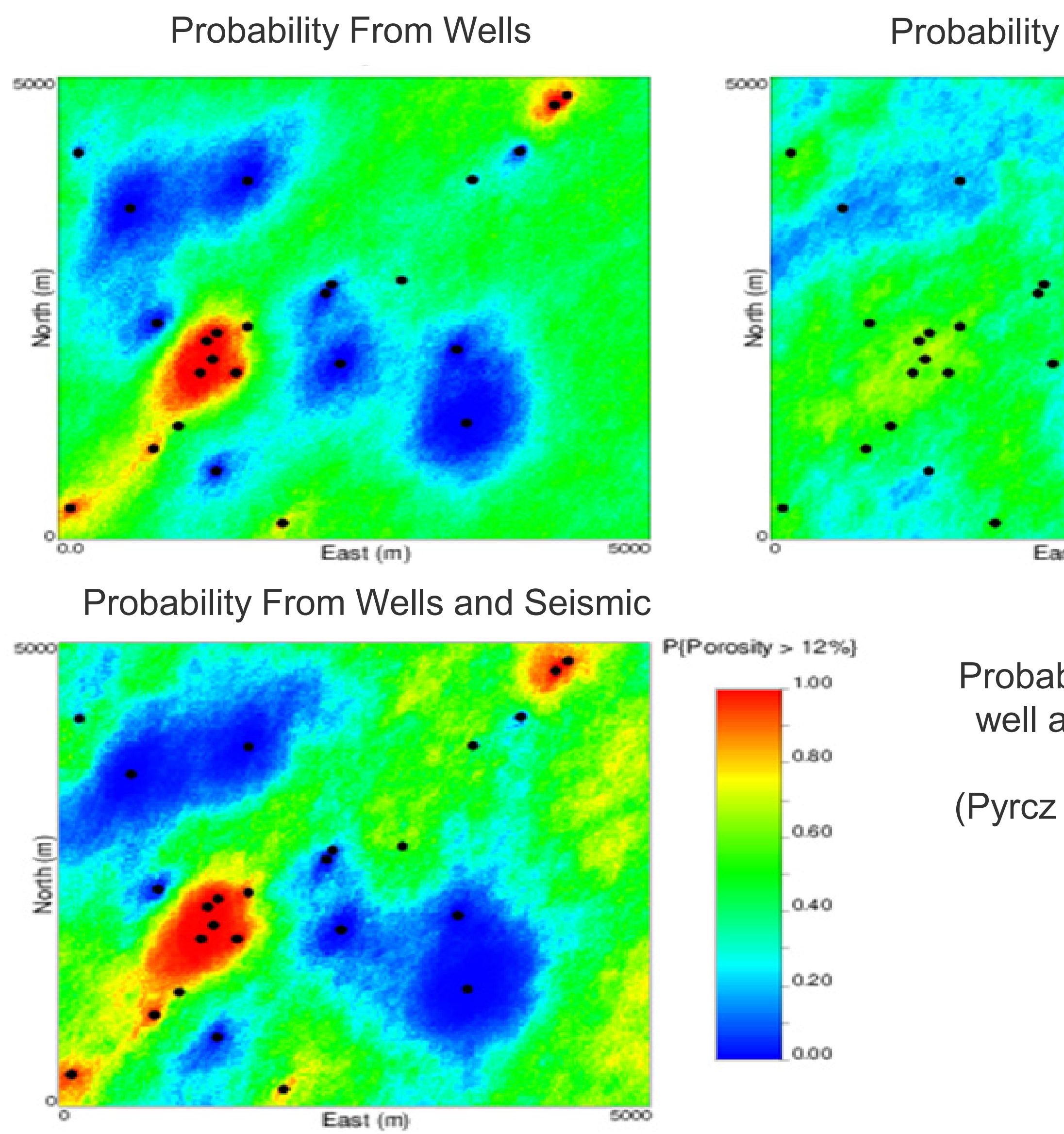
Various examples of object-based geometric parameterization (Pyrcz and Deutsch, 20

decision to parameterize (abstract) geology and then we can test sigr

tistics provides a robust treatment of probability

reatment of Probability

- hods to calculate the required probabilities
- bability-based workflows
- robability Aggregation
- ayesian Updating
- robability Combination



Probab
well a

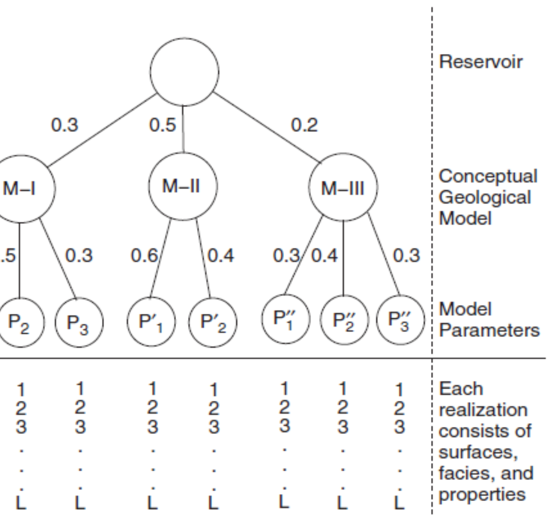
(Pyrcz

Tools for calculating the required probability distributions.

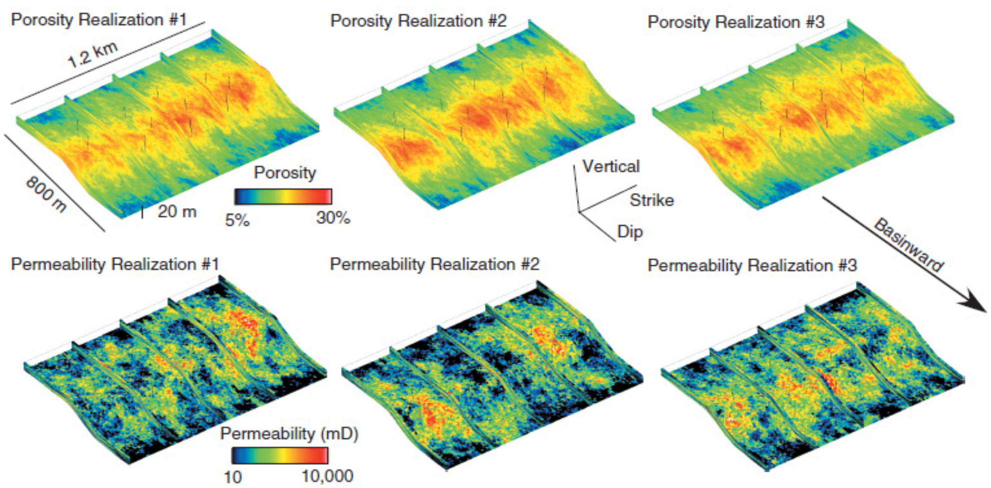
tistics provides an uncertainty model

Realizations to Account for Uncertainty

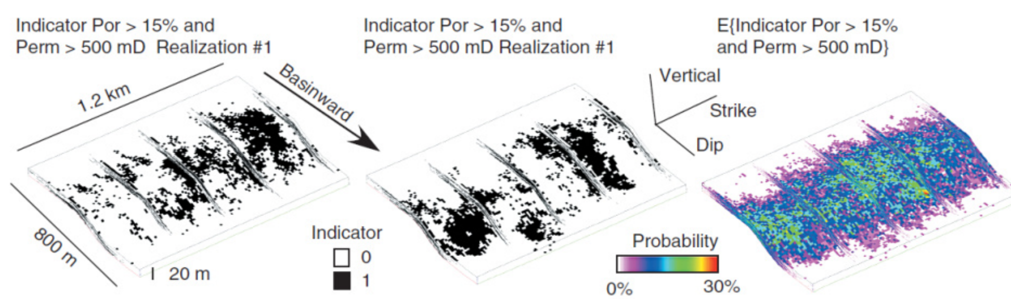
- ient calculation of scenarios and realizations
- ummarization, post-processing,
- ansfer functions



model through scenarios and realizations (Pyrcz and Deutsch, 2014)



Multiple porosity and permeability realizations (Pyrcz and Deutsch, 201



Local uncertainty model based on multiple realizations (Pyrcz and Deutsc

Efficient exploration of uncertainty through scenarios and realizations

ted Uses Conclusions

ar is high for expectation / fundamental pillars of geostatistics

onditional

eterogeneity

ncertainty

ble compromises

have you got something better?

n you handle all of this practically?

does – you are one of us!

'll make space in the tool box.

timization-based, indicator-based, multiple point-based, process-mimi

tistical reservoir modeling - talk outline

rted uses

non abuses

derstandings

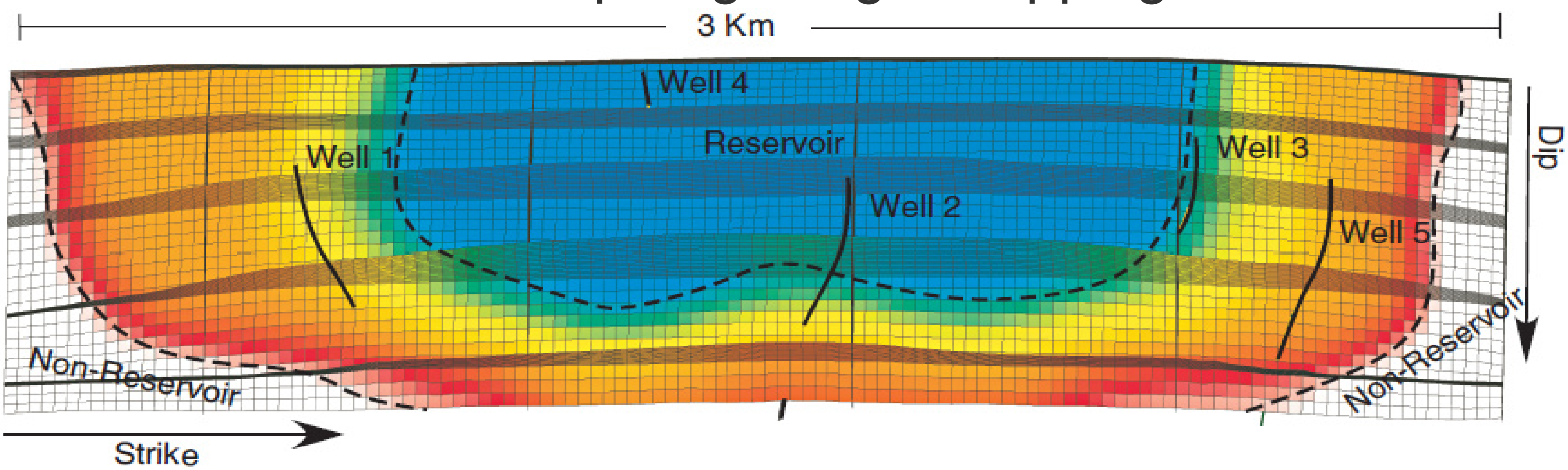
purpose

e research directions

- Geologist in a box
- Statistical representativity
- Precisely honor inputs
- Fully geologic realism – limi statistics, limited constraints
- Complete geologic realism
- Complete uncertainty

tistics does not create geologic knowledge

- eplace Geologic Interpretation
- vishly honors inferred statistics and trends
- produces data integrations at data locations
- **rst Practice**: conduct reservoir modeling as a statistical data fitting st
- **st Practice**: focus on expert geologic mapping



Geologica
trend moc
reservoir q
well da
Deuts

sumes stationarity except data conditioning, secondary information a

tistics will propagate sampling bias unless correcte

or Biased, Non-representative Sampling

vishly honors inferred statistics and trends

rst practice is to use poorly chosen regions to for inference and mod erred statistics

st practice is to use geologic and engineering constraints to segment bsurface into unique populations for investigation

rst practice is to rely on naïve data statistics

st practice is to model the input statistics

rst practice is to rely on a stationary statistical model

st practice is to constraint the statistical model with geological conce

Must model and take ownership the inputs.

tistics may not perfectly honor the input statistics

Precisely Honoring of Input

odic Fluctuations

put statistics fluctuate, can be predicted

tradictions

bility to honor various inputs

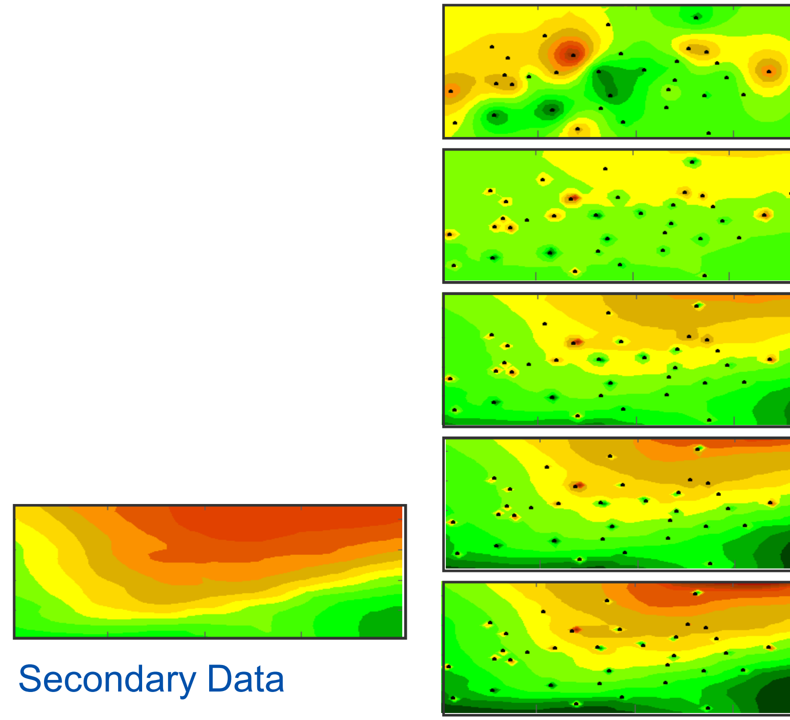
o explicit check for contradictions

onditioning priority is implicit

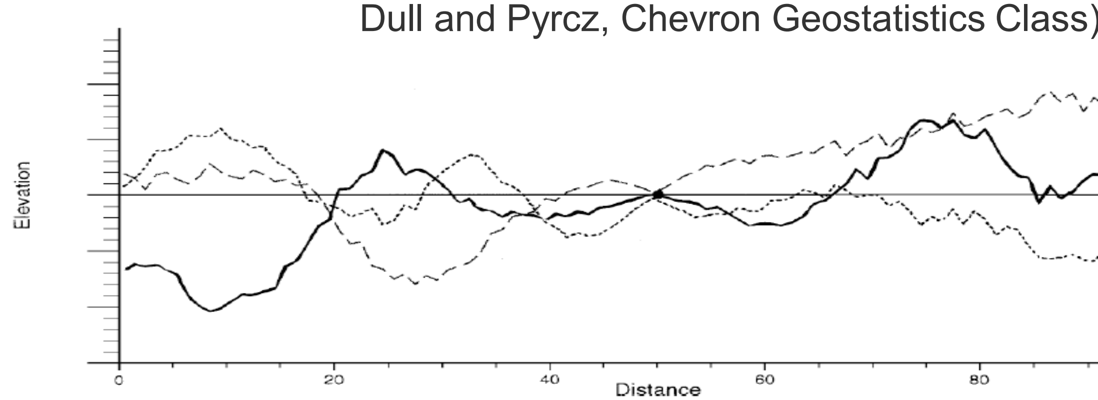
acts

ome known artifacts e.g. P-field, collocated
g etc.

judgment is critical



Impact of contradiction between primary, secondary and cross spatial r
Dull and Pyrcz, Chevron Geostatistics Class)



P-field simulation honors data as local minima or maxima. (Pyrcz an

You need to understand what is happening under the hood.

tistics will not always provide complete geologic

e Geologic Realism

el of required realism depends on the
eling question / modeling purpose

of a limited set of input statistics

ostraction

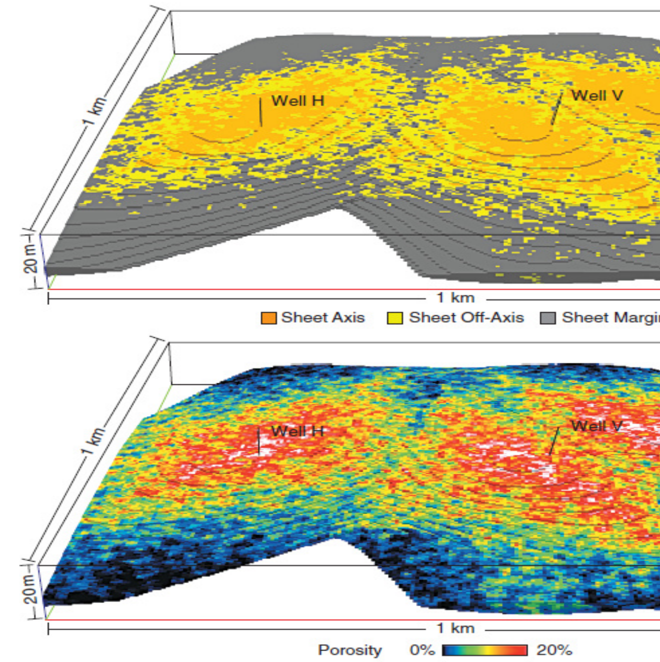
ationarity

ansparent, defendable – objectivity?

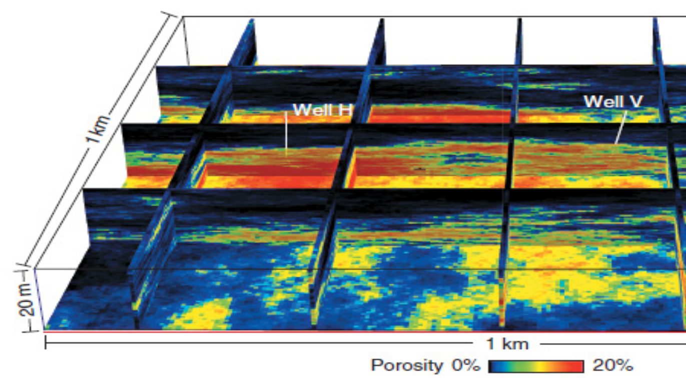
zation and ts → Reproduction in model → Decision Making

tures beyond the imposed statistics
roach maximum entropy

n-conservative flow response.



Deepwater lobe reservoir model with geome
(Pyrcz and Deutsch, 200



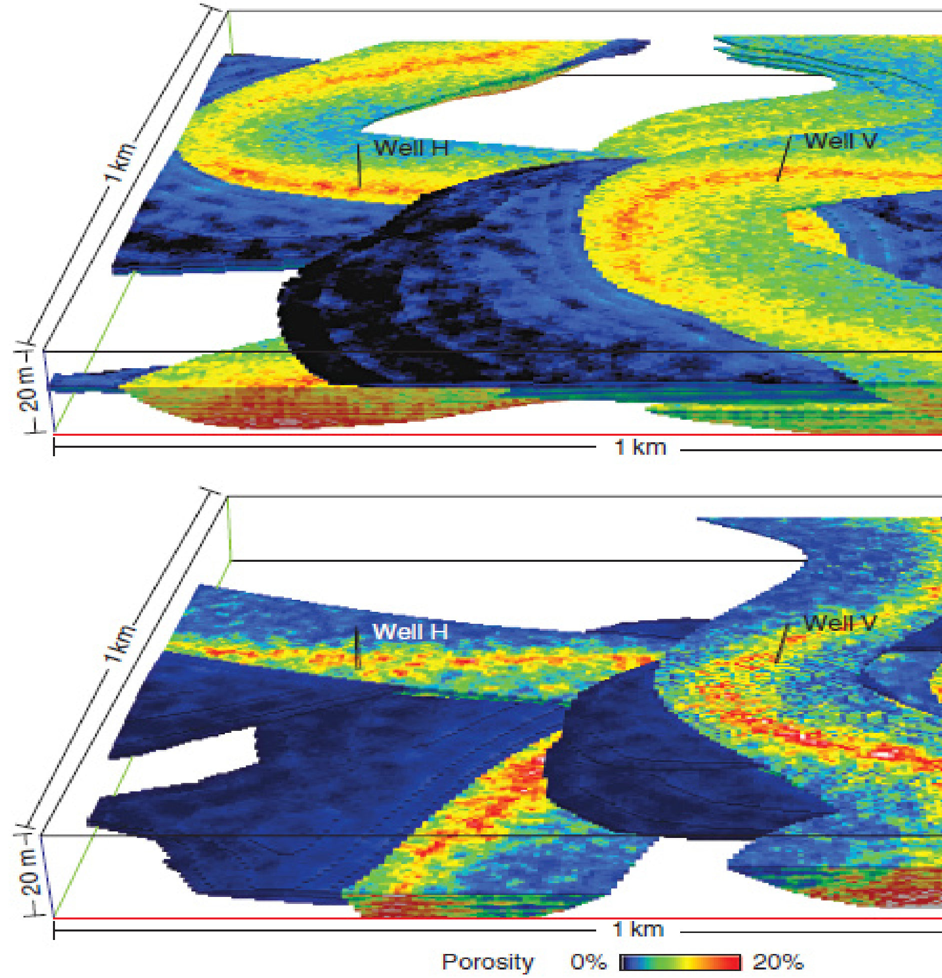
Stationary variogram-base
(Pyrcz and Deutsch, 20

ical characterization and reproduction within geologic framework is po

tistics cannot capture all possible uncertainties

e Uncertainty Model

- el of subjectivity in estimation and ertainty modeling
- eologic mapping and concepts are central
- logic concept uncertainty must be explicitly ned
- cenarios of framework, reservoir types, ends
- ctical decision to limit investigation of ertainty sources
- ocus on those assessed to be most portant
- ncertainty in the uncertainty is not useful
- certainty is a model
- annot predict black swans



Deepwater channel reservoir model with 2 realizations fro uncertianties.
(Pyrcz and Deutsch, 20014)

There is no “true” uncertainty.

on Abuses Conclusions

geology is fundamental

erienced / black box use is dangerous

romises must be understood

know when to stop

tistical reservoir modeling - talk outline

rted uses

non abuses

derstandings

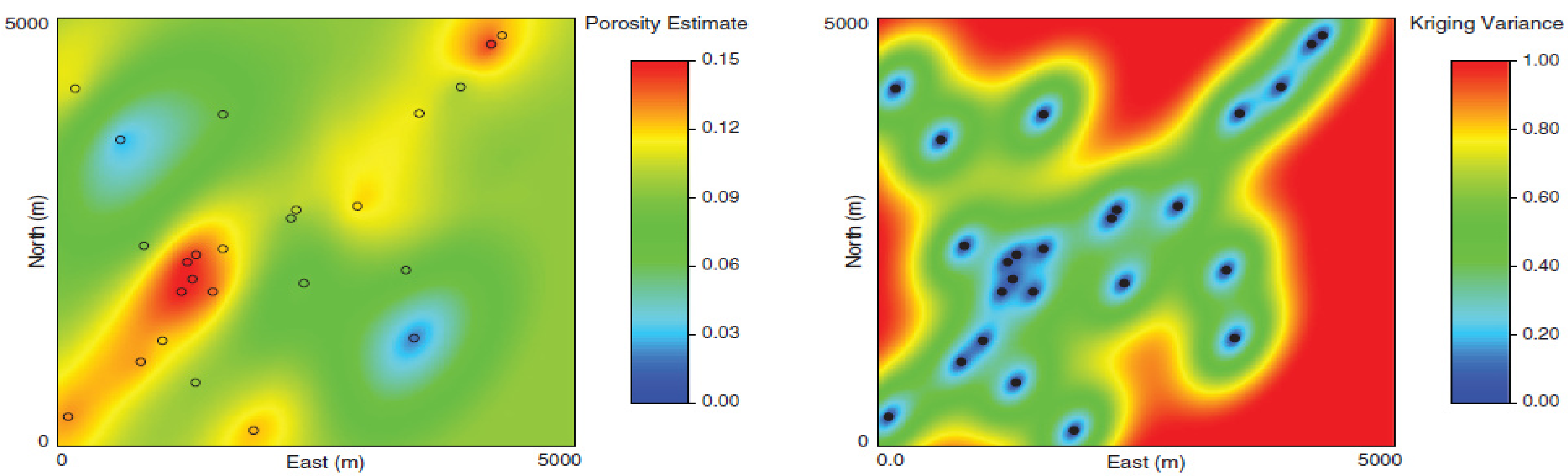
purpose

e research directions

- Reserves – potential issues drivers
- Avoid Making Decisions
- Use of a Single Realization
- Misuse of Ranking
- Models are Frozen

tistics may not be the right method for reserves

- case for geometric criteria for resources and reserves classification
- eutsch and others (2007), understandable by the public, driven by experience
- eling decisions within a purely geostatistical approach may have significant, unexpected ir lts
- ugget effect is important and hard to infer
- uld use concepts of spatial continuity to calibrate geometric approaches
- concept of kriging estimates and estimation variance



Kriging estimates and standardized kriging variance for porosity (Pyrcz and White, 2014).

Geostatistics may be used to support a geometric reserves method.

tistical model decisions cannot be avoided

Making Decisions

n the null choice is a strong decision – we must always make a choice

- o Trend -> good quality reservoir away from wells fills the AOI
- o Training Image -> 2 point continuity and maximum entropy with optimistic flow
- o Reference Distribution -> preferentially sampled wells provide representative statistics
- o Facies -> porosity and permeability mixing throughout AOI
- o Correlation -> porosity and permeability are potentially independent

ter to make a decision then document and defend

n to:

- ely on a default
- ely on an implicit model assumption
- ely on a very general stationarity assumption

xplicitly make and document choices and integrate uncertainty if need

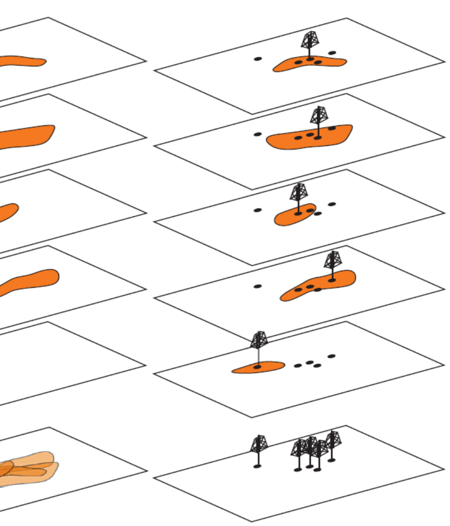
stical uncertainty requires consideration of multiple ons

a Single (or Too Few Realizations)

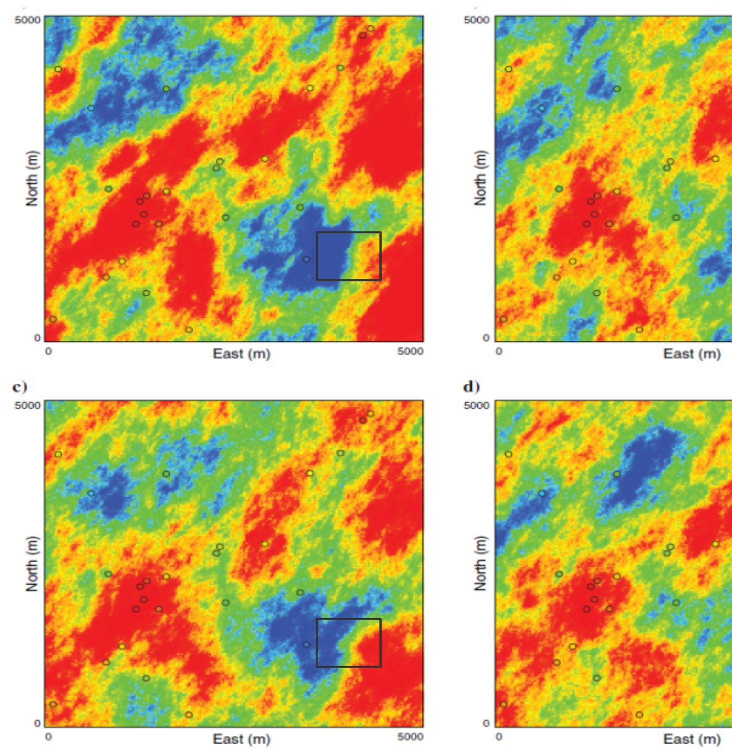
t consider scenarios and realizations jointly

ochastic islands

ufficient models for local distributions of uncertainty nore than H, M, L)



with single and multiple realizations
cz and Deutsch, 2014).



Multiple porosity realizations (Pyrcz and

– Integration of multiple realizations to evaluate joint u model

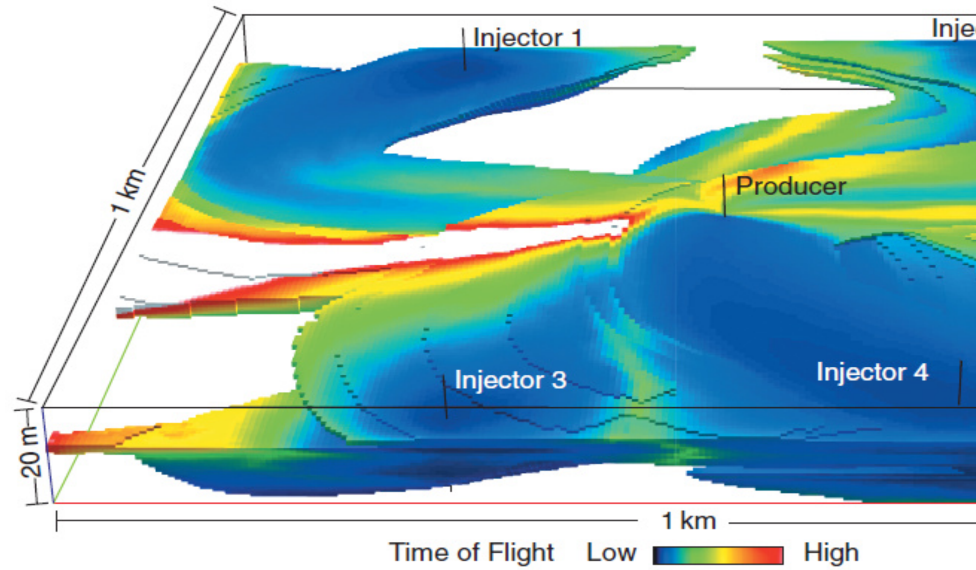
Results in global optimum vs. “L” suboptimal re

aluate uncertainty and optimize decision making jointly over realizatio

tistical ranking should be avoided or used with car

anking

- el ranking is the use of an efficient proxy to r realizations and to select realizations for the plete transfer function
- king precision is variable
- el ranking is only valid for the specific ranking ria
- anks are “sticky” and abused
- king criteria must be documented with rank es
- king must be repeated for a new question
- en transfer function is “fast enough” apply all els



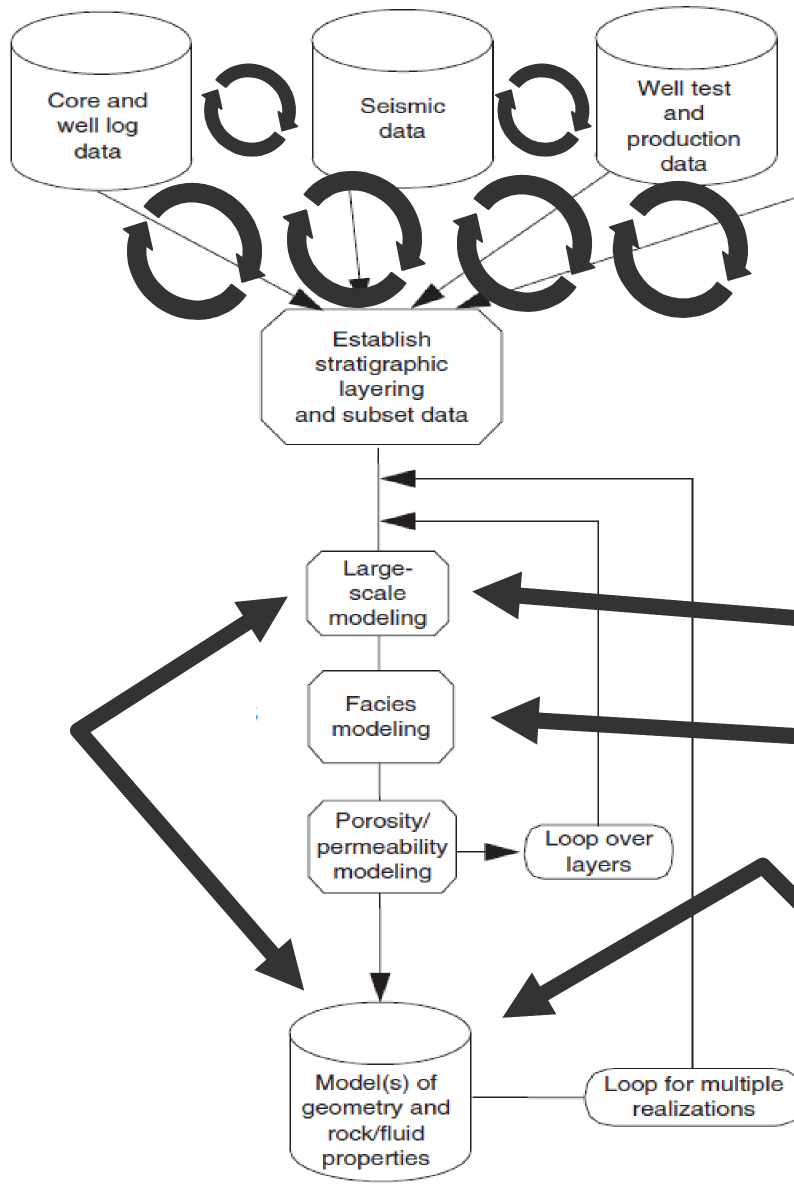
Time of flight based on streamline simulator for m
(Pyrcz and Deutsch, 2014).

When possible use all realizations and calculate uncertainty on-the-fly

tistical models are living assessments of reservoir

hould Either be *Disposable* or
n

- not freeze the reservoir model
- ew information
- ew Project Objectives / Questions
- eling is empirical
- *lens* to help understand the reservoir
- p-down, fit for purpose approaches
- reservoir model is not often the final product
- *ecision support* is the product
- rkflows must support the concept of the evergreen
del.



The geostatistical model is primarily a tool for decision support.

erstandings Conclusions

ves have different drivers

ot avoid decisions

tainty through multiple realizations

fall in love with your model

tistical reservoir modeling - talk outline

rted uses

non abuses

derstandings

purpose

e research directions

– Fitness has to be tested

– Purpose has to be specified

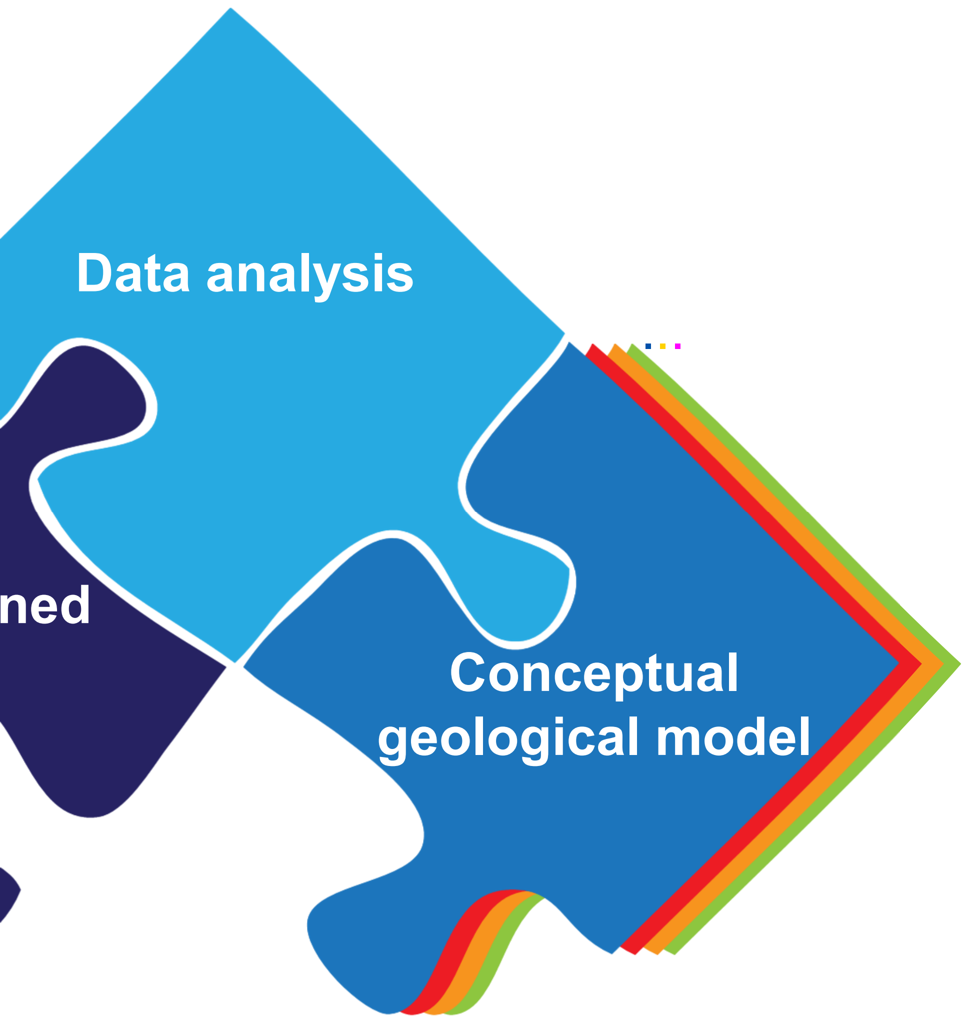
– Lack of fitness can be identi

tistical Reservoir Modeling – how is fitness obtaine

1. Linking the problem to the data
   - establish a plan, strategy and tactics
   - establish expectations
   - specify the uncertainties and identify ga
   - anticipate changes (to the problem and/

this defines what actions should be taken
criteria against which results from the r
products can be judged

tistical Reservoir Modeling – how is fitness obtaine

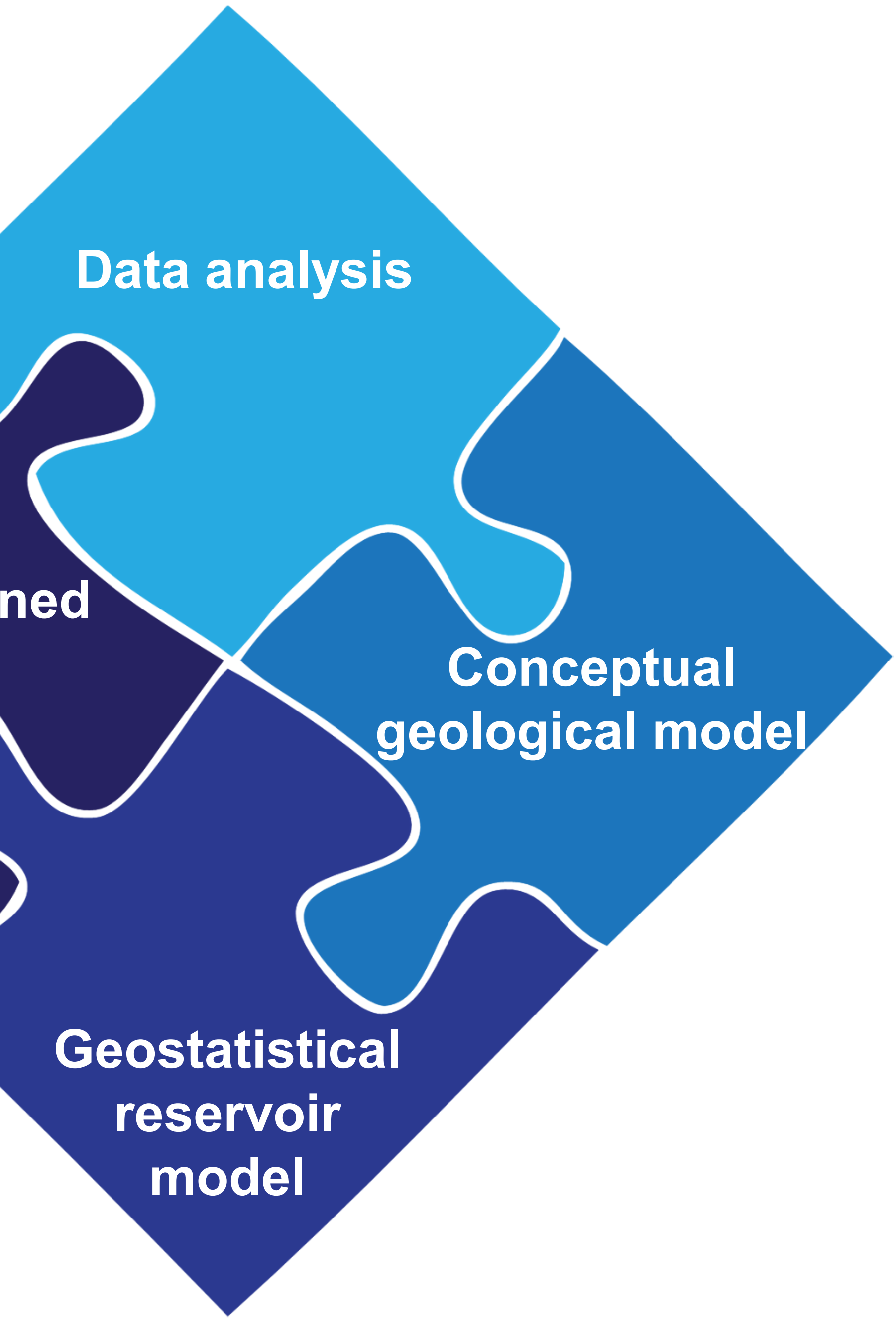


2. Integrating the data with under
geological concepts

- are observations consistent with expect
- how many degrees of freedom?
- analogue examples?
- known knowns…known unknowns…

*this constrains the reservoir model w
understanding of the geology and the e
scenarios we're dealing with*

tistical Reservoir Modeling – how is fitness obtaine



3. Exploring parameter space thr geostatistical reservoir modeling

- can we satisfy the input conditions?
- where are compromises made or expec
- can a response be measured to impact

this integrates our knowledge of the data of the uncertainty space and helps us nav solutions that are underpinned by s

tistical Reservoir Modeling – how is fitness lost?

1. Decoupling the model from the

   – statistics from data alone is not sufficie

   – quest for objectivity is alluring but misle

   – regions and trends from geologic mapp critical

   – data driven extrapolation is not typically

   – statistics alone is not sufficient …even t be convinced otherwise by the colourfu able to produce

tistical Reservoir Modeling – how is fitness lost?

2. Losing sight of the goal
   - …or never having a view of it in the first
   - modeling choices all rely on understand

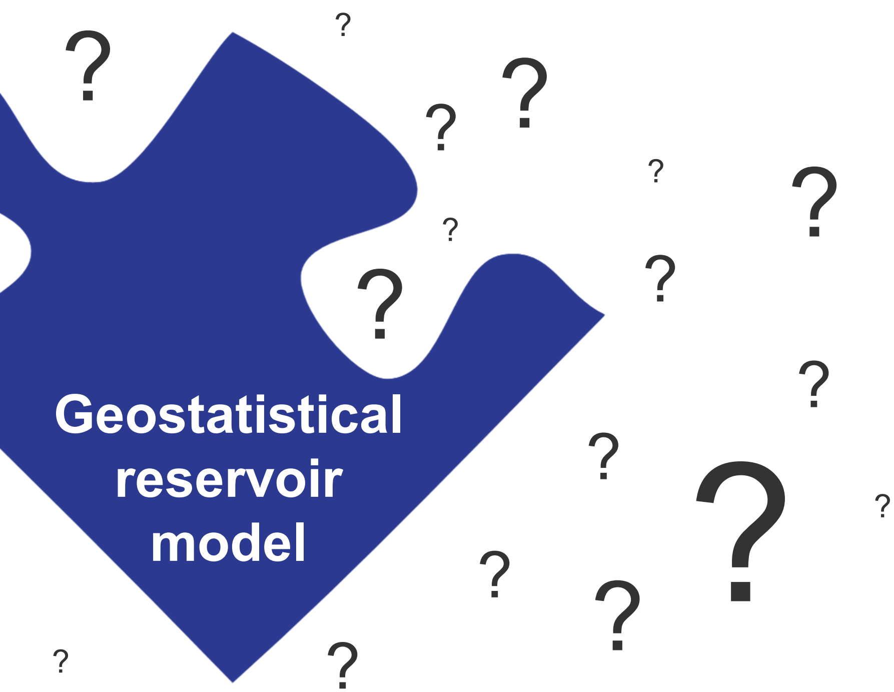
ising the limits of reservoir modeling…do we?

re Our Examples, and Why Are They So Difficult to Come By?

ain wrecks happen, but where are the loop backs?

nitations in documentation and corporate memory, and success cultur

uses are often traced back to (1) fundamental model inputs (inferenc
w heterogeneity (reproduction).



- *we think we know the cure, b*
  not very good at self-diagnos

Purpose Conclusions

- ng linked to data and projects goals+
- by conceptual geologic model
- rained by limitations of modeling methods
- an eye on the goal

tistical reservoir modeling
k outline

rted uses

non abuses

derstandings

purpose

e research directions

– More geologic realism

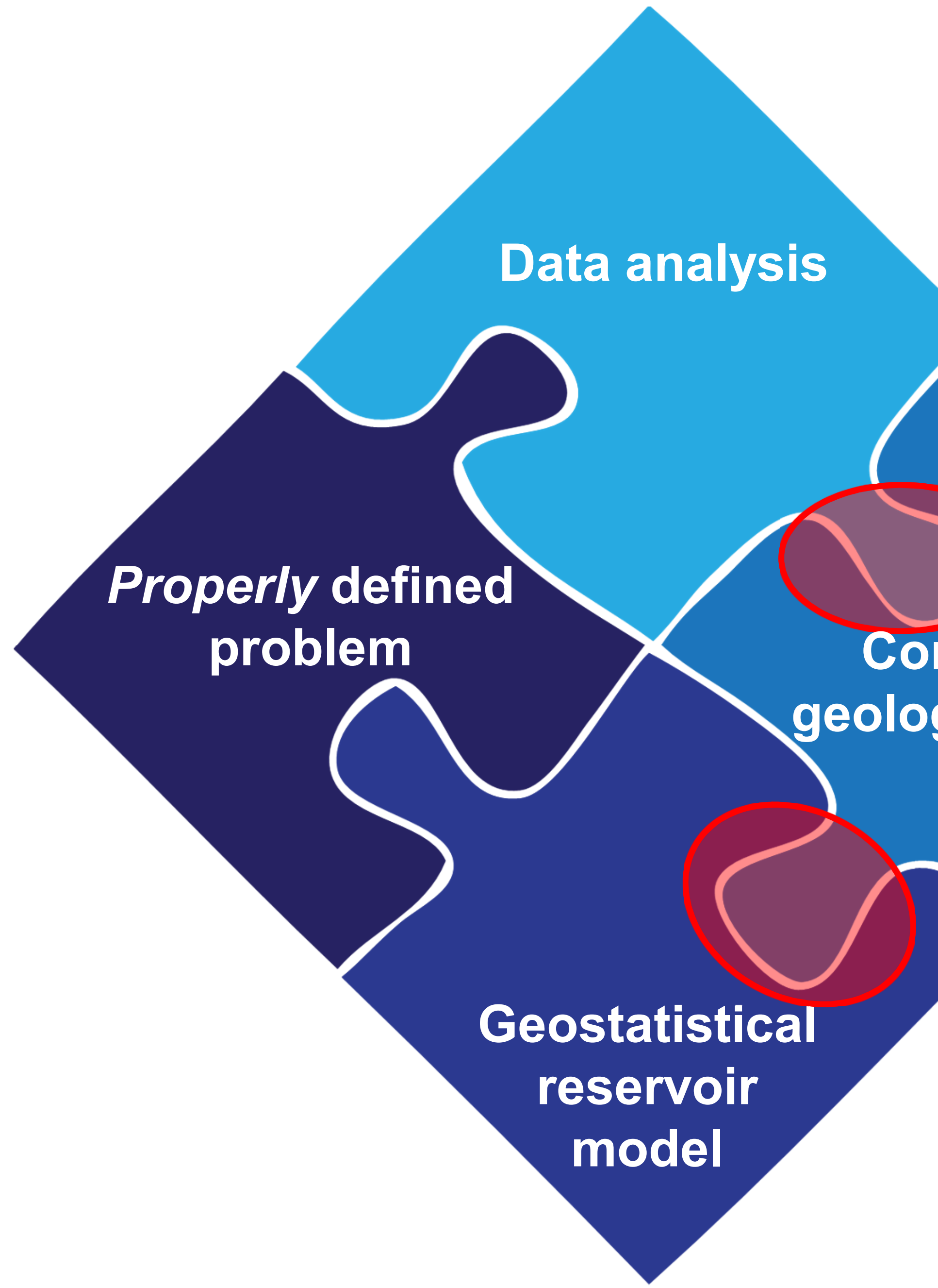
– More empiricism

– Advanced integration

– Improved Uncertainty Mode

research directions

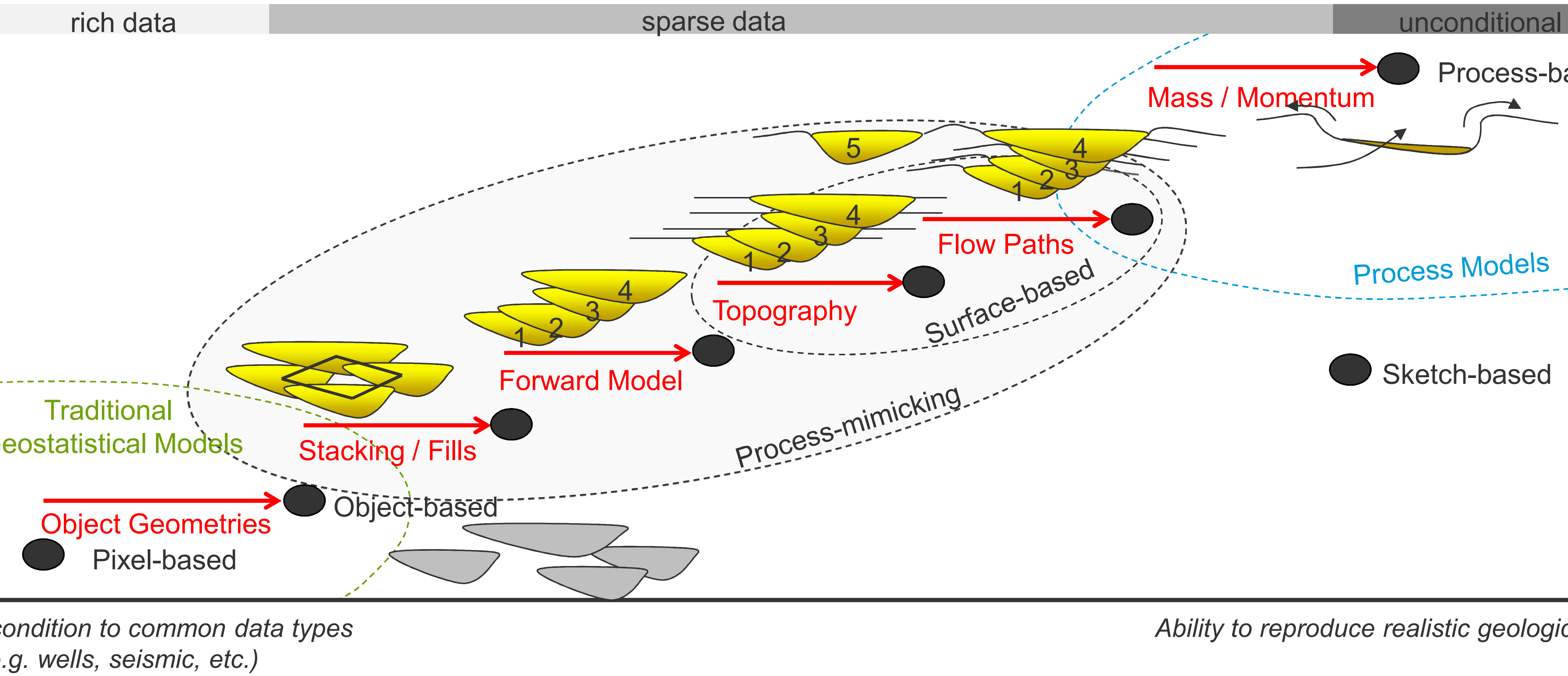
active research in order
ve reservoir
g processes



tistical models can incorporate process informatio

logically Realistic

ortunities through the improved integration of geological process information



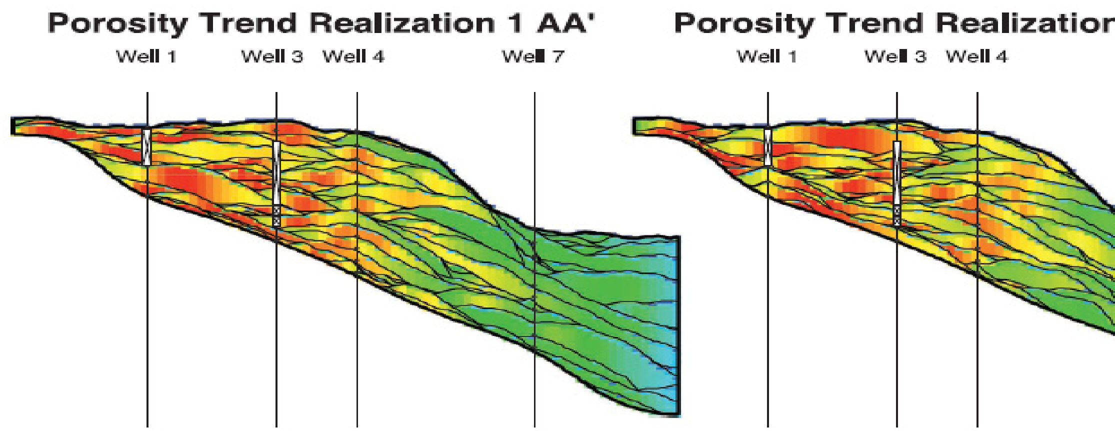
Continuum of geological process-based modeling (Pyrcz et al., in press)

There is a continuum of opportunities to improve geologic realism.

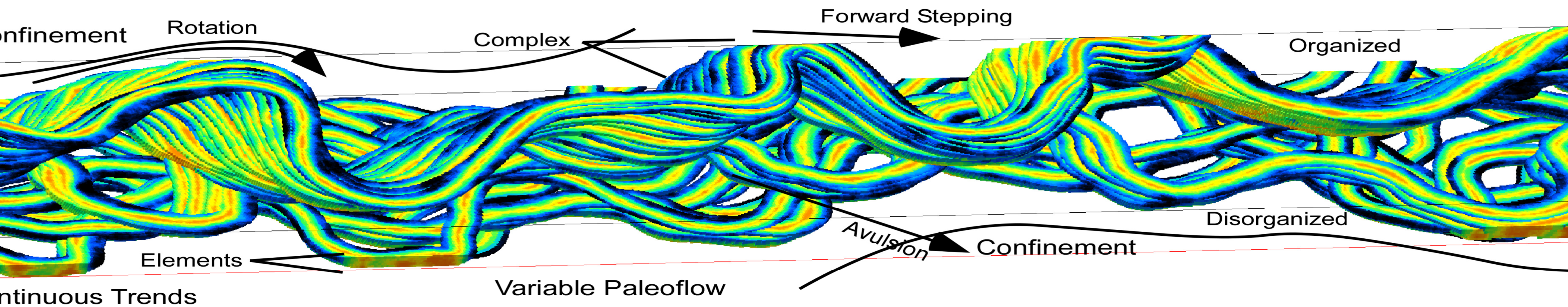
stical modeling with event-based / process-mimicking

ologically Realistic

- turing geologic rules in a “forward statistical modeling method”, object and ace-based methods
- ybrid modeling, event-based modeling, ocess-mimicking
- es are intuitive
- ificant increase in geological realism
- onditioning limitations similar to object-sed methods



Continuum of geological process-based modeling (Pyrcz e

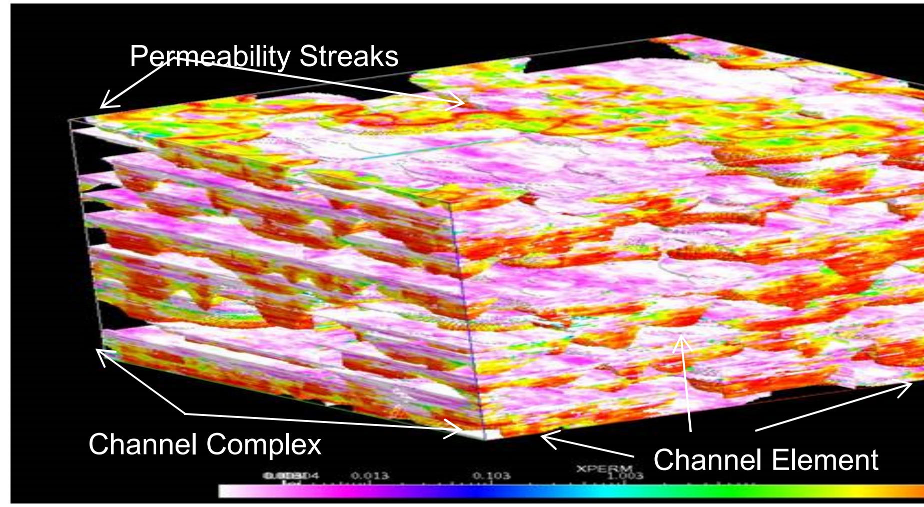


Example of Process-mimicking Deepwater Slope Valley Model (Pyrcz et al., 2012)

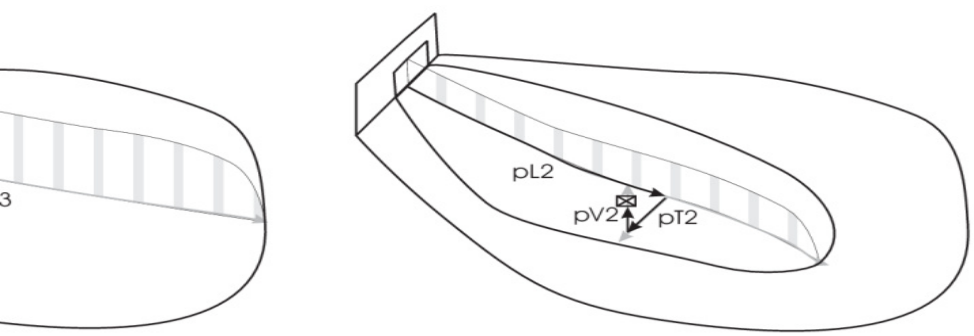
stical workflows can rely on a greater degree of empiricis

piricism

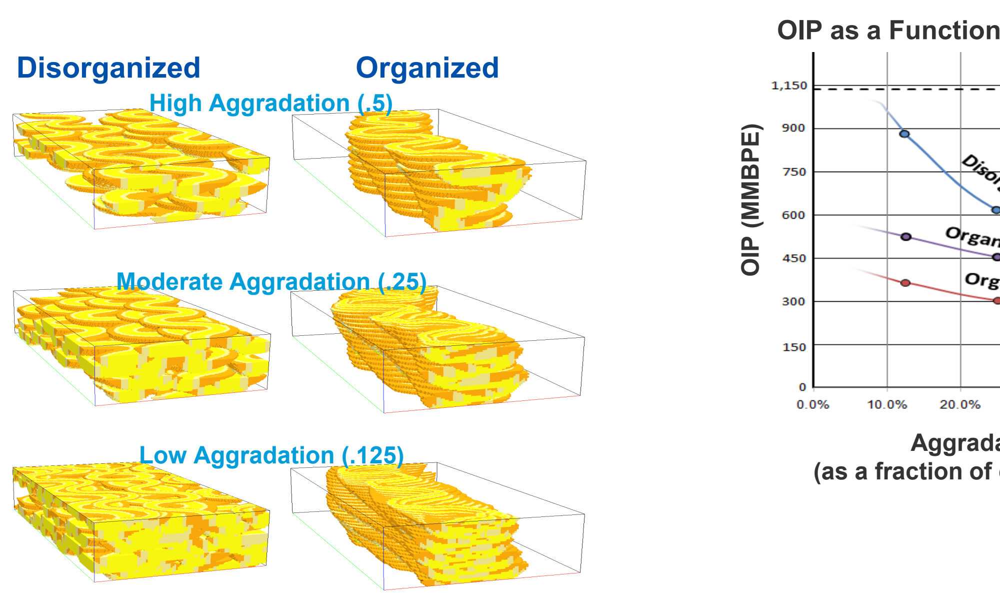
- ing, mitigation in presence of rogeneity / connectivity risk
- down modeling
  - crementally add details from large ale to small scale
  - etermine require level of complexity to eet project objectives



Permeability model from a deepwater disorganized channe



onal coordinates for 2 orders of deepwater lobes (Pyrcz et al., 2005)



Empirical study on the impact of DW channel t

Methods to explore models and learn from them.

tistics with advanced integration

d Integration

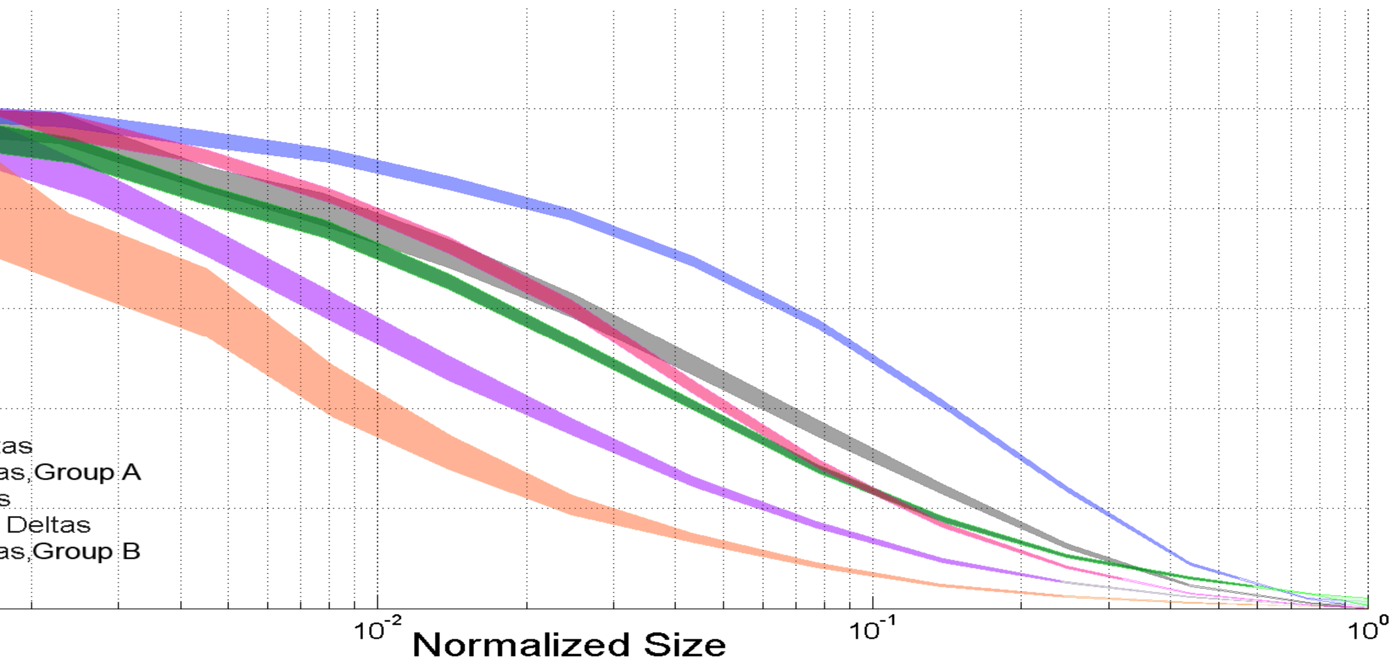
statistical quantification from earth scientists

ompensational Index

pley-K Function

cunarity

rtunity to integrate these new measures



or different types of deltas (Baumgardner, Perlmutter and Pyrcz, 2012).

Amazon delta (image by Sarah Ba

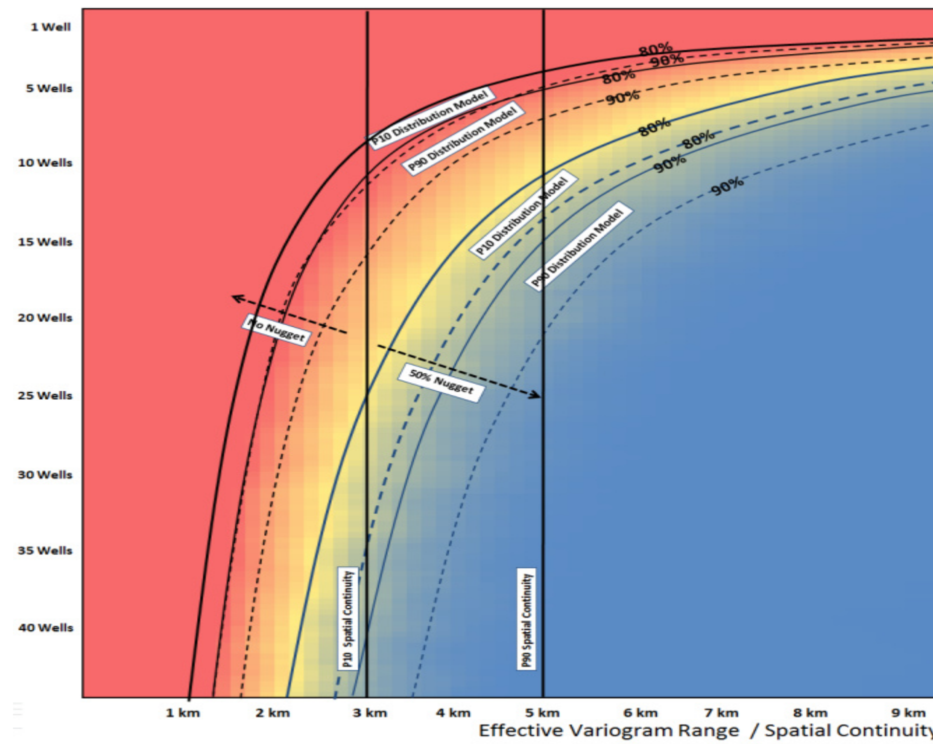
Pechora delta (image by Sarah

Quantitative geology is challenging modelers.

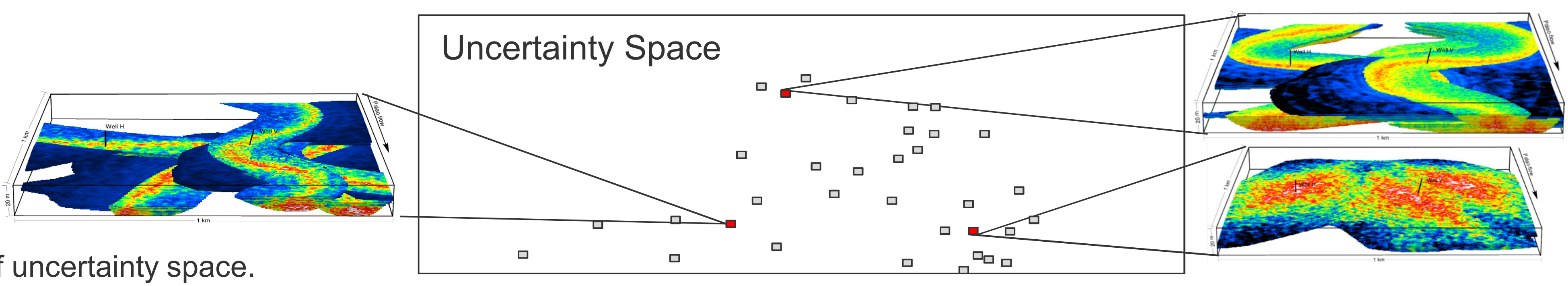
tistical approaches with improved uncertainty mod

Uncertainty Models /
ty Space Visualization

- ntitative methods to determine parameter ertainty
- patial bootstrap, conditional finite domain c.
- uced dimensionality visualization of model arity (Caers, 2014)
- nables analysis of the uncertainty space, ustering, ranking



Response surface for block uncertainty (Pyrc



f uncertainty space.

Learning from the uncertainty space.

Research Directions Conclusions

- s could be more realistic and integrate more information
- could be asked of the models
- e fundamental pillars remain
- nditioning to data
- terogeneity reproduction based on quantification
- certainty modeling through multiple scenarios and realizations

sions

- e optimists.
- s, there is misuse.
- s, more could be done.
- s, there are new opportunities.
- st evolution, not a revolution
- ostatistics is a practical approach that latter obtained theoretical unde
- d if you go something better – add it to the tool box

yledgements

on Energy Technology for supporting this work and permission
n

voir Modeling R&D

onika Kaplan

c Stratigraphy R&D

rgan Sullivan, Bruce Power, Jake Covault, Zoltan Sylvester, Brian Wil

utational Stratigraphy R&D

o Sun

voir Modeling Technical Service Team

dy Palfrey, Mike Hogg

ents *******slide to be removed**********

are the abuses, misuses and misunderstandings in geostat res

., stationarity (it's a decision), maximum entropy (pixel based), huge u
und parameter requirement (object-/event-based: shapes, sizes, rules
ussian principle, scales/volume support (mind the gap), tickling uncer
lizations rather than really testing it with scenarios; change cell size b
tistics. **State the potential cost associated with each issue as a co
nt on the slide**

sonable expectations: won't look like google earth (sometimes
ometimes we don't); black box; management seduced by colo
't create data, only uses what goes in (it's not magic)

*o*stats for a reason – has to be some measure of control and p
standing…yes, it can be overly constrained, but try not doing th
hat happens…

stical Modeling – fit and unfit for purpose

- Limitat

*********slide to be removed************

(now and work arounds) – unfit – why? - ways to avoid

ologic interpretation, geologist in a box,

tistical representativity, Stationarity, Regions, Mapping

sed on limited inputs + intrinsic assumptions that are often under-appr

ly geologic realism – limited statistics, limited constraints, temporal

ck swans – you get back what you put it - Limits to prediction – away

l is simply a function of trend and spatial continuity not concepts of ph

ability to capture unexpected features / emergent features / convex op

erequisites – hinge on the framework, trends, regions