

Stochastic Fault Network Simulation with Variable Connectivity: Application to a Compartmentalized Reservoir Affected by Large Structural Uncertainties*

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Search and Discovery Article #41716 (2015)**

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Abstract

Several oil and gas domains raise 3D seismic imaging challenges or are only imaged with 2D seismic lines. In both cases the shape and the connectivity of faults is subject to uncertainties which may be consequential for the determination of migration paths, trap geometry and reservoir compartmentalization. Stochastic fault network simulation aims at generating a set of 3D structural models honoring prior structural concepts and conditioned by interpretations made from wells and seismic data. This set of models aims at sampling the uncertainty space related to the fault network geometry and connectivity (topology is variable from one realization to the next and emerges from the simulation process). We apply this stochastic approach to a highly-uncertain and complex fault network at reservoir scale. The used dataset is composed of several wells and 3D seismic data that poorly image the reservoir. We show how the tectonic history and the structural style can be conveyed to a stochastic fault modeling system in order to ensure the simulation of consistent 3D fault networks. We also discuss the strategy to generate suitable spatial interpretations from 3D seismic data. We then use statistical analyzes to evaluate the uncertainty about the number of faults and the number of compartments in the reservoir.

References Cited

Cherpeau, Nicolas, Guillaume Caumon, and Bruno Levy, 2010, Stochastic simulation of fault networks from 2D seismic lines: SEG Technical Program Expanded Abstracts, v. 29/1, p. 2366-2370.

Julio, Charline, Guillaume Caumon, and Mary Ford, 2015, Sampling the uncertainty associated with segmented normal fault interpretation using a stochastic downscaling method: Tectonophysics, v. 639/1, p. 56-67.

Lallier, Florent, Charline Julio, Guillaume Caumon, Stephane Vignau, and Pierre Bergey. 2014, Structural uncertainties: Do we need a new paradigm for the seismic structural interpretation?: Second EAGE Integrated Reservoir Modelling Conference.

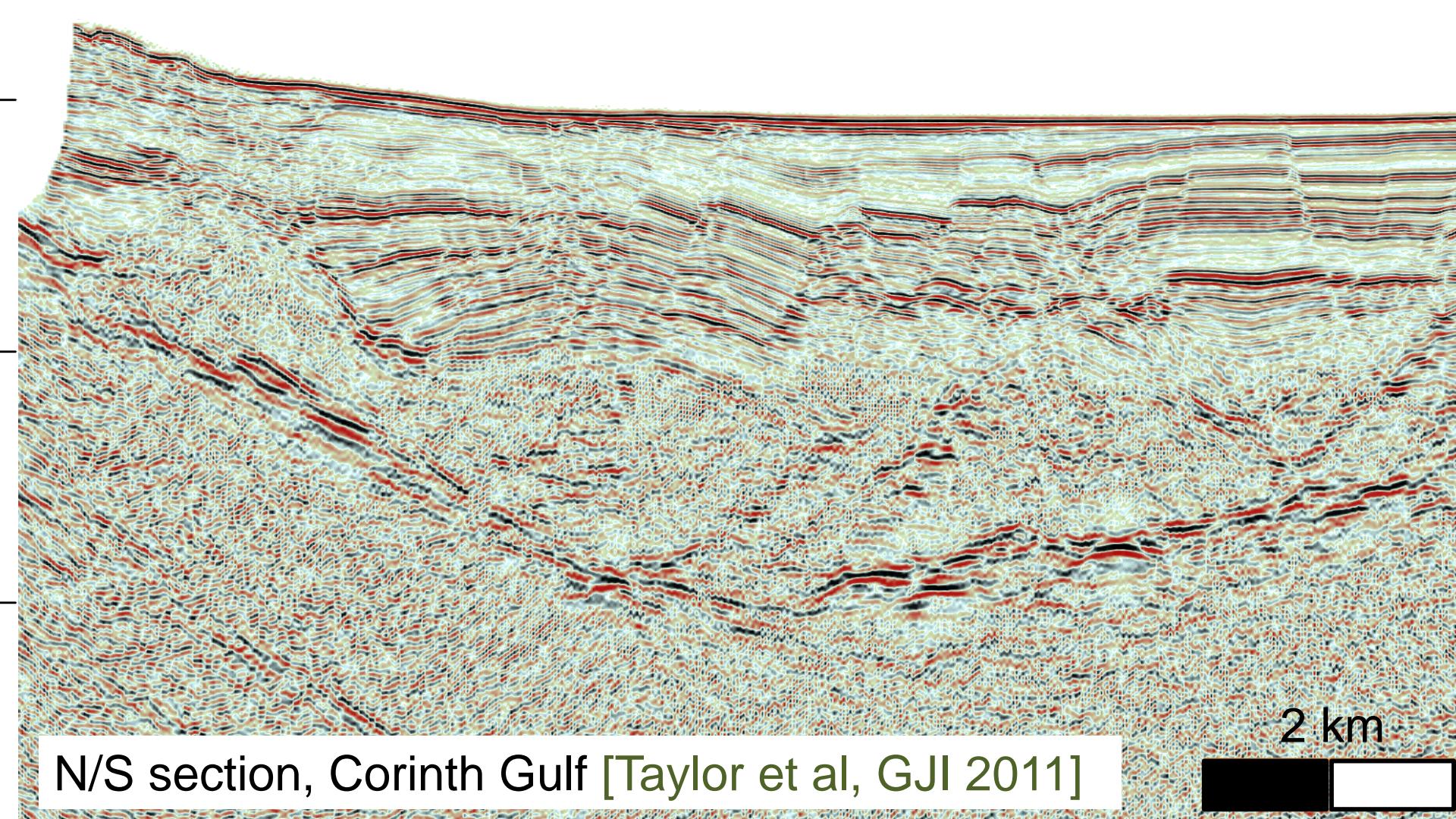
Taylor, Brian, Jonathan R. Weiss, Andrew M. Goodliffe, Maria Sachpazi, Mireille Laigle, and Alfred Hirn, 2011, The structures, stratigraphy and evolution of the Gulf of Corinth rift, Greece: Geophysical Journal International, v. 185/3, p. 1189-1219.

Stochastic Fault Network Simulation With Variable Connectivity: Application to a Compartmentalized Reservoir Affected by Large Structural Uncertainties



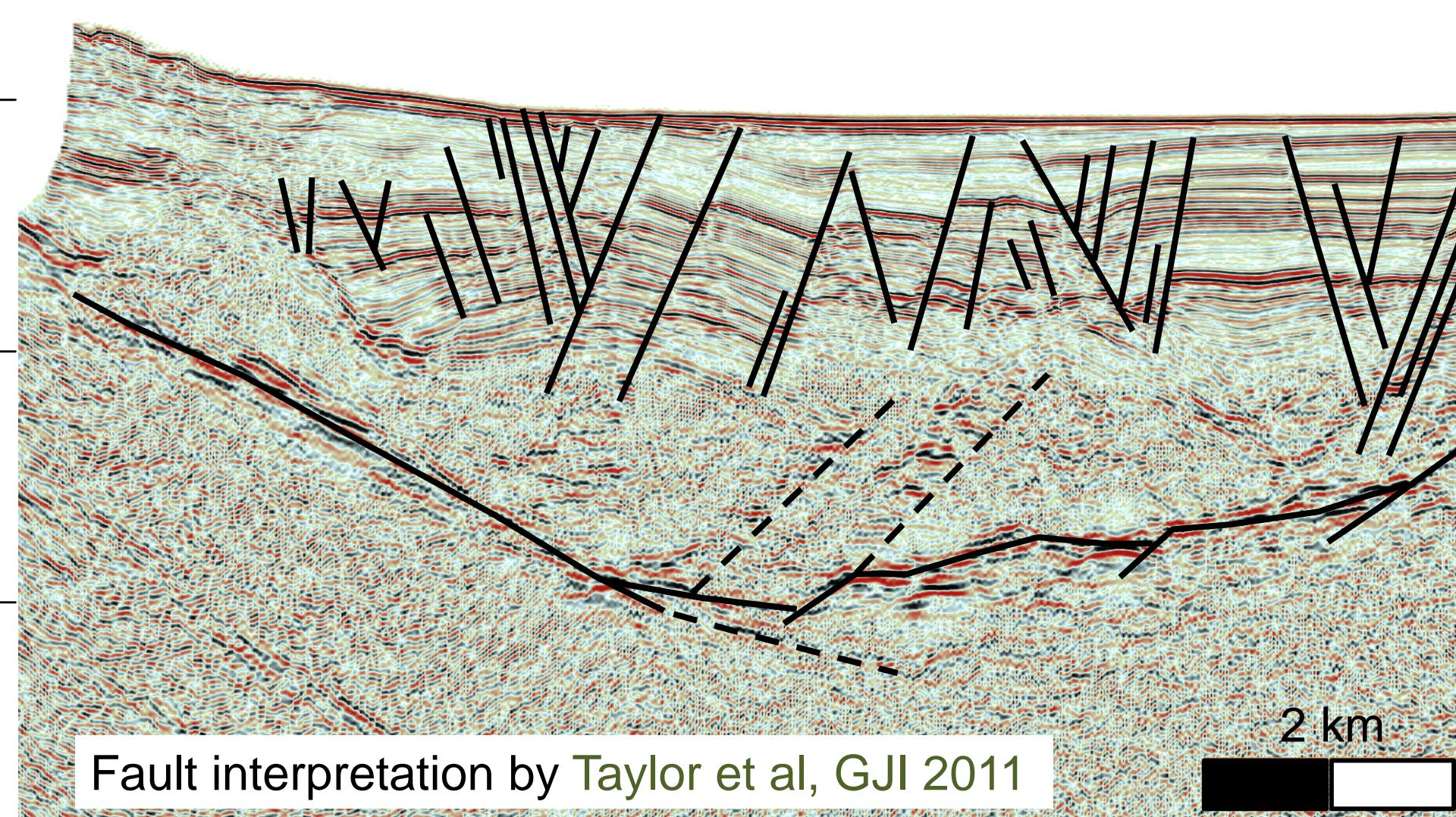
Charline Julio, Florent Lallier, Guillaume Caumon*
AAPG ACE, June 2015

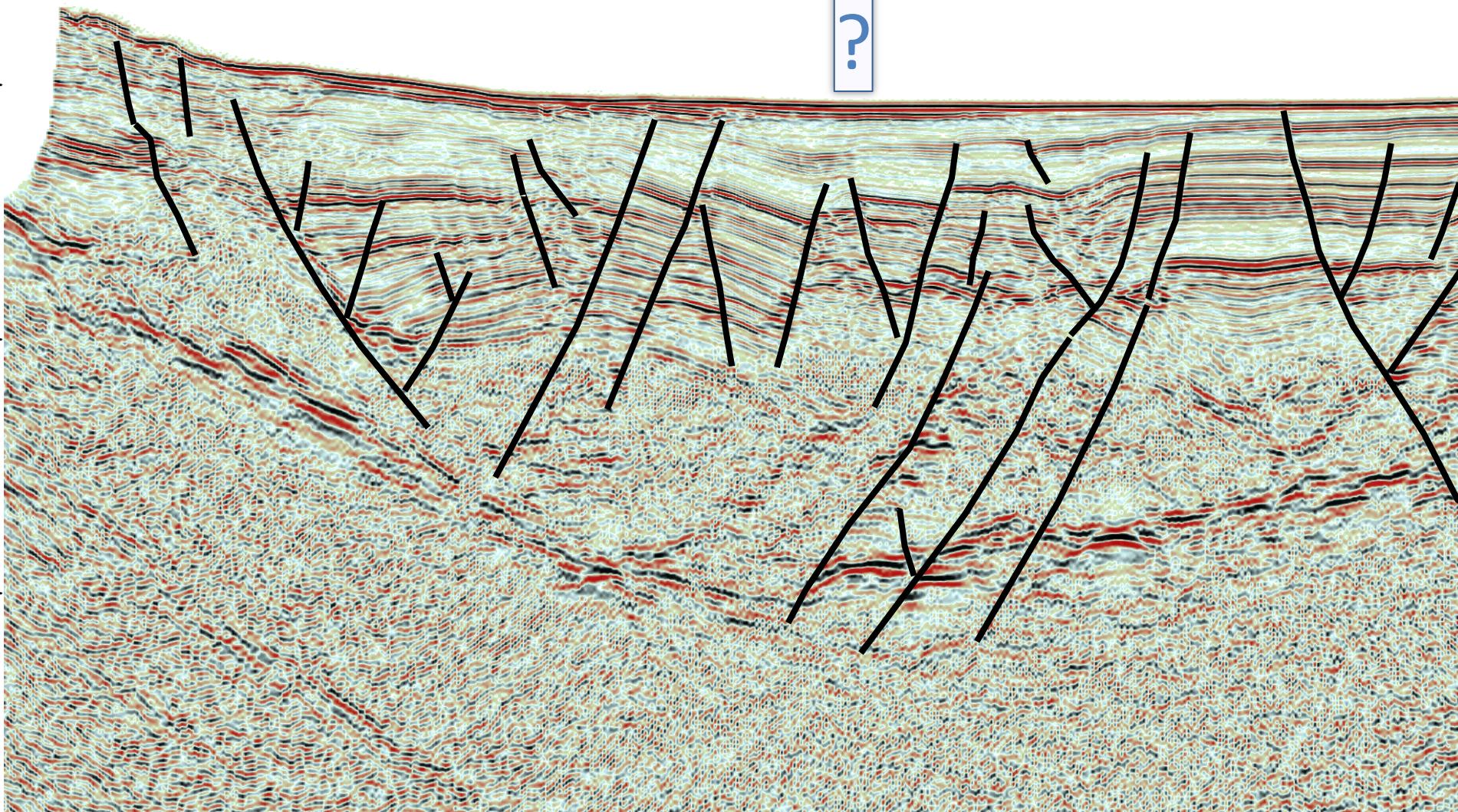


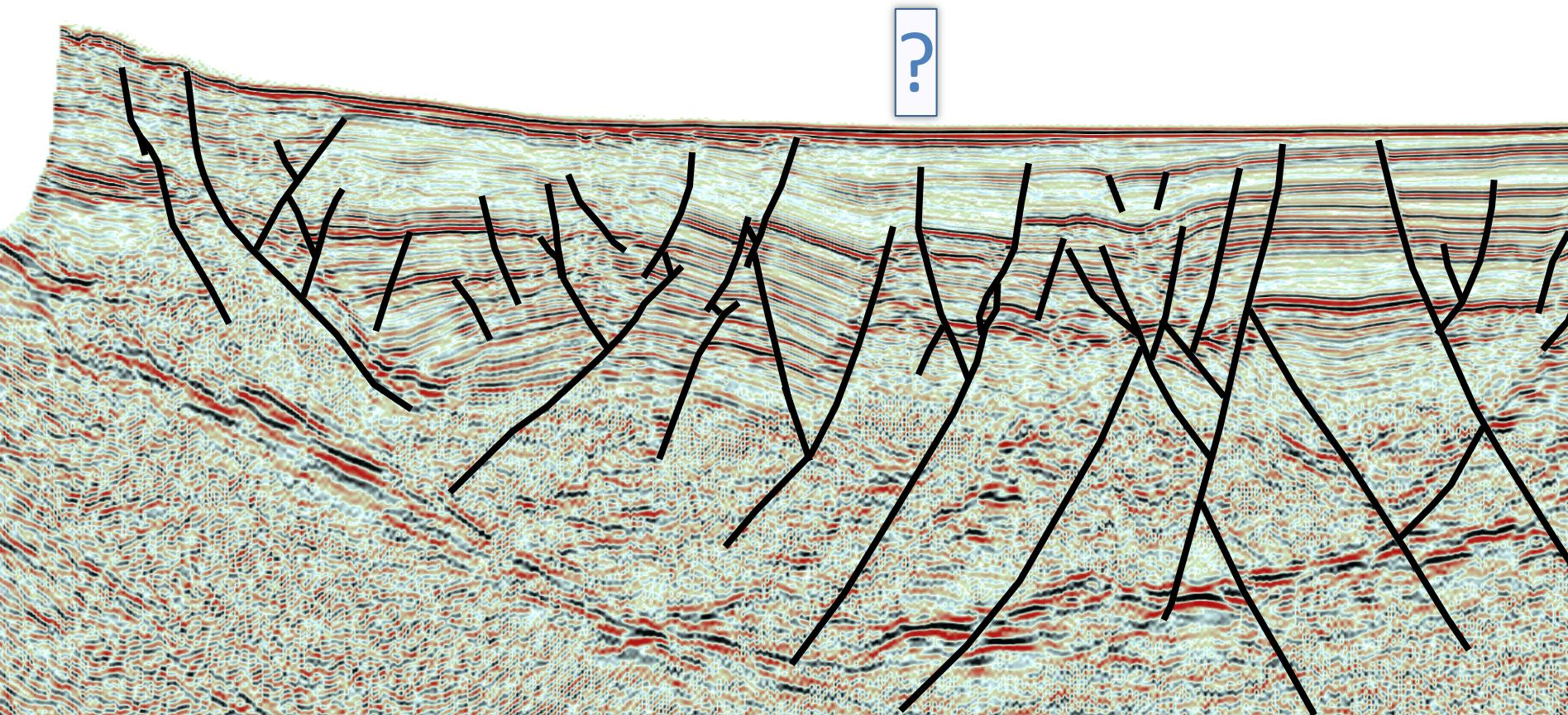


2 km

N/S section, Corinth Gulf [Taylor et al, GJI 2011]







Could interpretation be more objective?
What if scenarios ?

Sources of interpretation uncertainty

Processing

Type?

Hypotheses?

Parameters?

Measurements

Incomplete coverage

Limited resolution, averaging

Lack of contrast

Geological concepts

Appropriateness?

Repeatability?



Interpretation / Model

Geometrical + topological uncertainty

Geometry

[Abrahamsen, Geostats 1993]

[Lecour et al., PG 2001]

[Thore et al., Geophys 2002]

[Holden et al, Math Geo 2003]

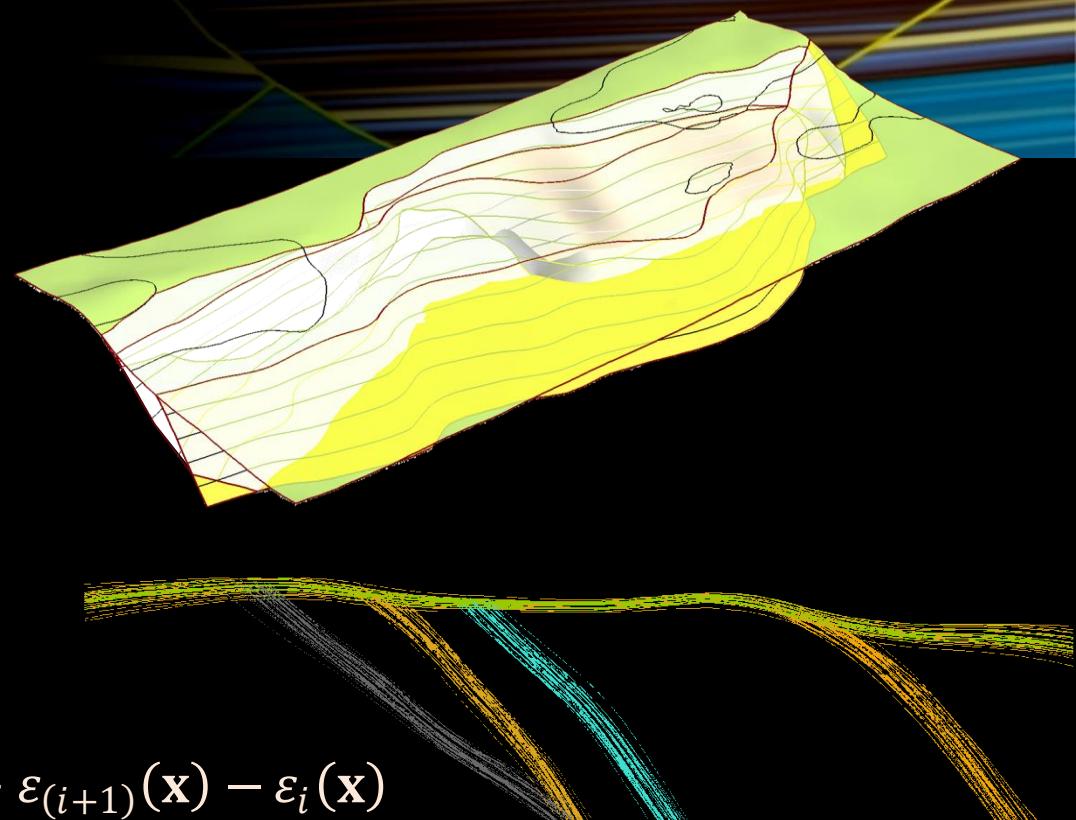
[Caumon et al, EAGE PG 2007]

[Tertois and Mallet, SPE 2010]

[Røe et al, Math Geosci 2014]

[Abrahamsen; Gringarten; Lallier; ...;

EAGE IRM 2014]



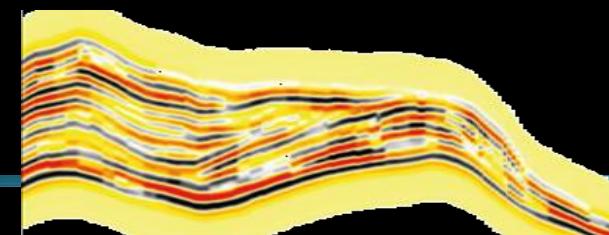
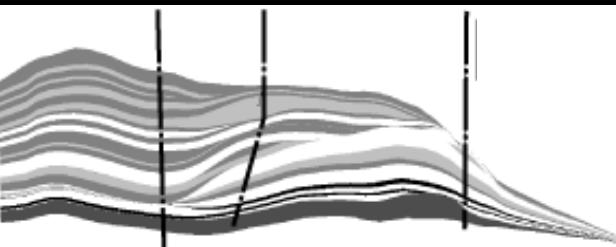
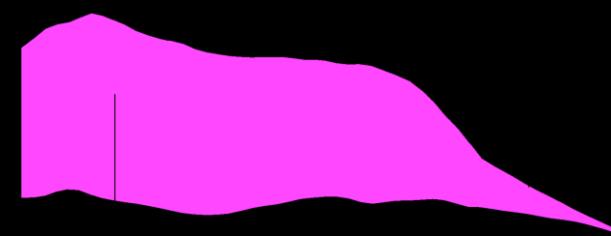
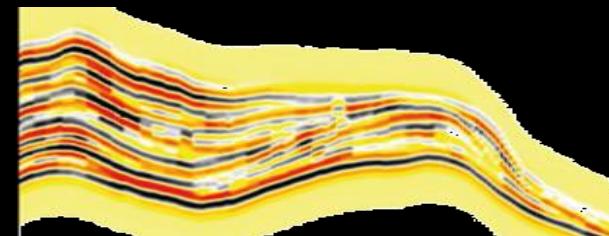
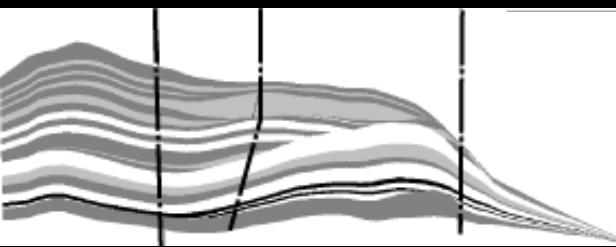
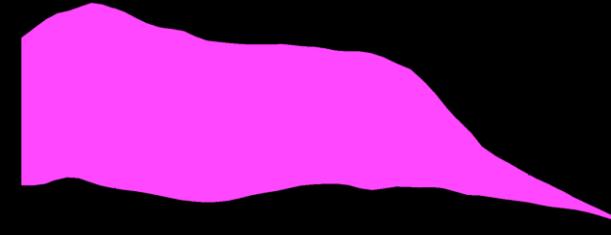
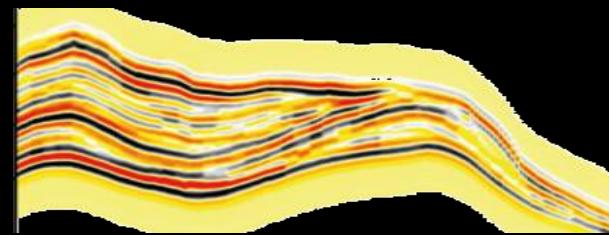
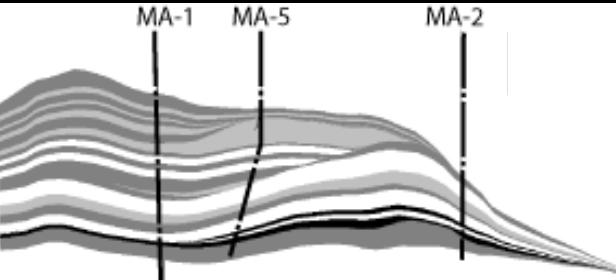
$$Z_{i+1}(\mathbf{x}) = Z_i(\mathbf{x}) + \sum_j a_{i,j} f_{i,j}(\mathbf{x}) + \varepsilon_{(i+1)}(\mathbf{x}) - \varepsilon_i(\mathbf{x})$$

Depth of Depth of Thickness
horizon $l+1$ horizon l trend

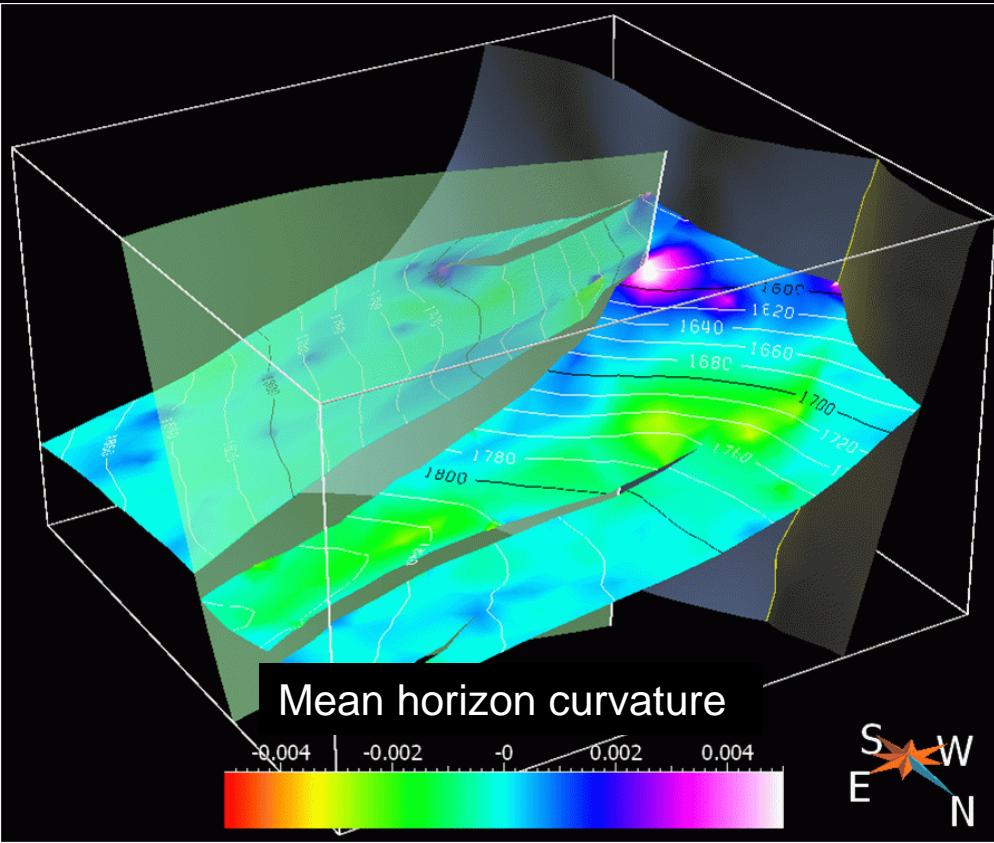
Depth Depth
error $l+1$ error l

Layer connectivity

[Lallier et al, GSL SP 2012]

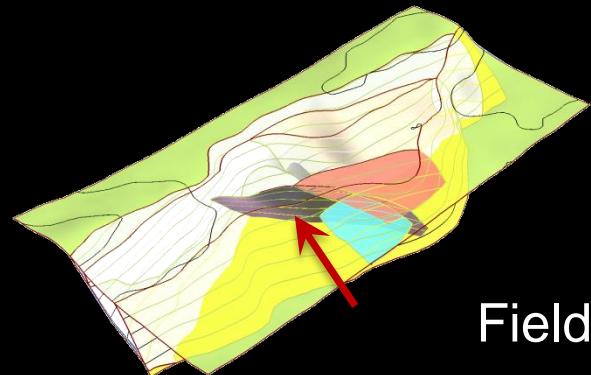


Fault extent and connectivity

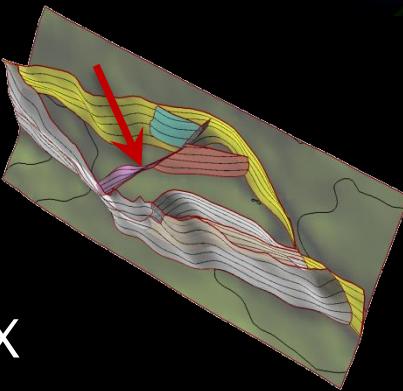


Imaging difficult at fault tips
and intersections

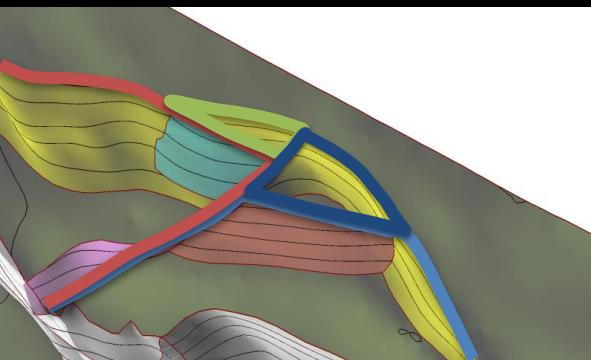
Fault connectivity : large-scale



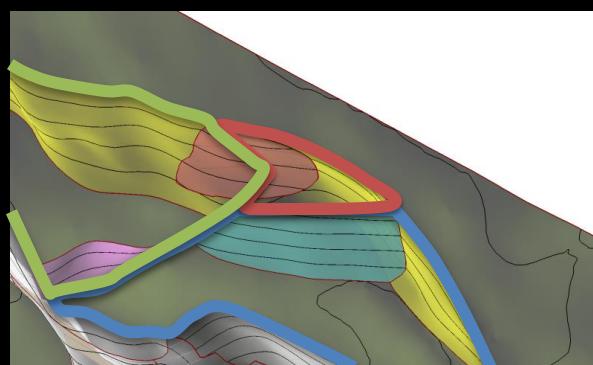
Field X



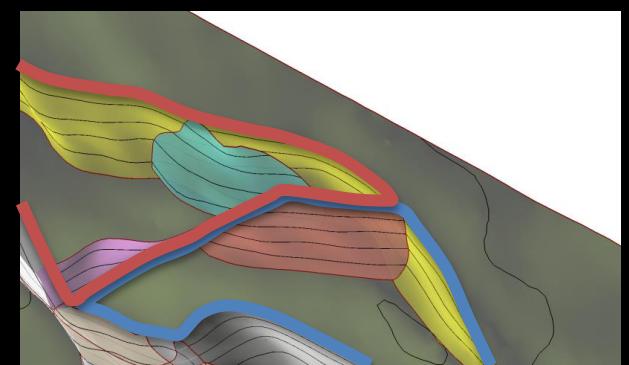
OOIP
Compartmentalization



4 compartments



3 compartments



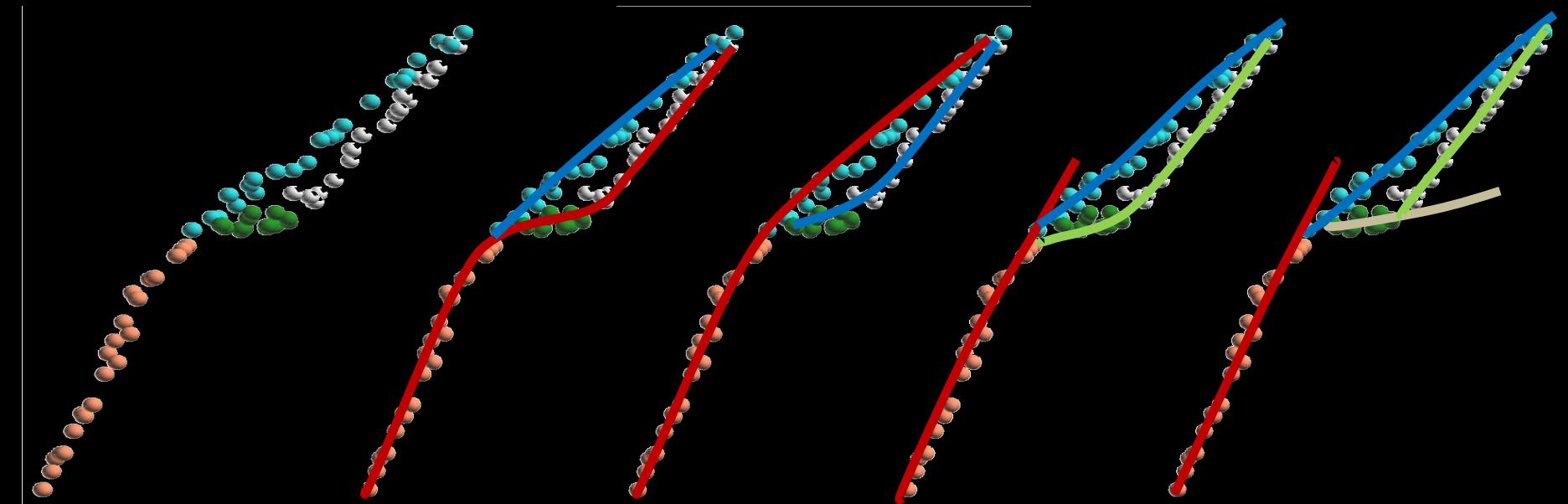
2 compartments

[Cherpeau et al, SEG 2010]

[Lallier et al, EAGE IRM 2014]

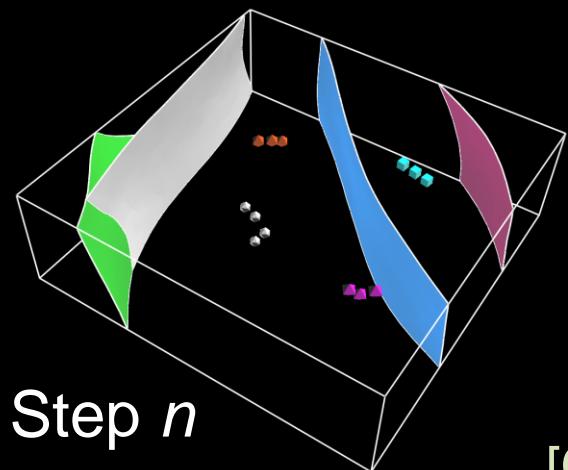
Fault connectivity: mid-scale

[Lallier et al, EAGE IRM 2014]



Field X

Sequential Fault Simulation



Data point
Drawing

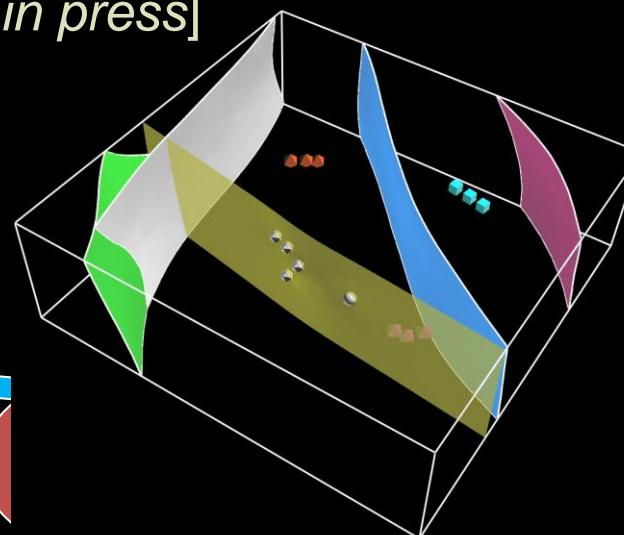
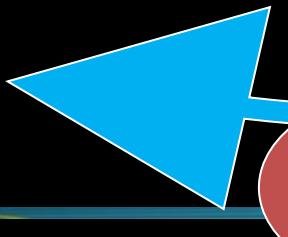
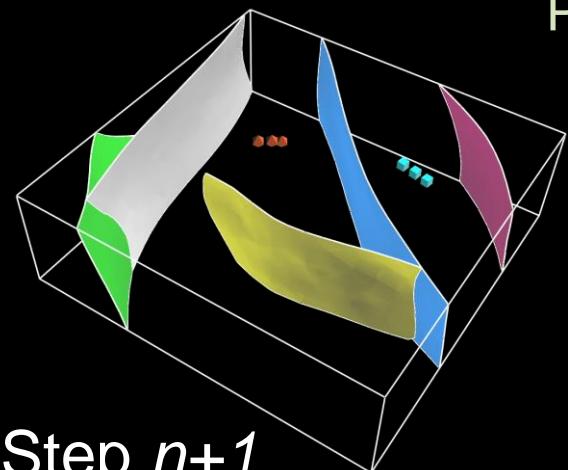
Orientation
simulation

Fault
nucleation

Data
clustering

Geometry
perturbation

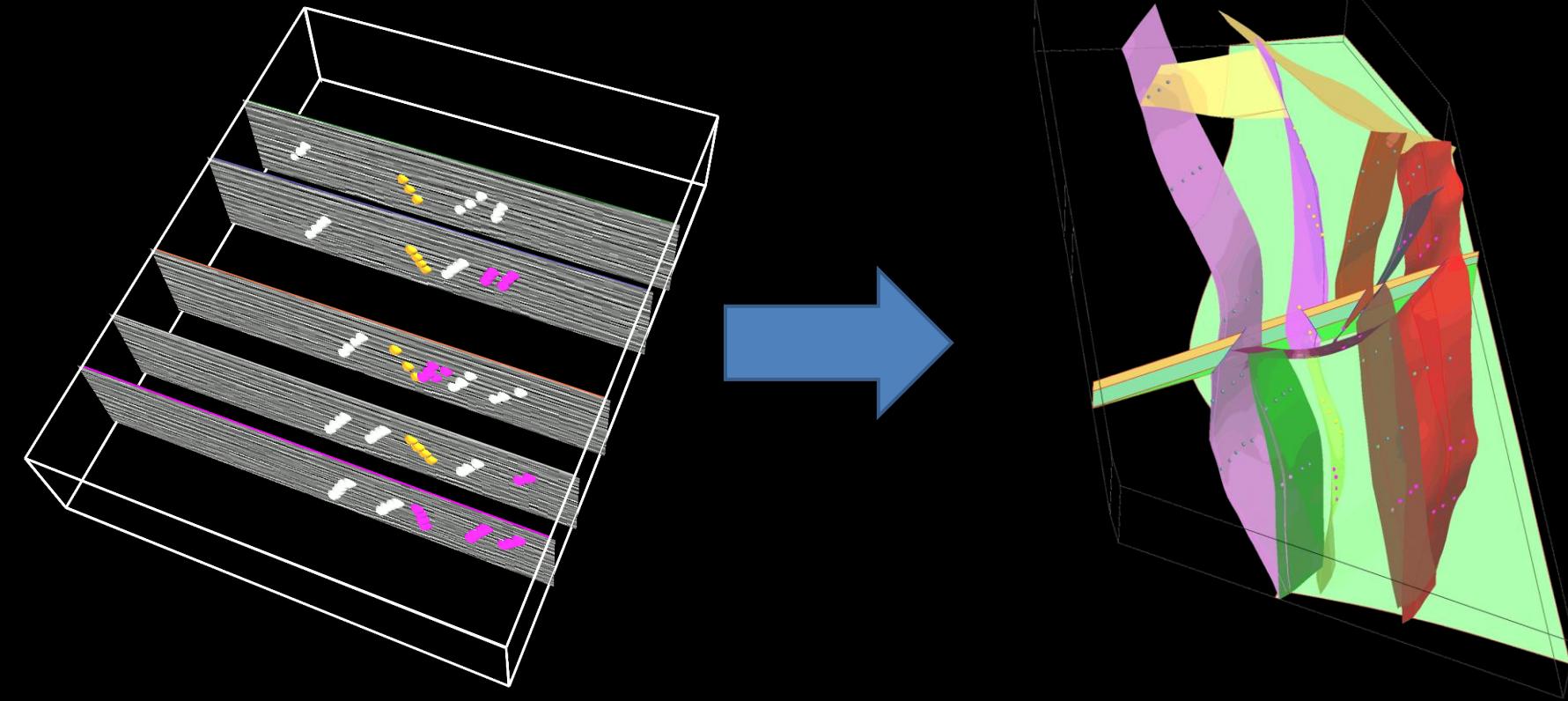
[Cherpeau et al
Petr Geosci, *in press*]



Step n+1

Topological uncertainty from sparse data

[Cherpeau et al, Petrol Geosci *in press*]



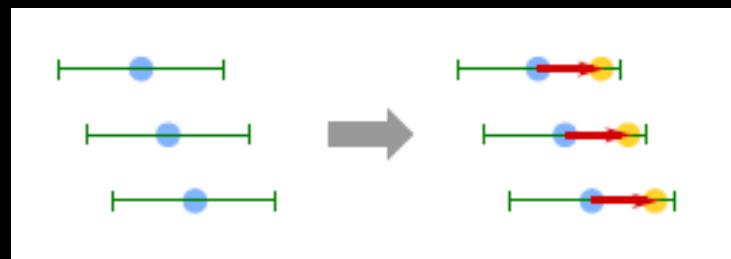
Sequential Fault Simulation: improvements

Account for deterministic faults and:

- Tip line uncertainty

- Position uncertainty

Account for pick uncertainty before data clustering

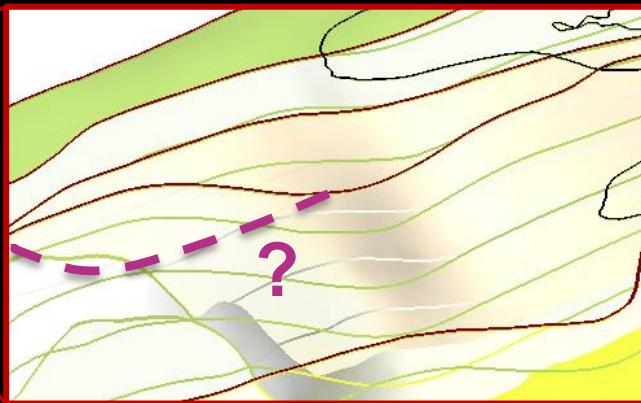


Reject faults when inconsistent with borehole observations

Fault connectivity: small scale



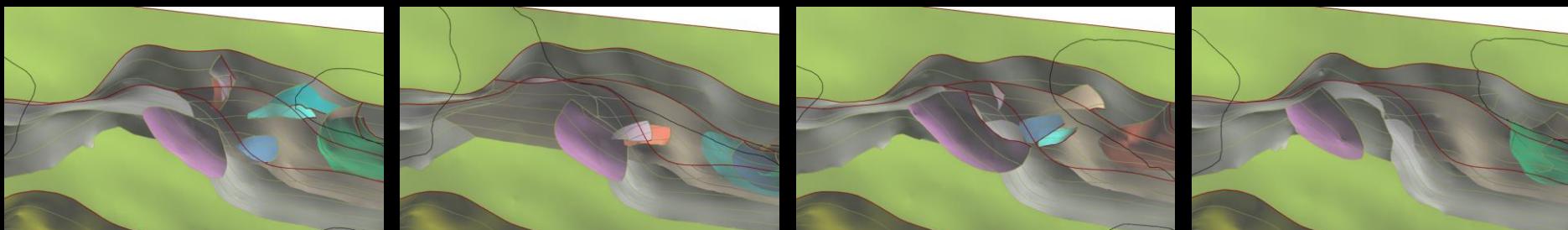
Field X



[Lallier et al, EAGE IRM 2014]
[Julio et al, Tectono 2015]

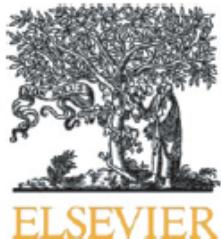
Tortuosity of an
interpretation → relay ?

Subseismic faults ?



Fault connectivity: small scale

Tectonophysics 639 (2015) 56–67



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journal homepage: www.elsevier.com/locate/tecto



Sampling the uncertainty associated with segmented normal fault interpretation using a stochastic downscaling method



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See also Julio et al, *Interpretation (in rev)* for impact on flow



Application to “Field Y”

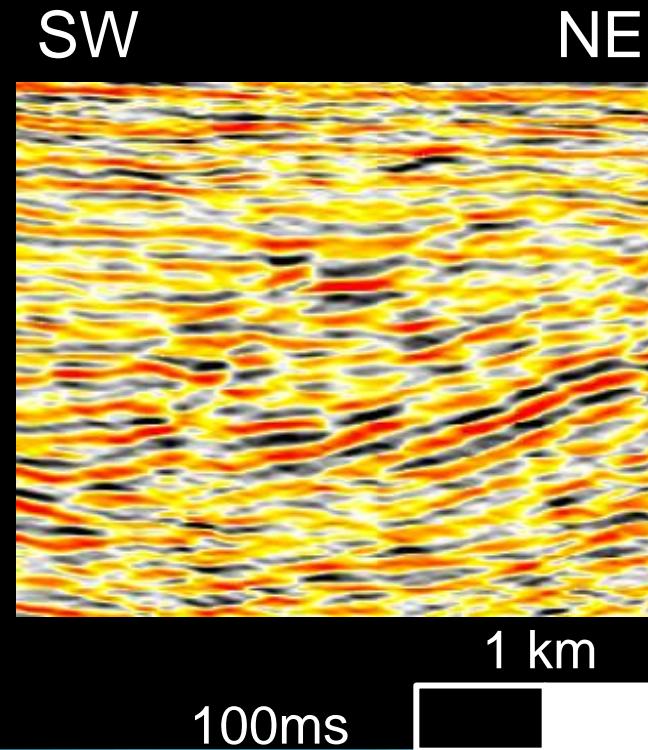
Settings

Graben, affected by three major tectonic phases

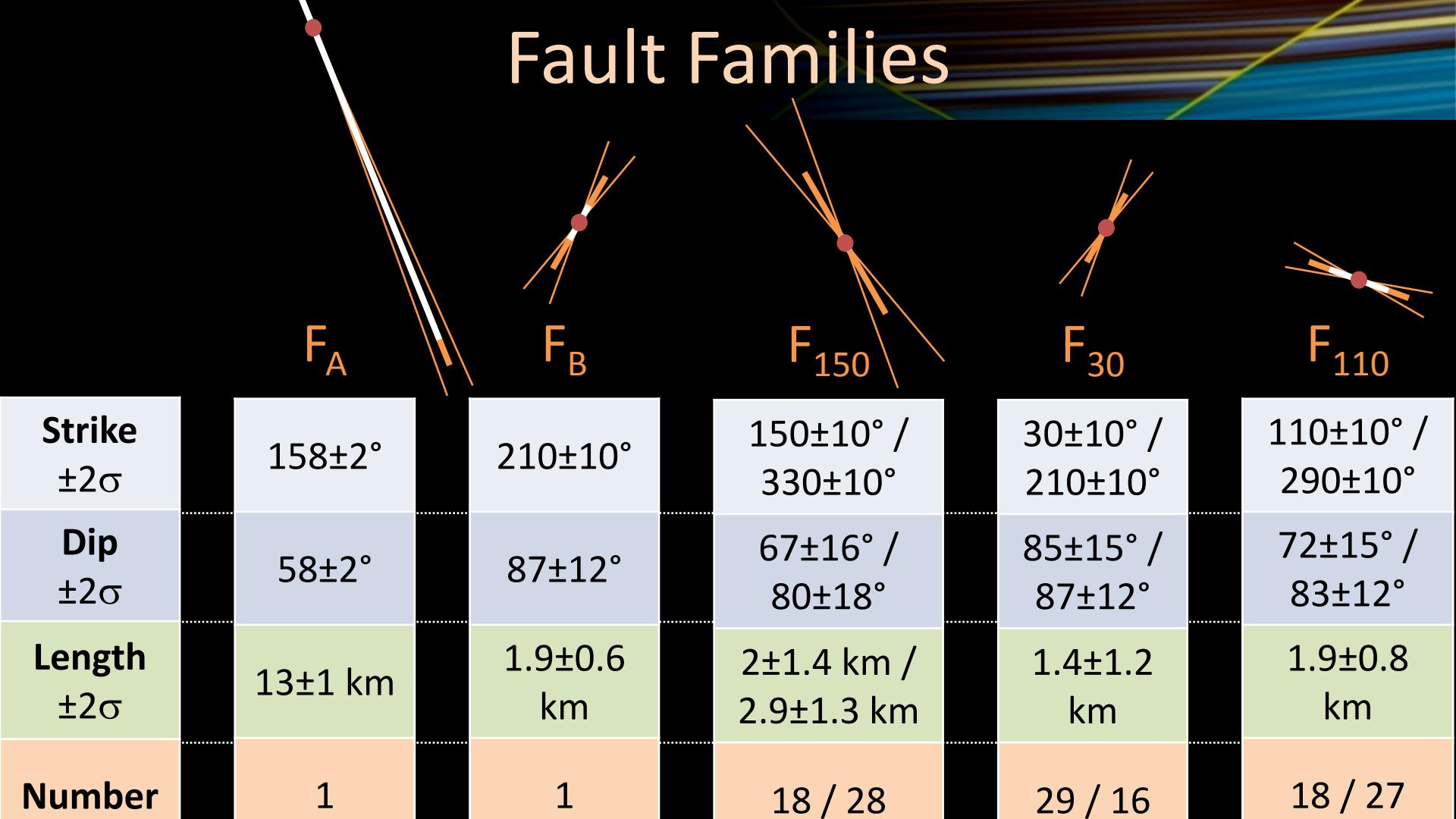
Fault imaging difficult in 3D seismic data

2 main interpreted faults striking
N158 and N 210, small uncertainty

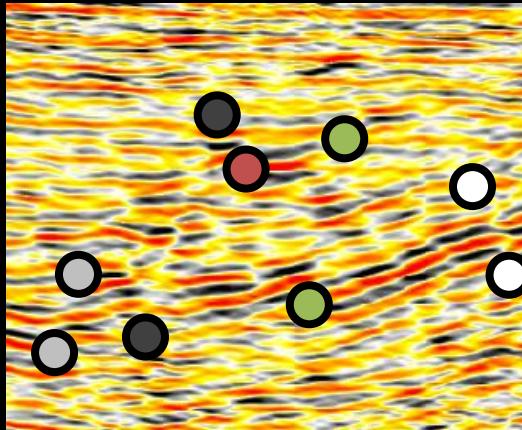
3 conjugate normal fault families
identified from regional knowledge and
regional analogs



Fault Families



Interpretations

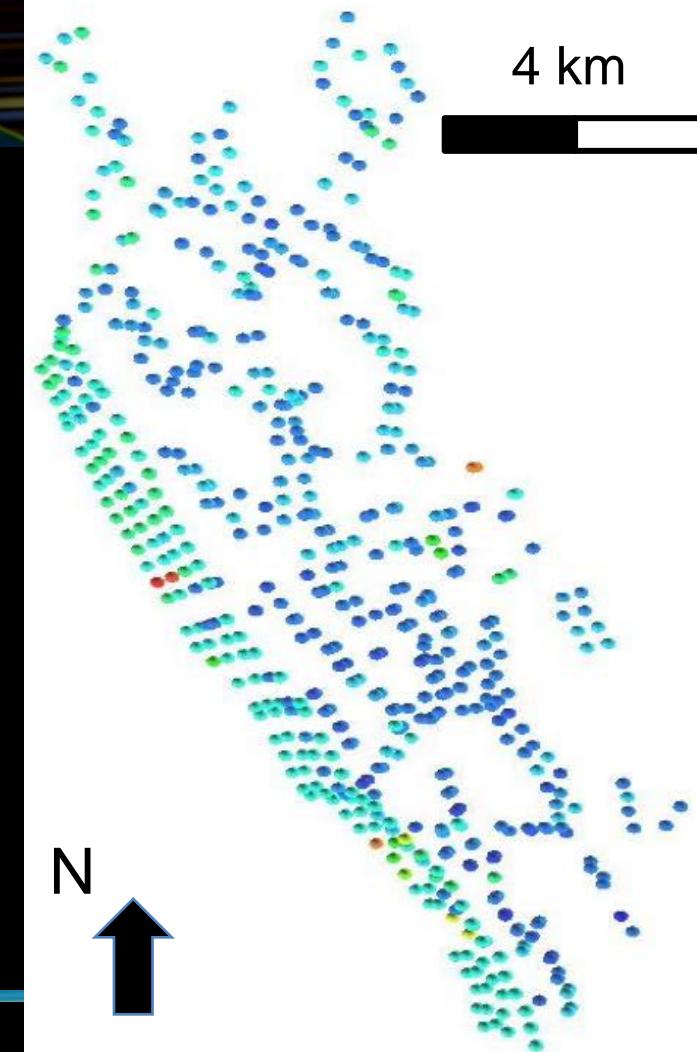


200 faulting evidences

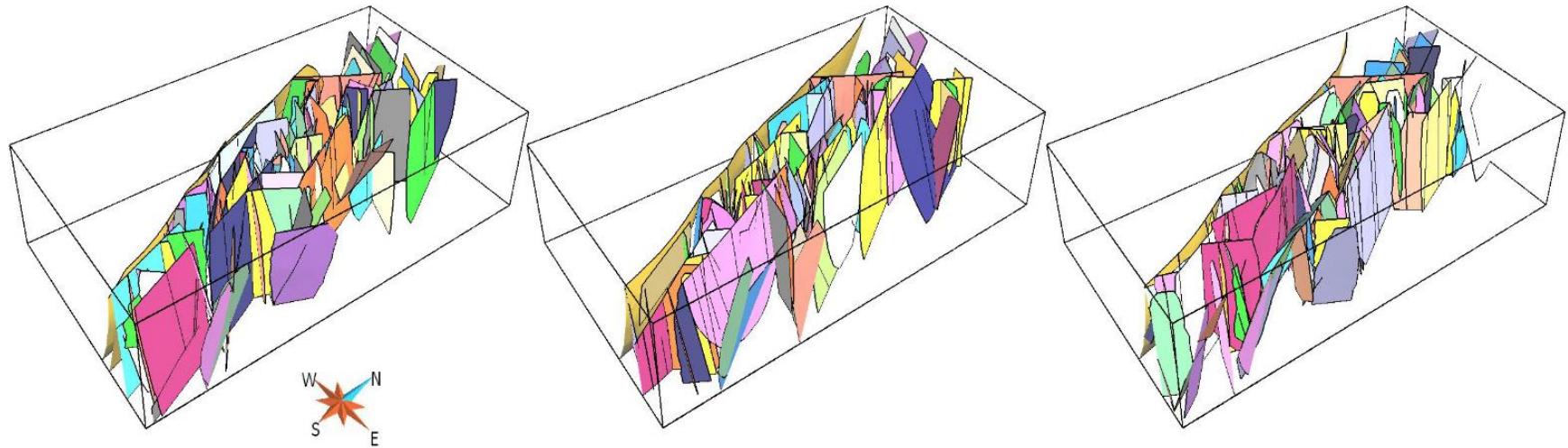
- 17 at wells
- Picks every 250m on crosslines
- Picks every 150m on inlines

~130 faults

Fault existence probability: 0.95



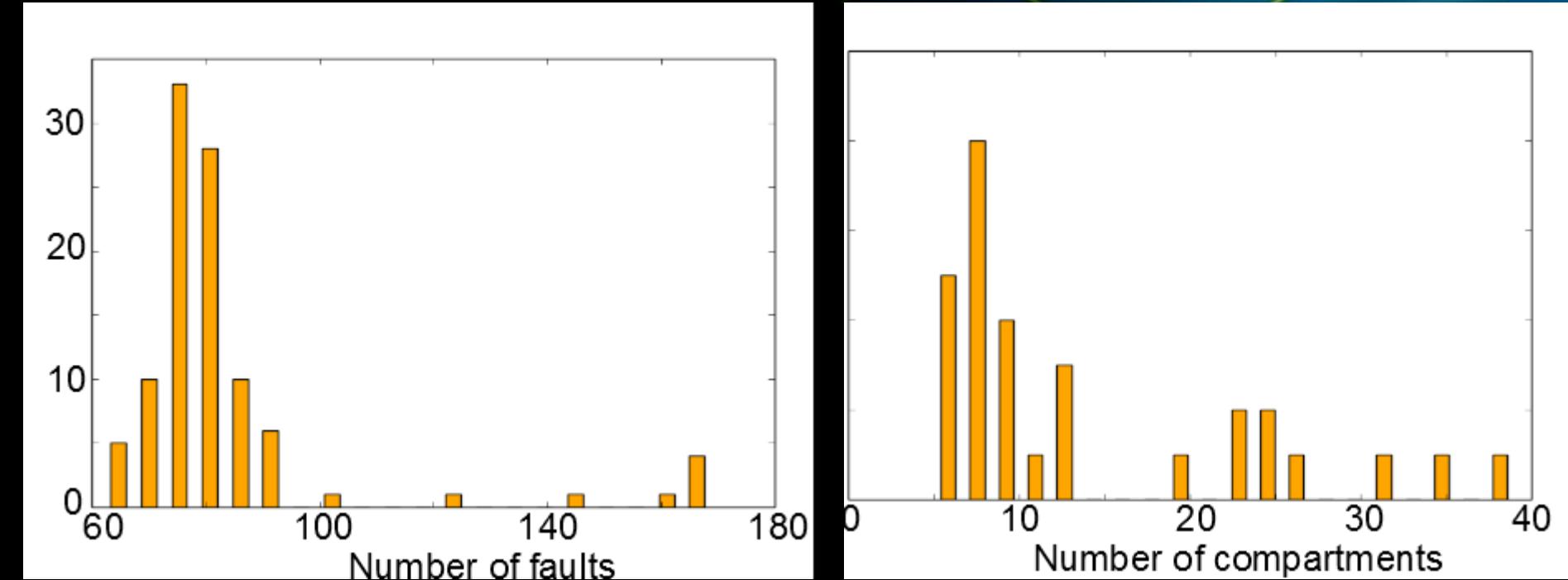
Field Y: Results



Simulation time: 1-3h/realization with the prototype C++ code (single threaded)

Rejection strategy at wells to be optimized

Statistics (100 realizations)



Conclusions

Fault Connectivity Uncertainty significant in interpretation

First application to 3D seismic interpretation:

- Choice of statistical parameters for fault families
- Choice of data clustering parameters
- Minimal seismic picks

Complements studies on :

- 2D data sets [Cherpeau et al, SEG 2010; Pet Geosci, in press]
- Fault segmentation uncertainty
[Julio et al, Tectonophysics 2015; Interpretation, in press]

Implications and challenges

Integrate fault interactions and stratigraphy

→ OOIP

→ Flow simulation

Appropriate scale

Dealing with a large number of structural models

Assessing geological likelihood ?

Validation?

No reference uncertainty !

Thanks

Gocad Consortium (www.gocad.org) for support and “Field Y”



131 Universities



for “Field X” data

Paradigm for Gocad software
Nicolas Cherpeau for FaultMod code