Uncertainty assessment in subsurface modeling: considering geobody shape and connectivity in complex systems

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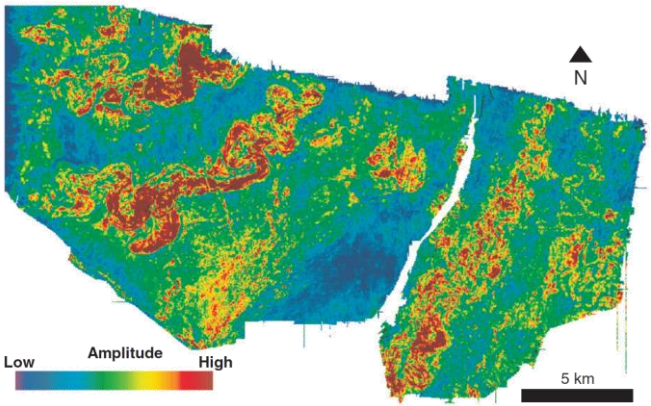
Uncertainties in subsurface

- **Various data , various resolution**

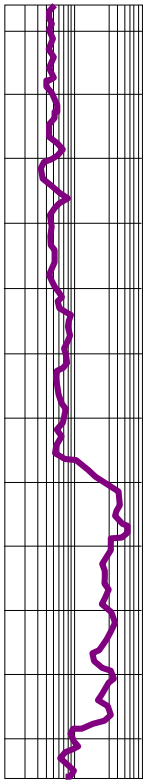
[SGU, 2019]

Gravity, electric and electromagnetic measurements

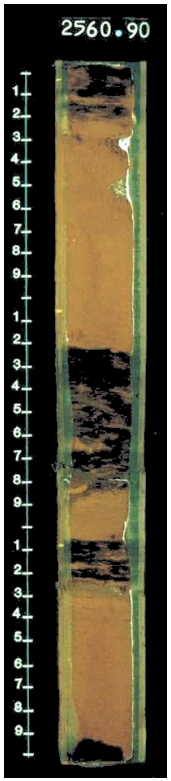


[Sikkema & Wojcik, 2001]

Seismic amplitudes



Well Logs



Core samples

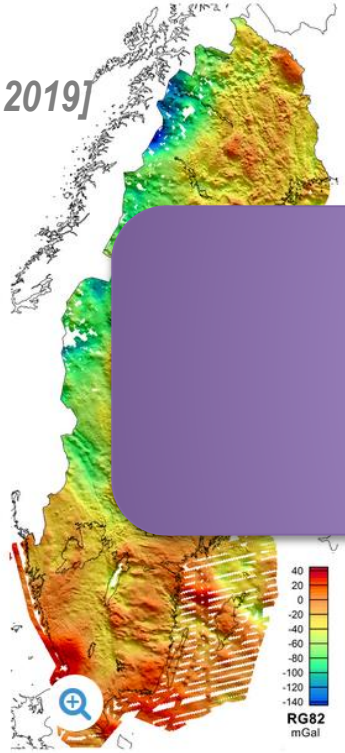
Increasing resolution

Interpretation process

Increasing scarcity

Uncertainties in subsurface

- **Various data , various resolution**



[SGU, 2019]

➔ **Huge uncertainties**

Seismic amplitudes

Gravity, electric and electromagnetic measurements

Well Logs

Core samples

Increasing resolution

Interpretation process

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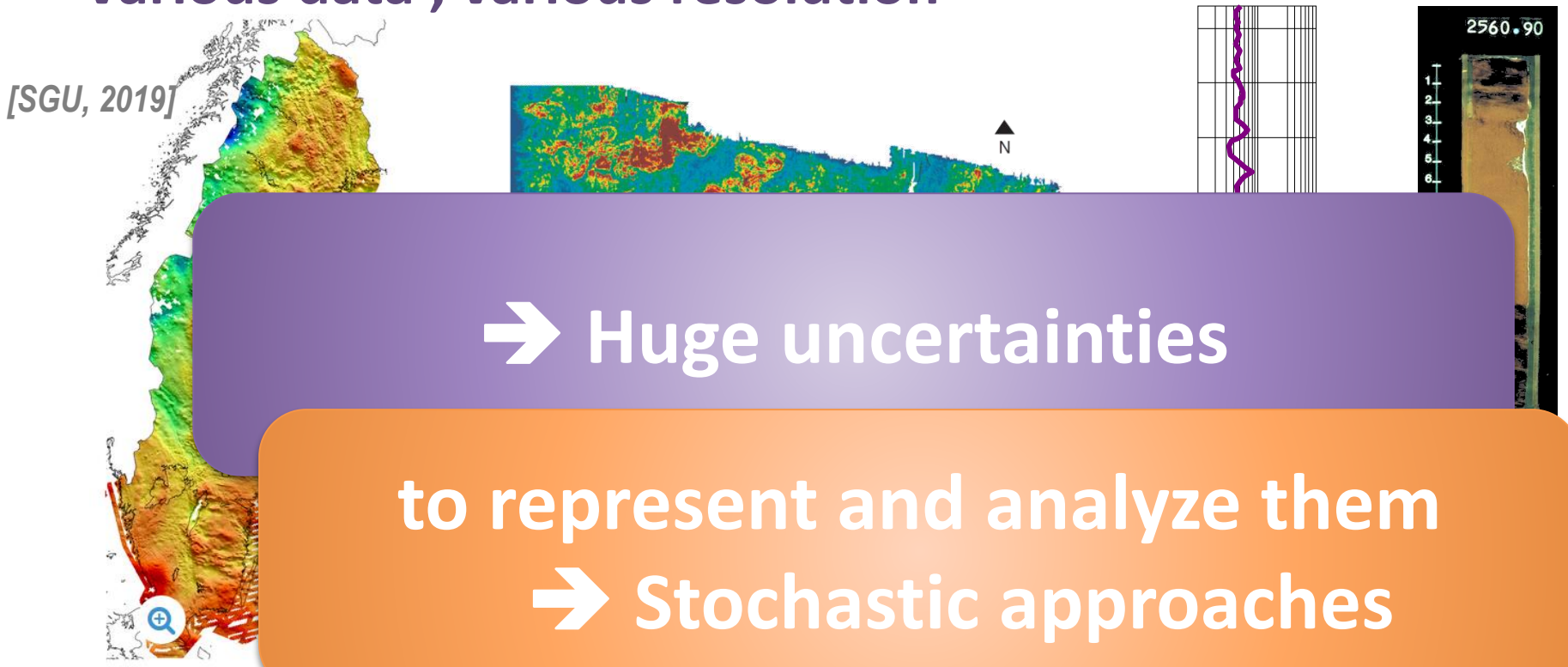
Uncertainties in subsurface

- **Various data , various resolution**



➔ **Huge uncertainties**

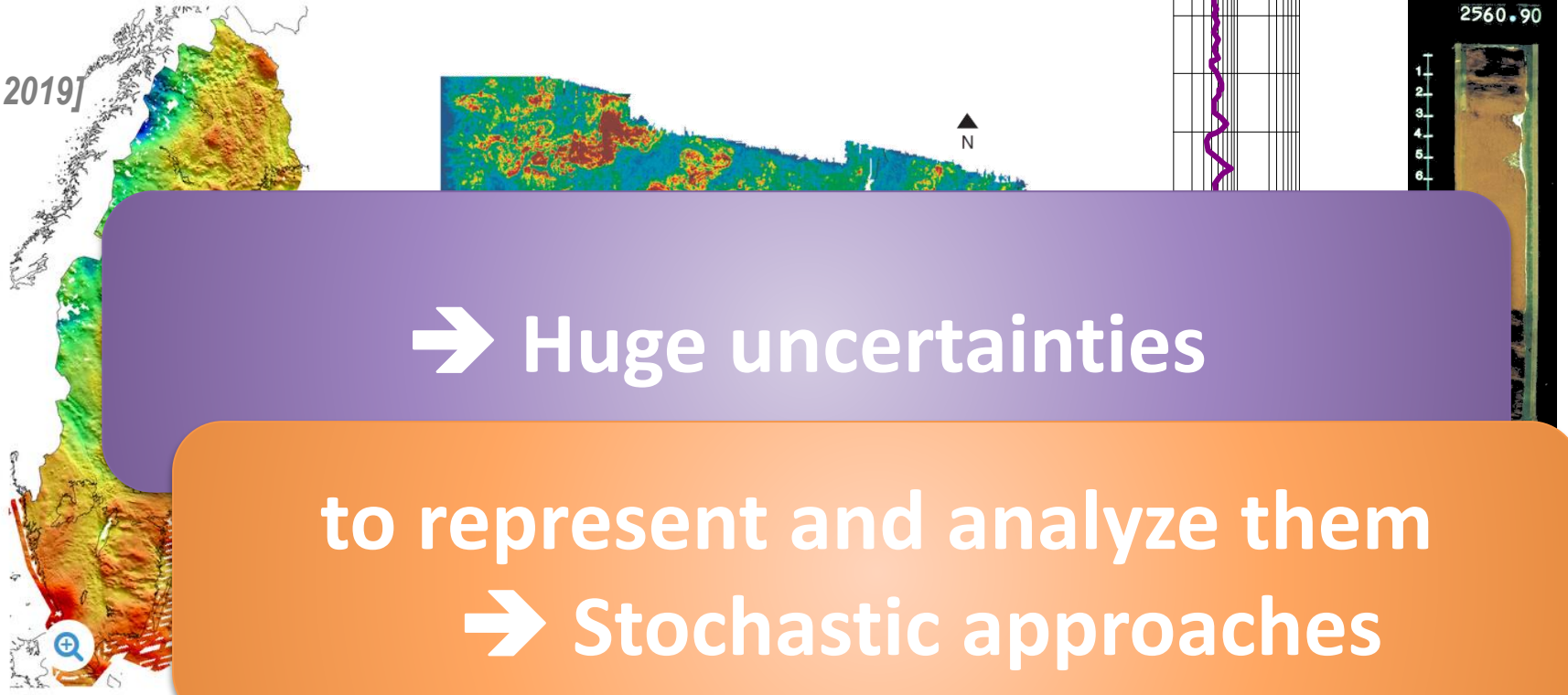
to represent and analyze them

➔ **Stochastic approaches**

Uncertainties in subsurface

- **Various data , various resolution**

[SGU, 2019]



➔ **Huge uncertainties**

to represent and analyze them
➔ **Stochastic approaches**

Gravity, electric
electromagneti
measurements

to reduce them
➔ **Geological concepts**

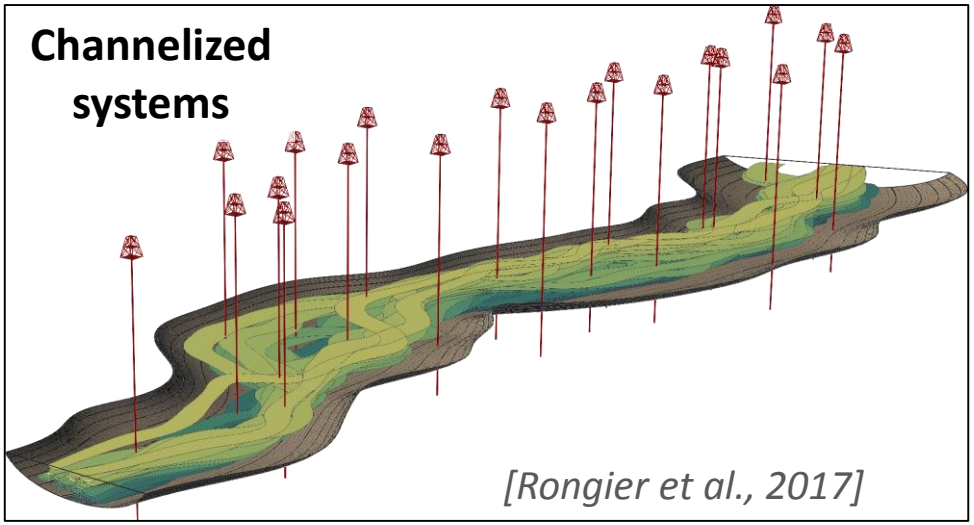
Interpretatic

Considering geobody shapes and connectivity

- **How to integrate geological knowledge in some specific environments ?**

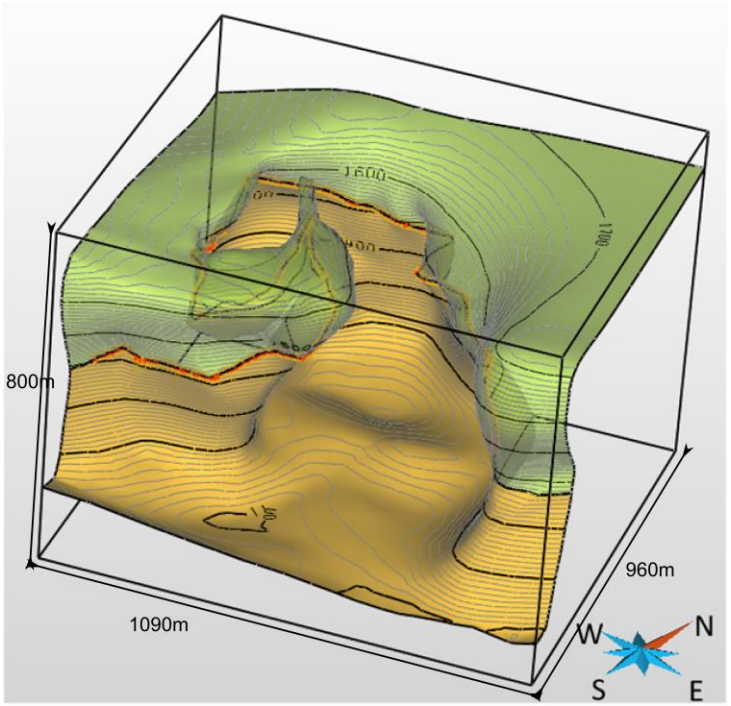
➔ **Focusing on 2 examples**

Channelized systems



[Rongier et al., 2017]

Salt tectonics



[Collon et al., 2016]

Introduction

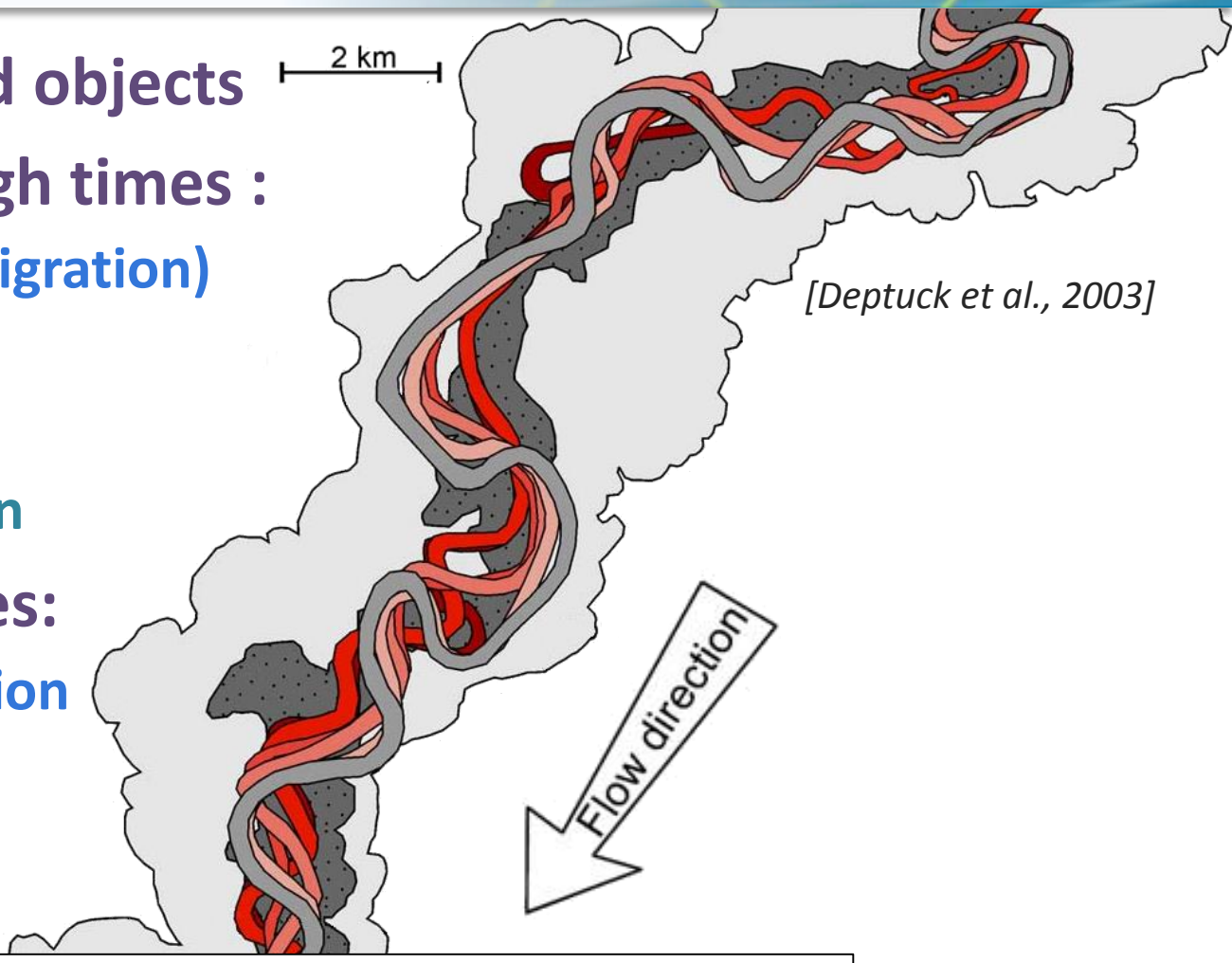
1. Channelized systems

2. Salt tectonics

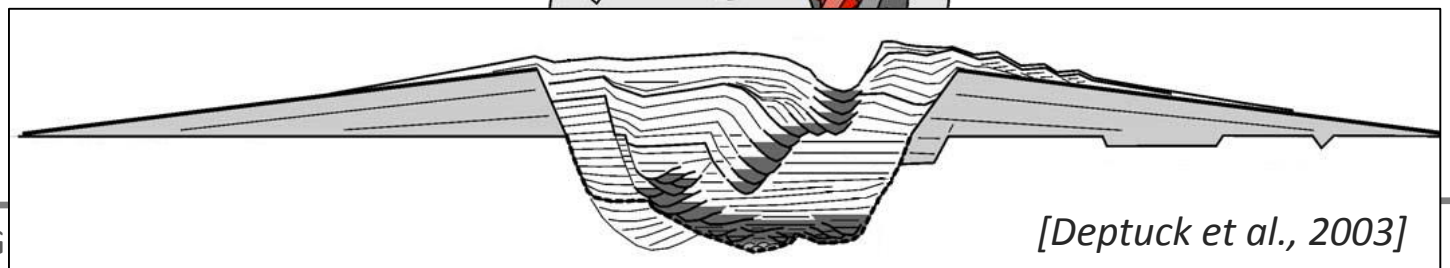
Conclusions and perspectives

The challenges of channelized environments

- Linear elongated objects
- Evolution through times :
  - Continuously (migration)
  - Abruptly :
    - Local avulsion
    - Global avulsion
- Erosive processes:
  - Loss of information



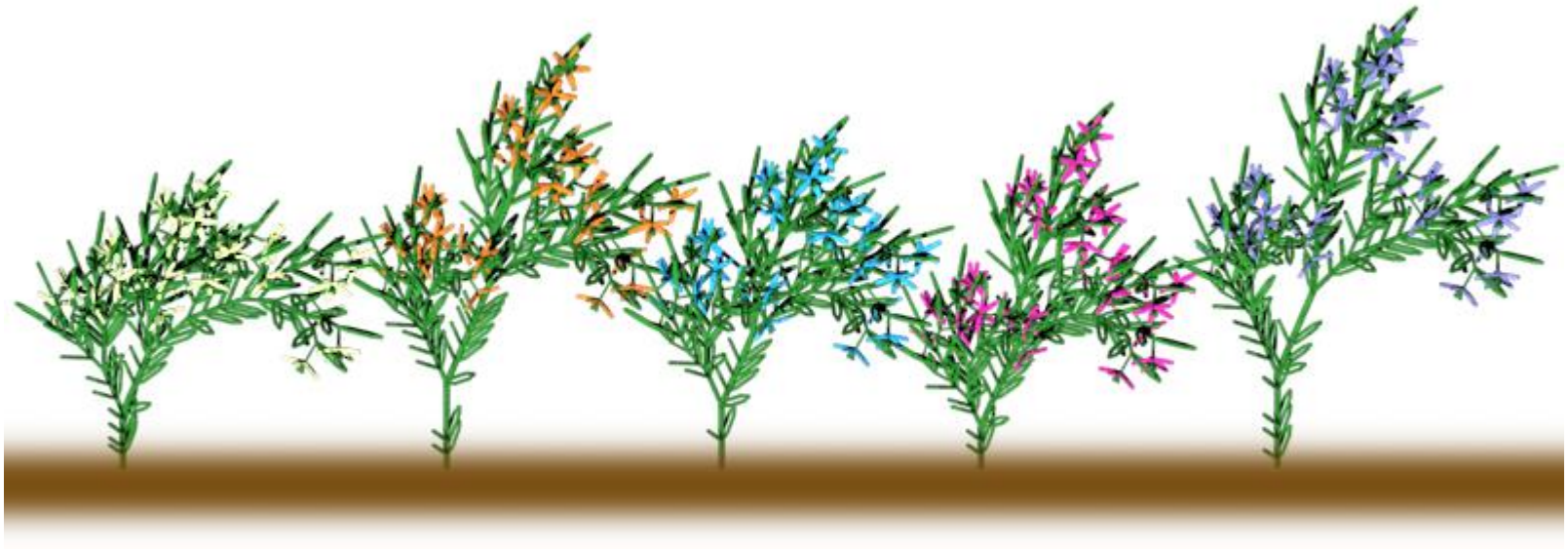
[Deptuck et al., 2003]



[Deptuck et al., 2003]

The Lindenmayer system

- **L-system** ***[Lindenmayer, 1968]*:**
  - **Formal grammar**
  - **Modeling vegetals (e.g. trees)**

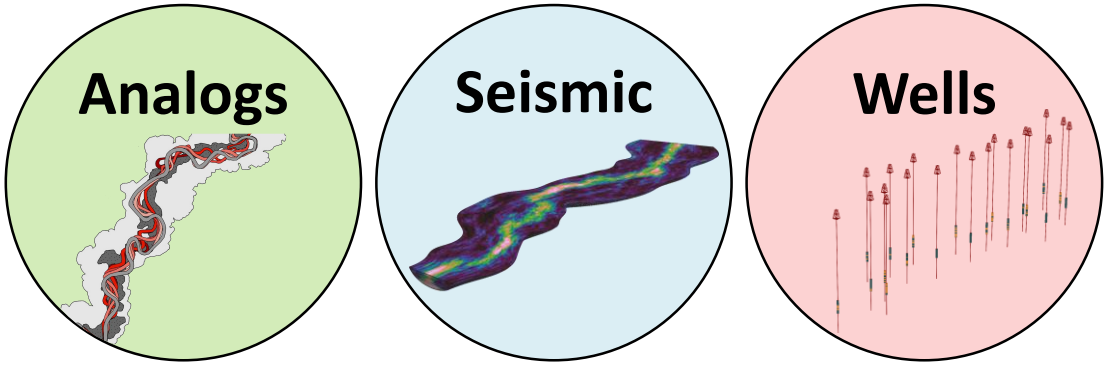


Some stochastic flowers.

[Allen Pike]

How to simulate channels?

➔ G. Rongier's PhD [2016]



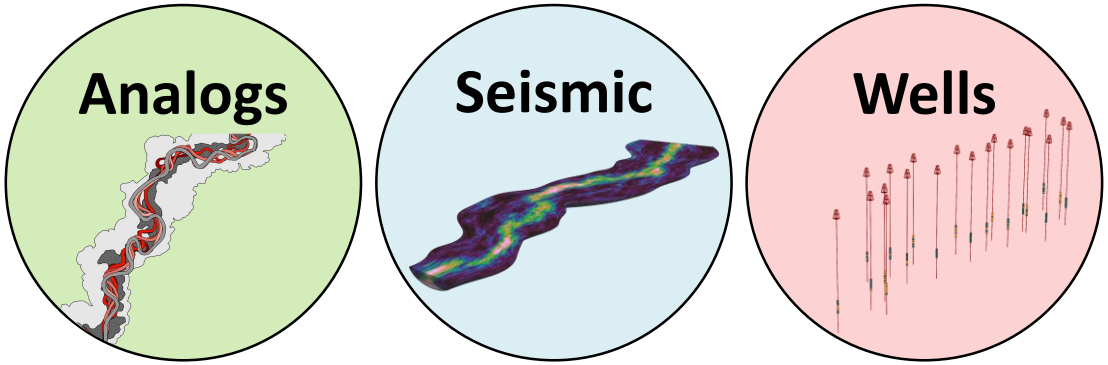
Parameters
Curvatures, amplitude, wavelength (…)

Channel morphology
L-system

Data conditioning
Constraints

How to simulate channels?

➔ G. Rongier's PhD [2016]



Parameters
Curvatures, amplitude, wavelength (…)

Channel envelope
NURBS

[Ruiu et al., 2015]

Channel morphology
L-system

Data conditioning
Constraints

Application: turbiditic channels

Constraints:

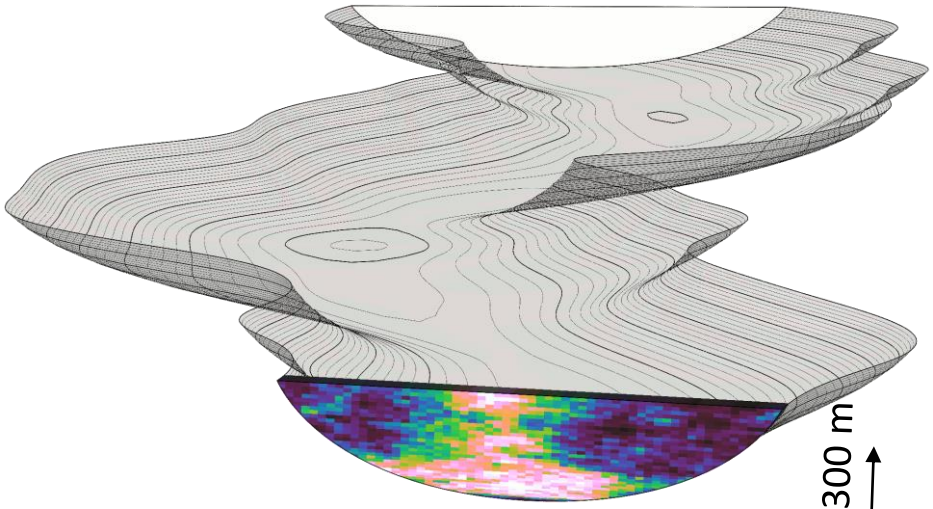
- The master channel sides
- The probability cube

Sand probability

0 1

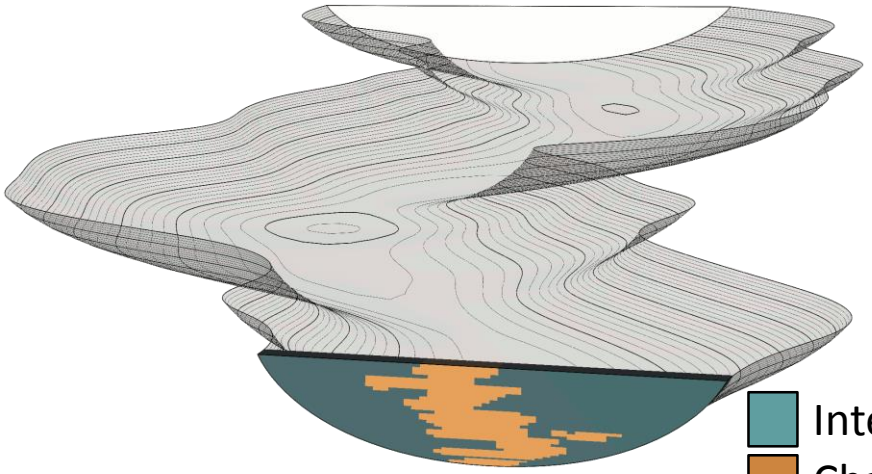
[Rongier et al, 2017]

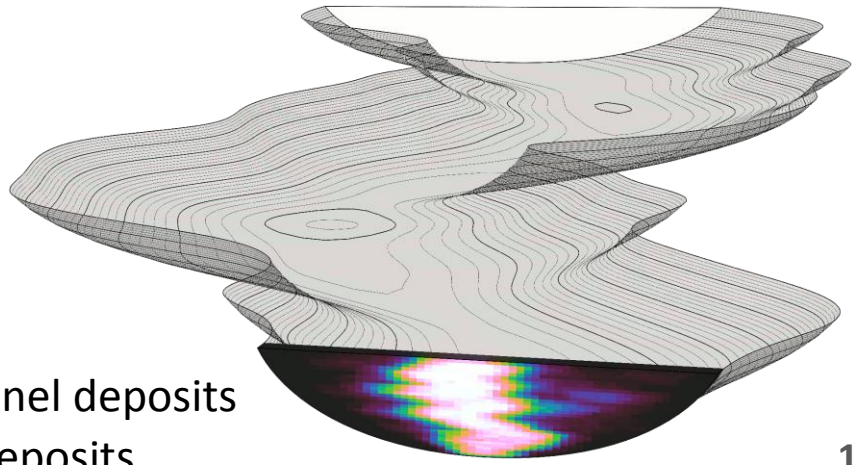
Sand probability



E-map of 100 realizations

One realization





Inter-channel deposits

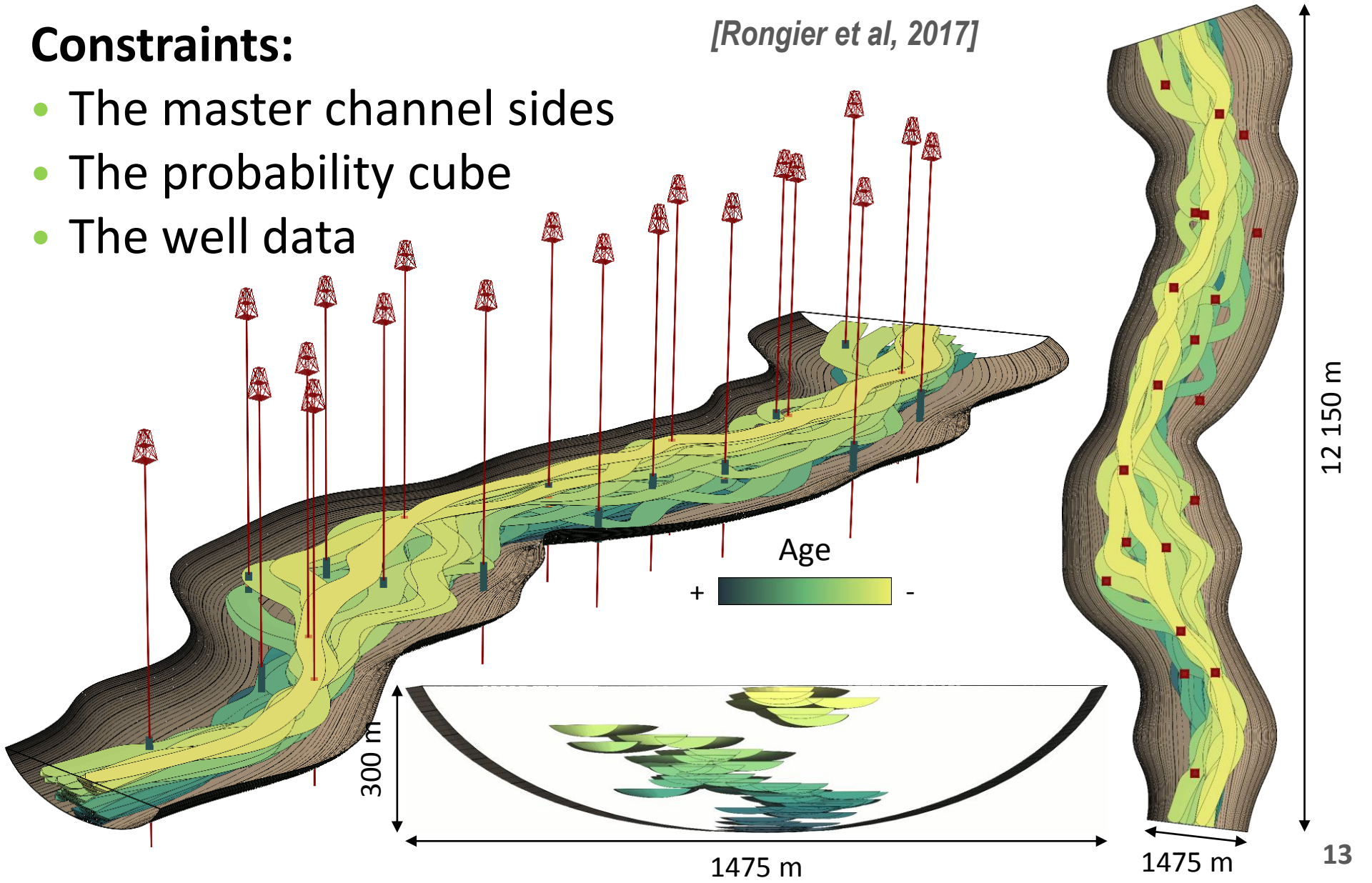
Channel deposits

Application: adding well sedimentary data

Constraints:

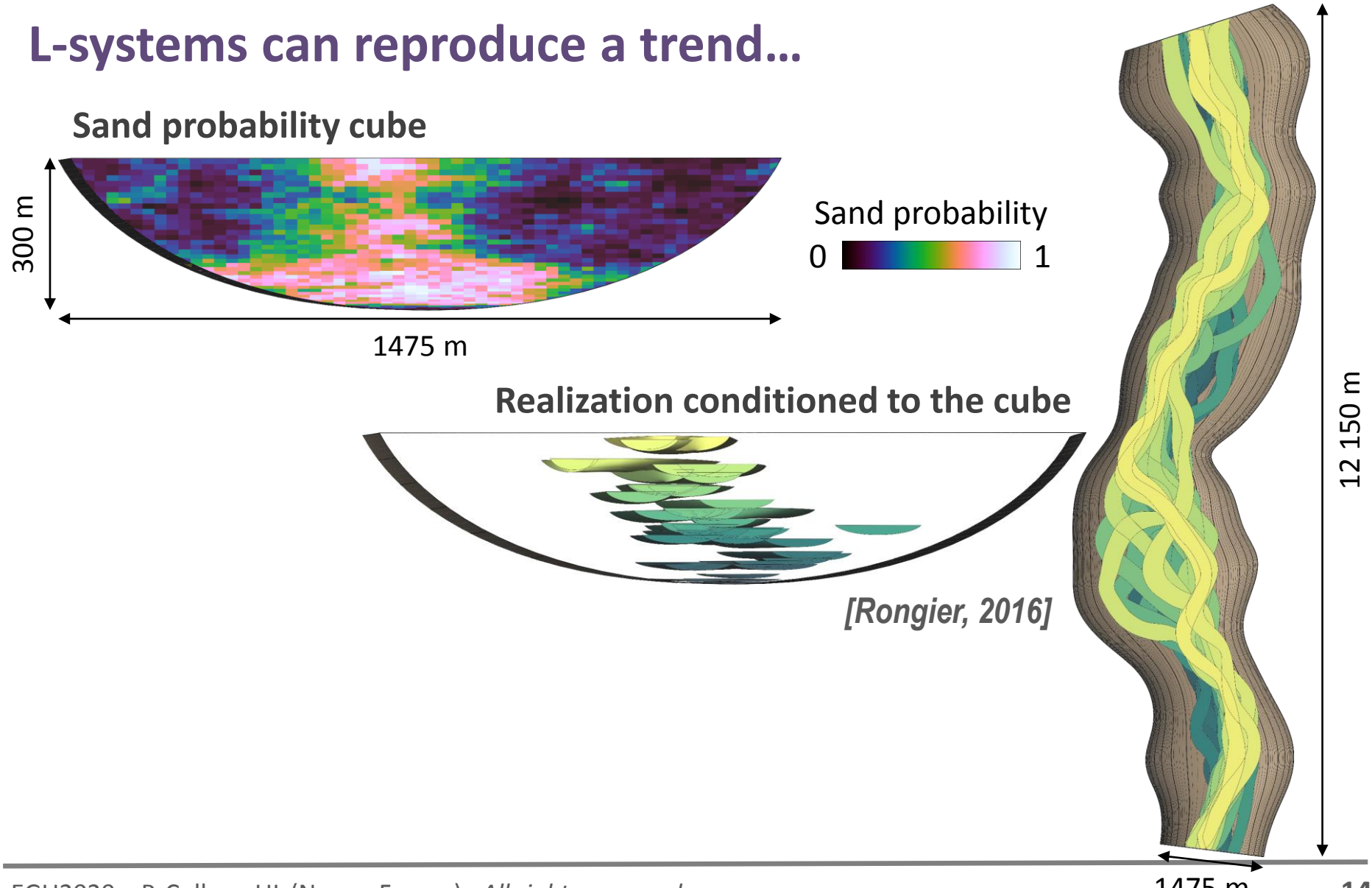
- The master channel sides
- The probability cube
- The well data

[Rongier et al, 2017]



Intermediate Conclusion

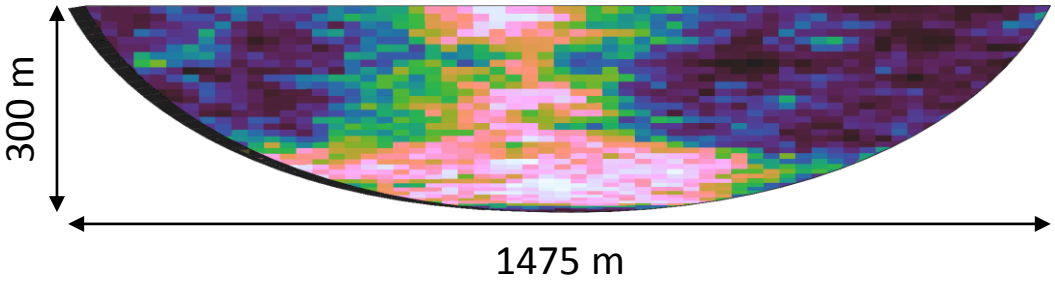
L-systems can reproduce a trend…



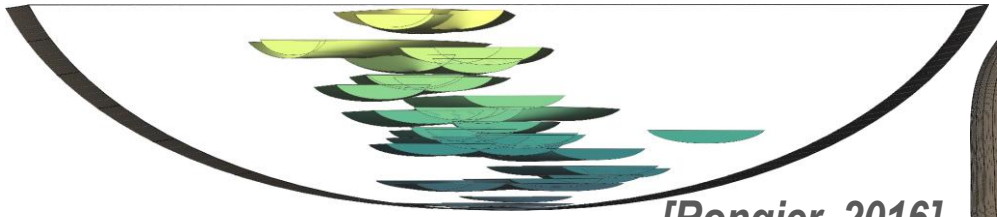
Intermediate Conclusion

L-systems can reproduce a trend…

Sand probability cube

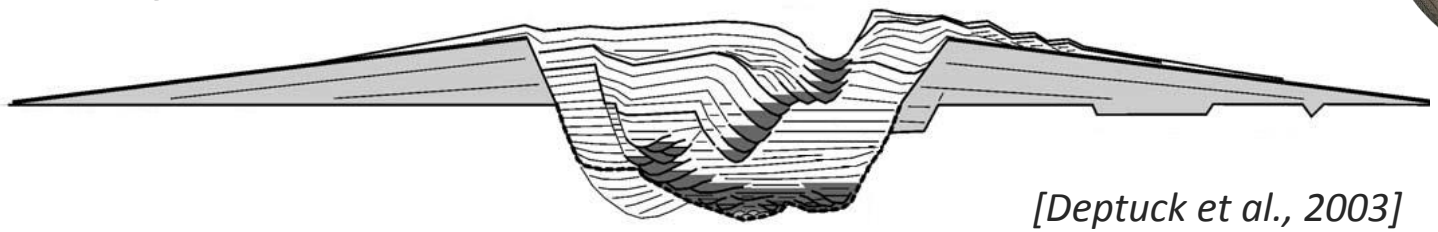


Realization conditioned to the cube

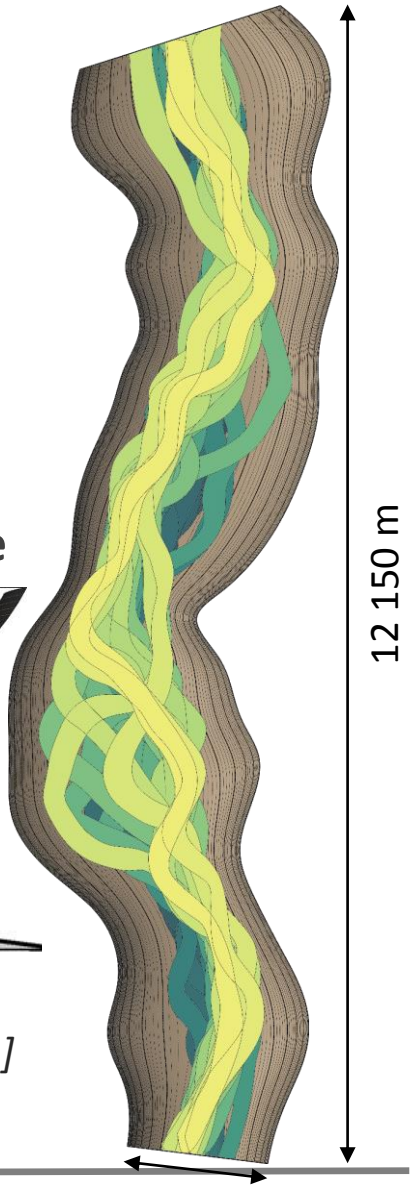


[Rongier, 2016]

Reality



[Deptuck et al., 2003]



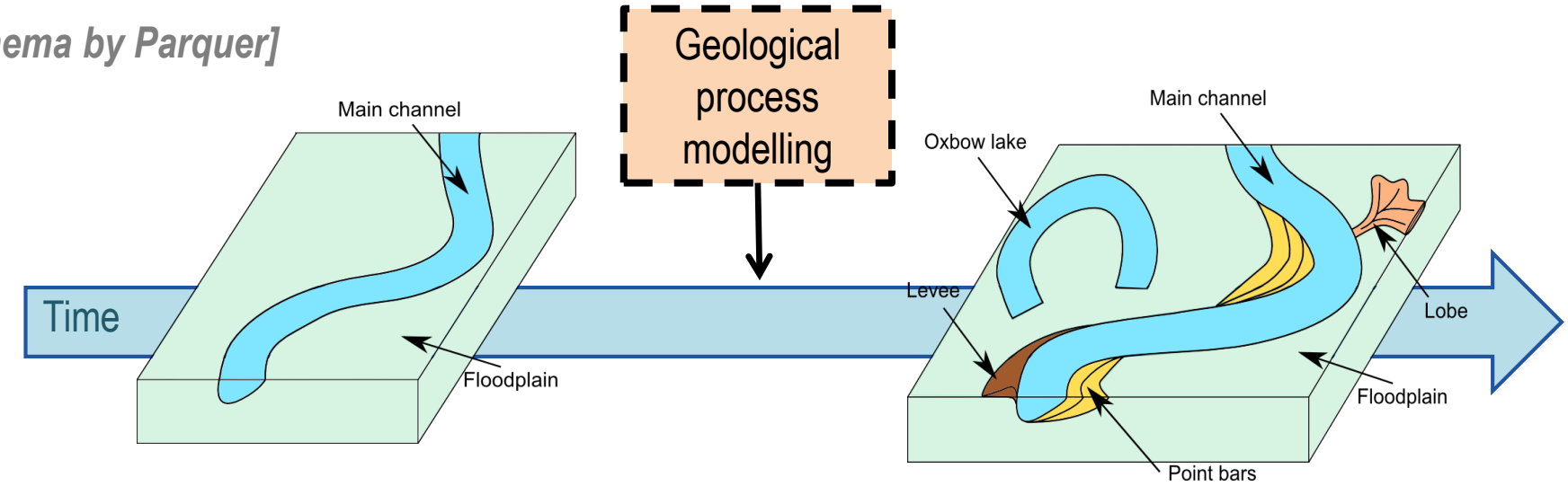
… but not a precise stacking

Channelized system modelling

- "Classical" approach
  - Direct: predict the system evolution
    - Physical modelling of geological processes

e.g. [Ikeda et al, 1985]
[Pyrcz et al, 1996]
[Labourdette, 2008]

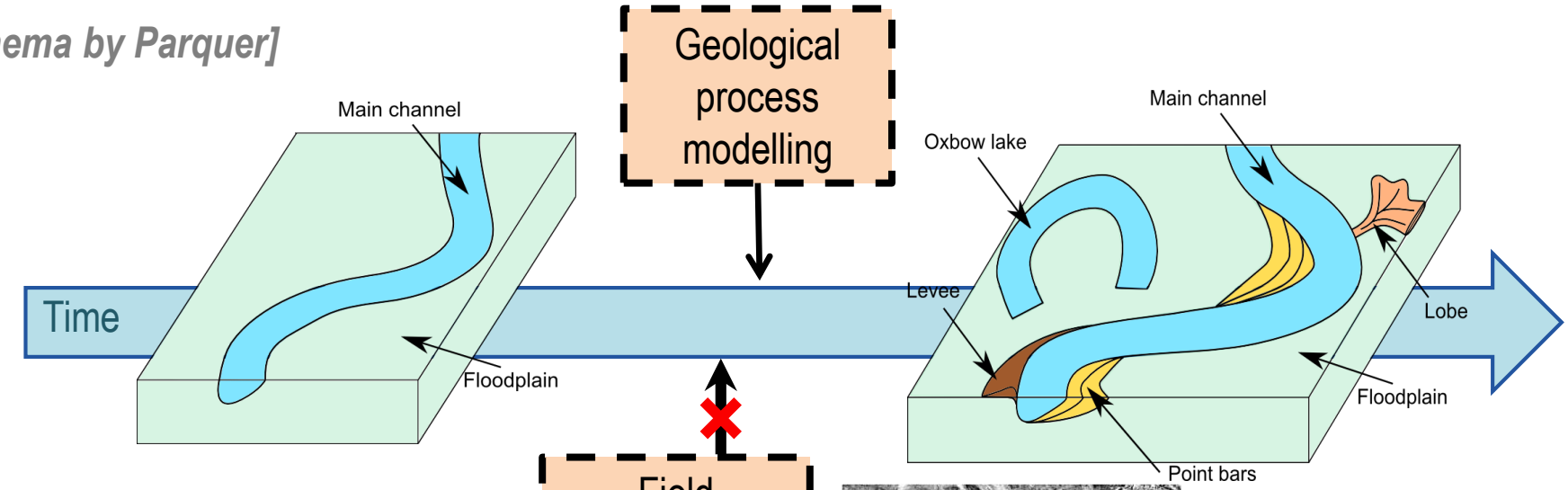
[Schema by Parquer]



Channelized system modelling

- "Classical" approach
  - Direct: predict the system evolution
    - Physical modelling of geological processes
    - Difficulties to honour data
    - Heterogeneity model not completely reliable

[Schema by Parquer]

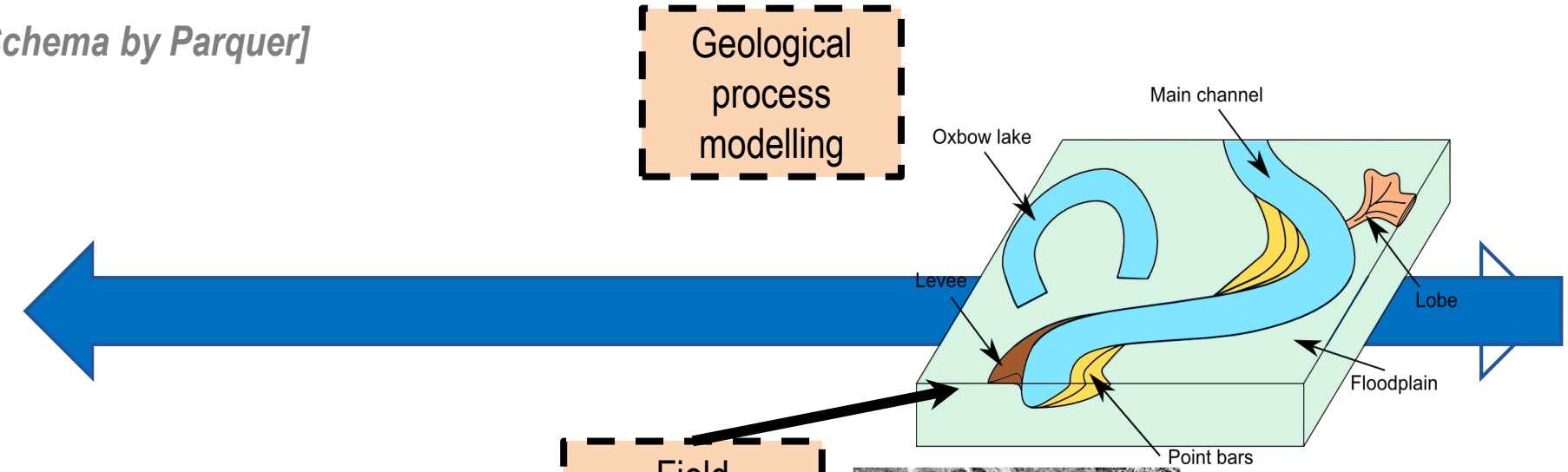


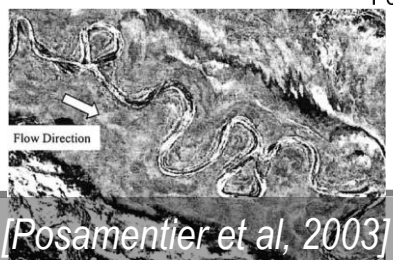
[Posamentier et al, 2003]

Channelized system modelling

- **Our Proposal:**
  - **Reverse Simulation**
    - **Last channel modelling**

[Schema by Parquer]



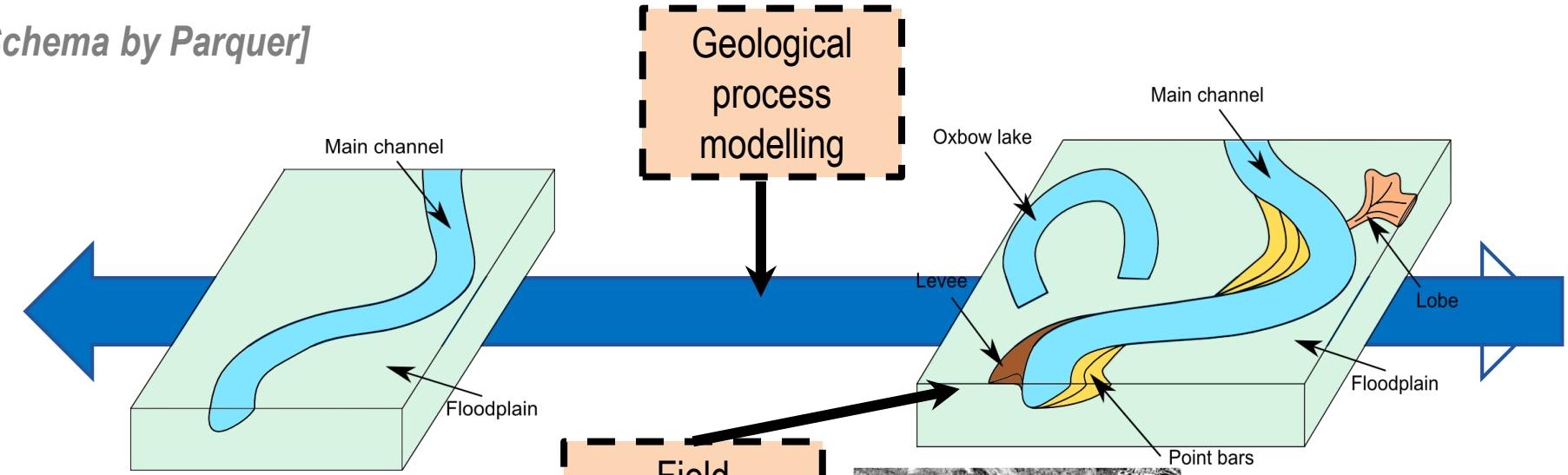


[Posamentier et al, 2003]

Channelized system modelling

- **Our Proposal:**
  - **Reverse Simulation**
    - **Last channel modelling**
    - **Reverse modelling of the channel to generate a channelized system based on field observation**

[Schema by Parquer]



[Posamentier et al, 2003]

What can we learn from field observations?

- **Natural migration of Mississippi**

[Parquer et al, 2017]

[Maps from US Army Corps of Engineers]

What can we learn from field observations?

- **Natural migration of Mississippi** *[Parquer et al, 2017]*
  - Migration considered by half-meander and decomposed into downstream and lateral components
    - Curvature / migration amplitudes
      - are only "slightly" linked
      - This relation is only relevant at half-meander scale
      - This relation is variable
    - ➔ There is a wide variety of migration patterns

A "mixed" approach for reverse migration

➔ M. Parquer's PhD [2018]

- **ChaRMigS :**
  - Geometrical description of migration process
    - With decomposition in downstream / lateral components
  - Uncertainties managed by geostatistical laws
  - Integration of abandoned meanders in the process

Satellite image of Tangnara river (Russia)

[Parquer et al., 2017]

A "mixed" approach for reverse migration

➔ M. Parquer's PhD [2018]

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Estimated abandonment ages

[Parquer et al., 2017]

A "mixed" approach for reverse migration

➔ M. Parquer's PhD [2018]

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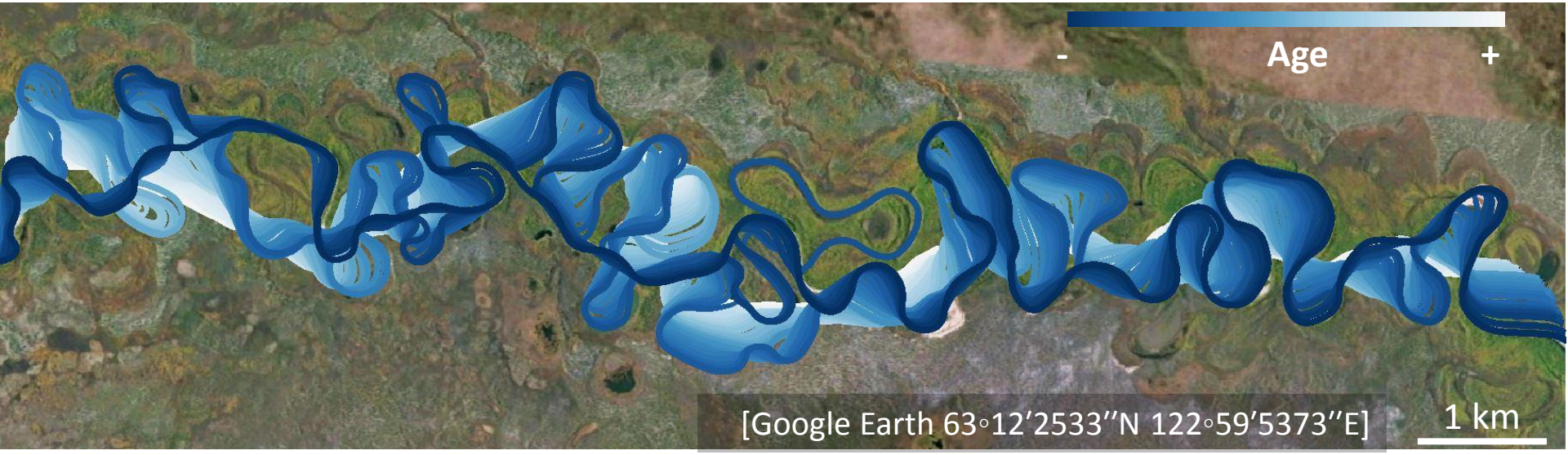
One realization

[Parquer et al., 2017]



A "mixed" approach for reverse migration

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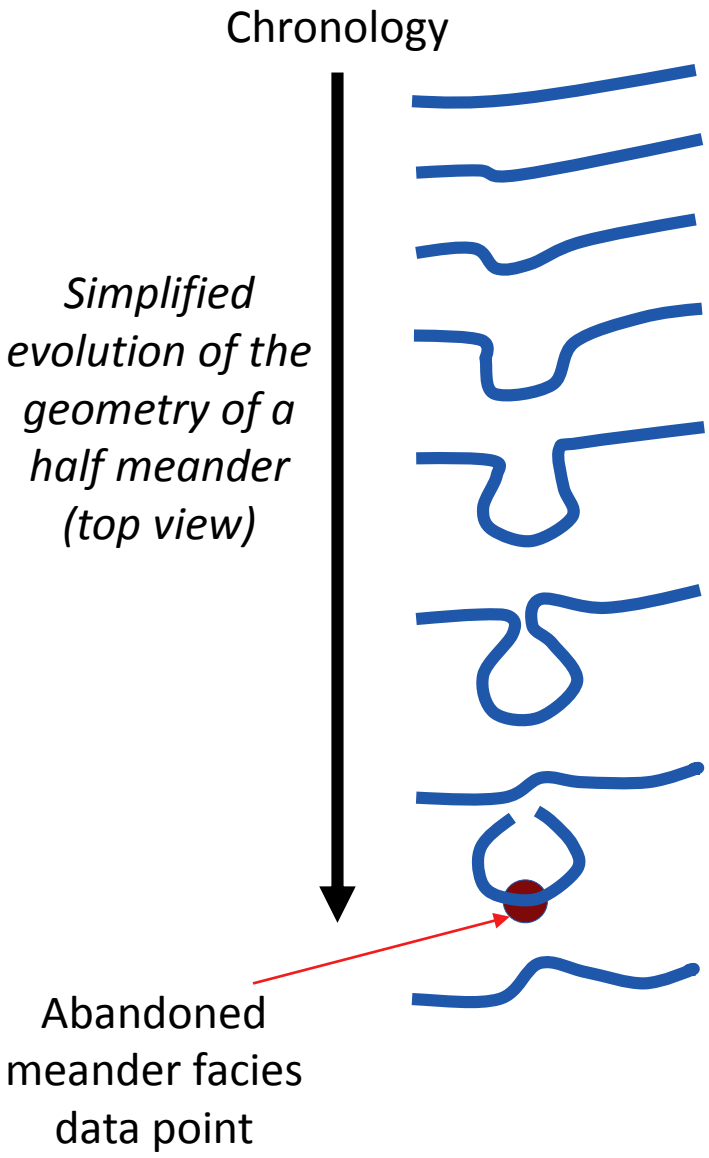
A second one…

[Parquer et al., 2017]

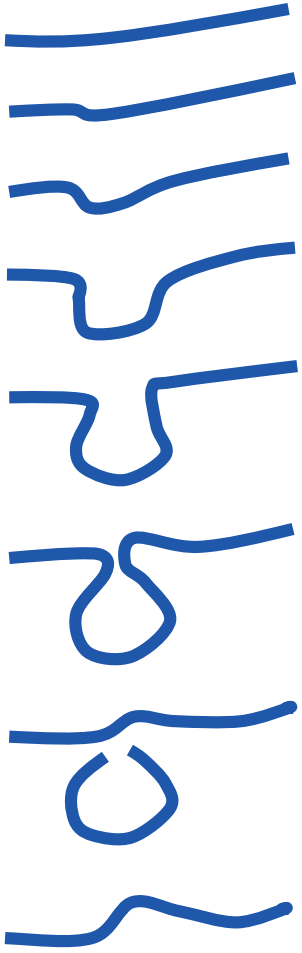
The particularities of reverse migration

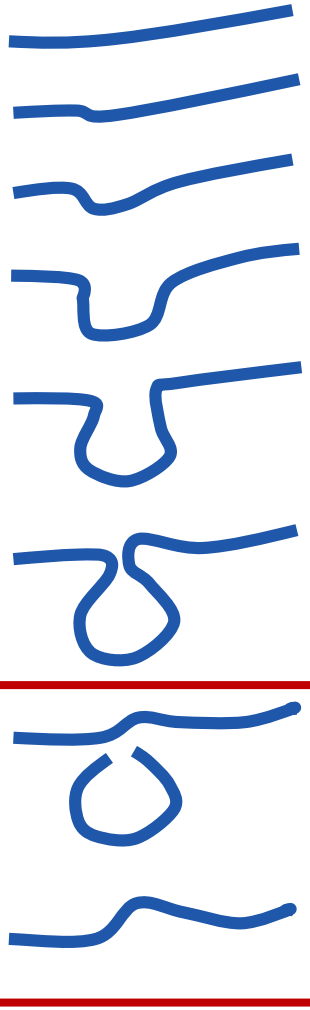


The particularities of reverse migration

Chronology

Simplified evolution of the geometry of a half meander (top view)





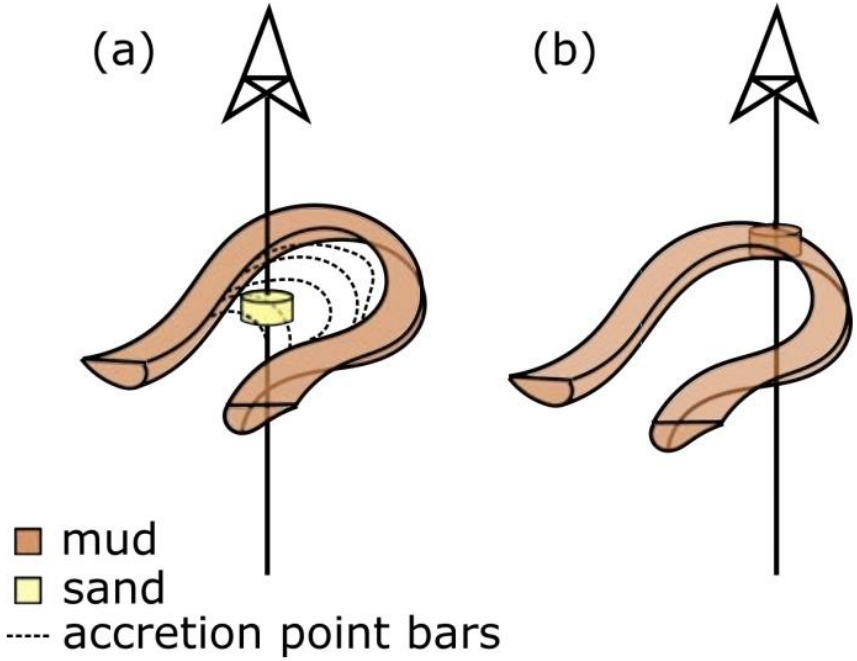
Simulation

Discrete event simulation

MSc : A. Cayrol

The particularities of reverse migration

- **Honoring well data in reverse migration** MSc : A. Cayrol

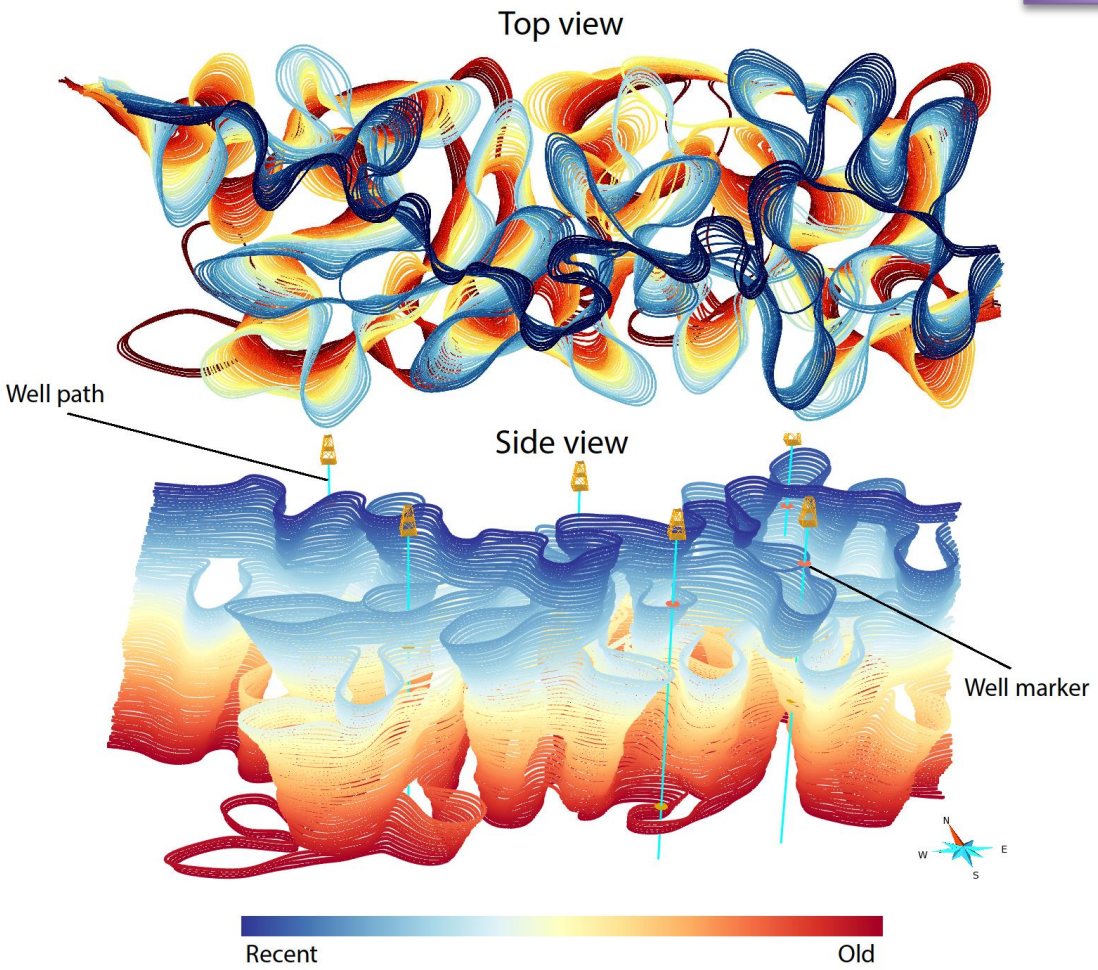


(a) Point bar facies data
(b) Abandoned meander facies data .
[Parquer, 2018]

Data conditionning in reverse migration

- **Honoring well data in reverse migration**

MSc : A. Cayrol



[Cayrol et al., RING Meeting 2019]

Perspectives

- Avulsion integration
- Go back into a wider context of subsurface modelling: petrophysical simulations, flow impact assessment …
  - Mesh generation
  - Petrophysical simulations
  - Upscaling (?)
- Considering “rhythms” in migration…

Introduction

1. Channelized systems

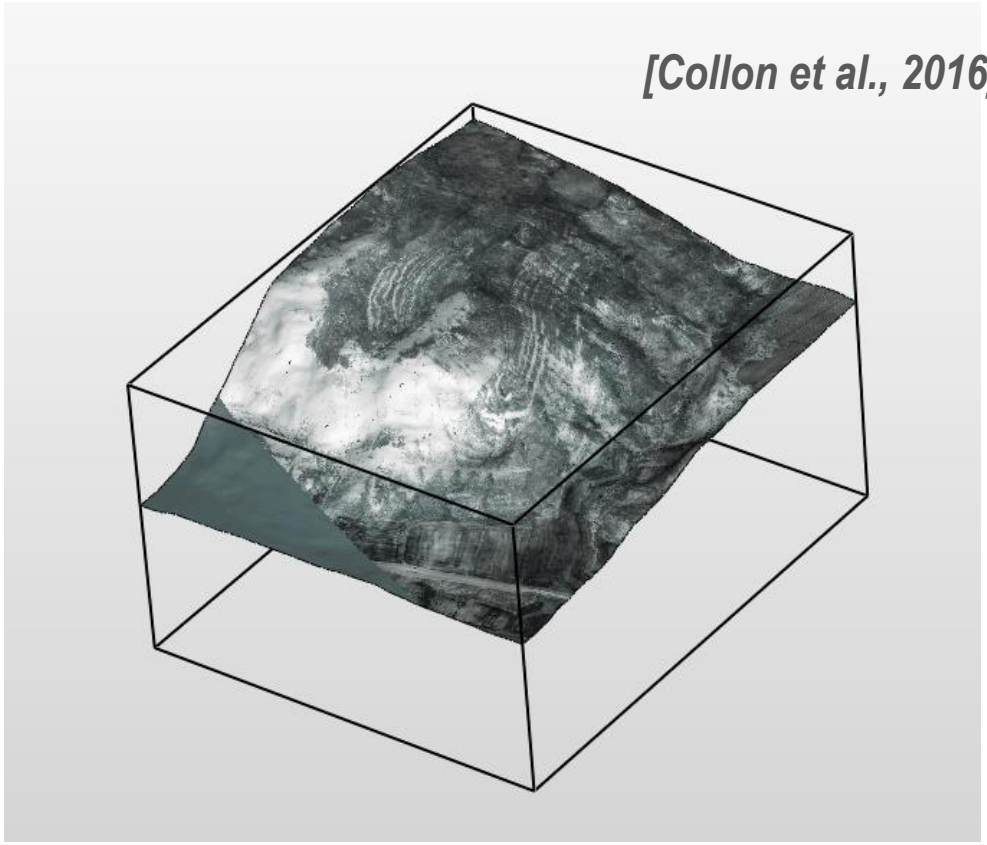
2. Salt tectonics

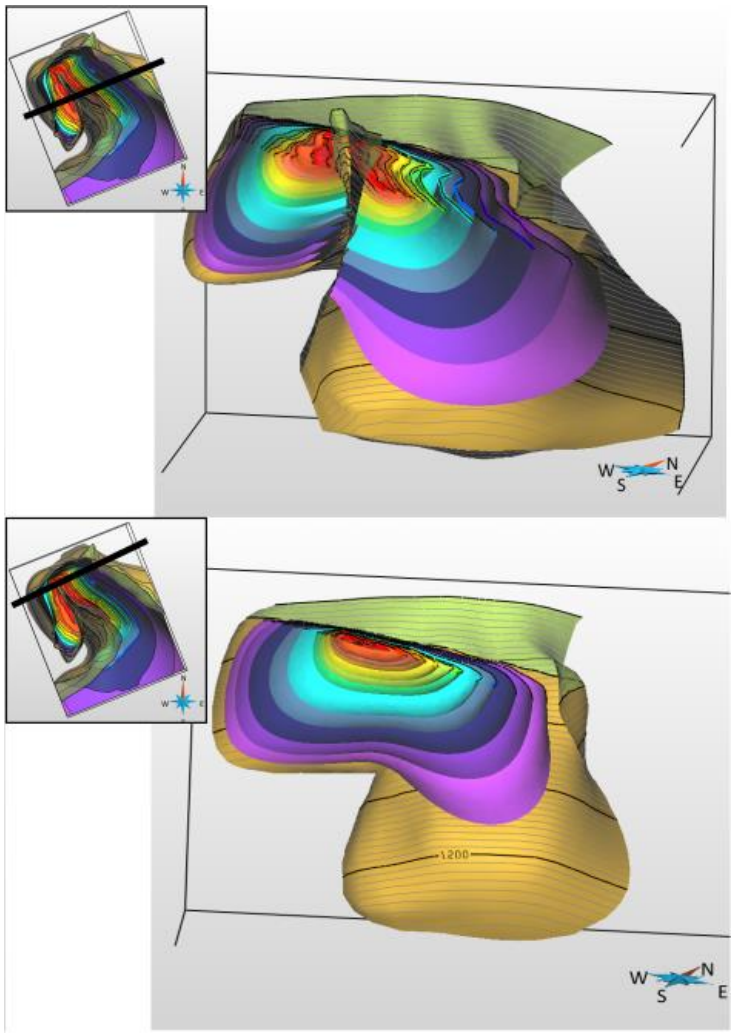
Conclusions and perspectives

The challenges of modelling salt tectonics

- **Salt modeling challenges** *[Collon et al., 2016]*
  - **Handling complex surfaces**
  - **Varying geometries and topologies**

[Collon et al., 2016]

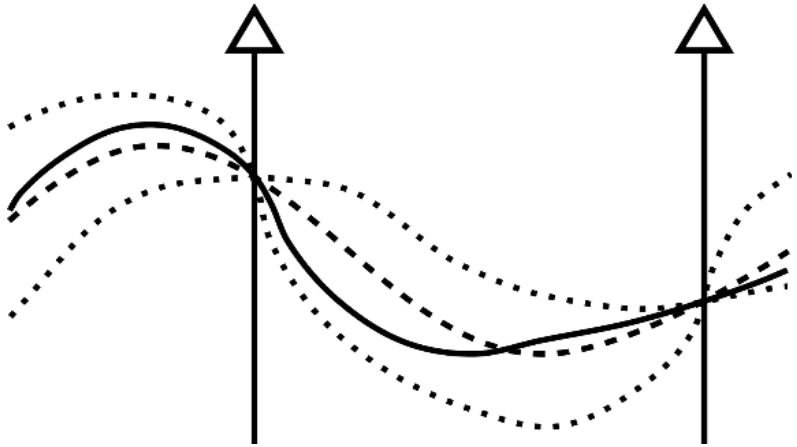




Stochastic salt modeling

➔ N. Clausolles's PhD [2020]

- Sampling strategy
  - Similar to P-Field approaches *[Lecour et al., 2001]*
    - Reference model
    - Uncertainty bounds
    - Perturbation

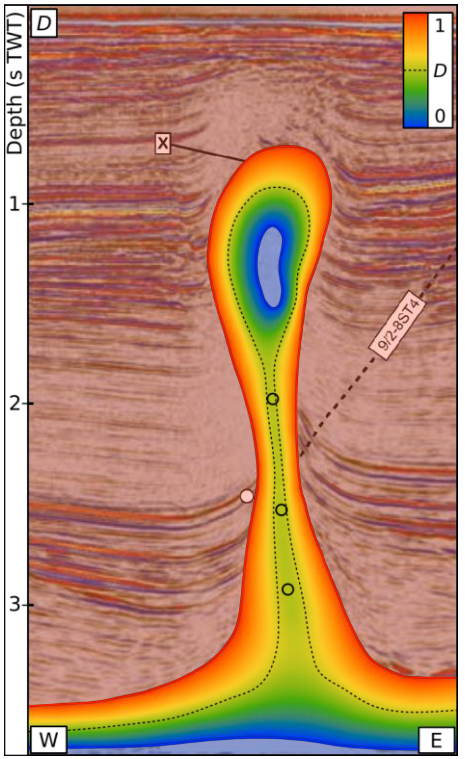


After Thore et al. (2002)

Stochastic salt modeling

➔ N. Clausolles's PhD [2020]

- Reference model
  - Pseudo-distance field *D*
  - Defines a "probability" of being in sediments
  - Construction
    - Boundary constraints
    - Interpolation *[Irakarama et al., 2018]*



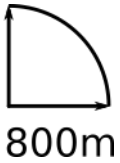
Seismic image from Jackson and Lewis (2012)

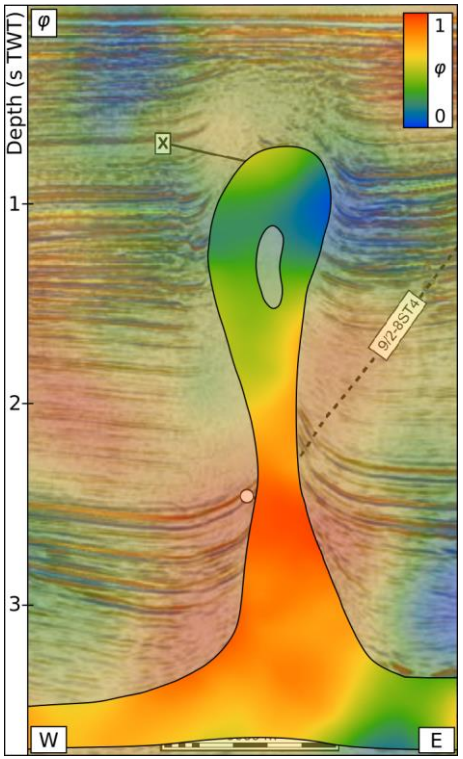
[Clausolles et al., 2019]

Stochastic salt modeling

➔ N. Clausolles's PhD [2020]

- **Perturbation**
  - **Spatially correlated random field φ**
  - **Sequential Gaussian simulation**
    - **Distribution model** $\varphi \sim$ 

    - **Variogram model** V: 800m 



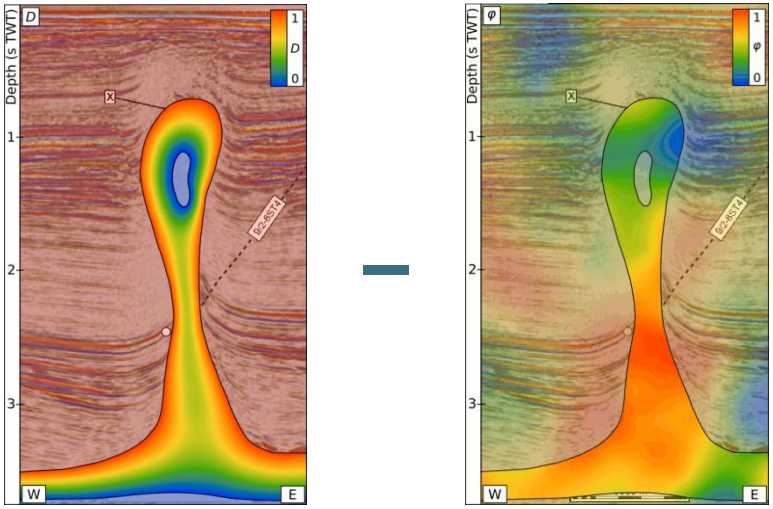
Seismic image from Jackson and Lewis (2012)

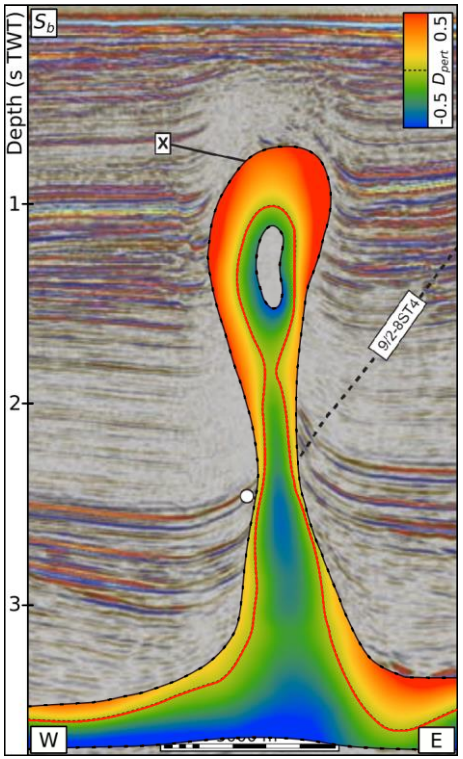
[Clausolles et al., 2019]

Sampling salt bodies

➔ N. Clausolles's PhD [2020]

- **Definition of the salt boundary**
  - **0-Level set of $D_{pert} = D - \varphi$**
- **Multiple salt boundaries**
  - **Multiple perturbations φ**





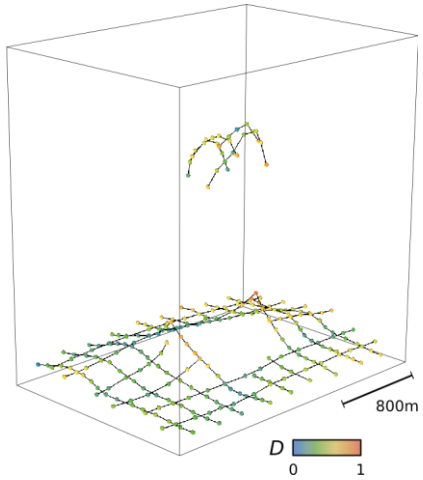
Seismic image from Jackson and Lewis (2012)

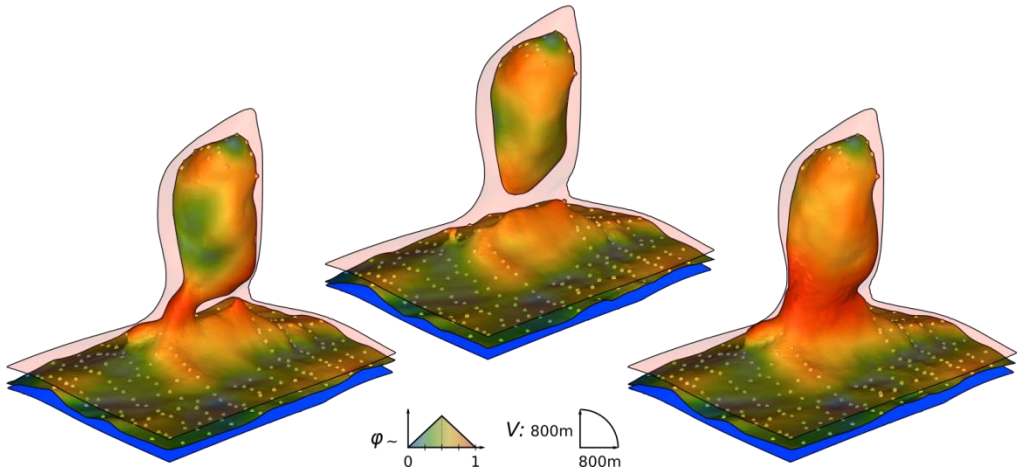
[Clausolles et al., 2019]

Stochastic salt modeling

➔ N. Clausolles's PhD [2020]

- Assessment of the proposed method
  - Simulates salt bodies and their connectivity
    - Integrates punctual data (about boundary and weld)



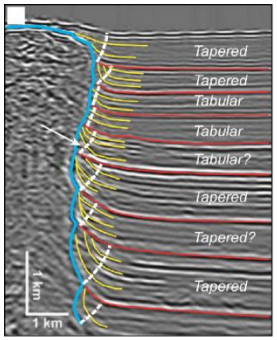


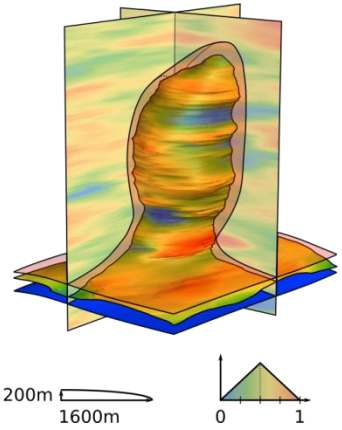
[Clausolles et al., 2019]

Stochastic salt modeling

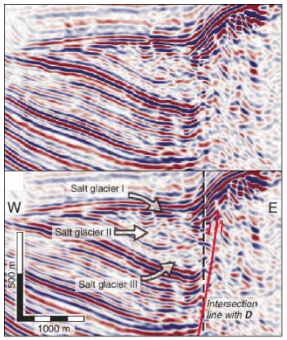
➔ N. Clausolles's PhD [2020]

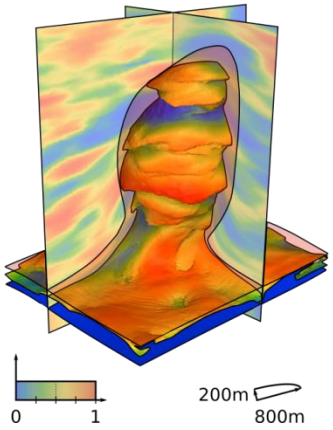
- Assessment of the proposed method
  - Simulates salt bodies and their connectivity
    - Integrates punctual data (about boundary and weld)
    - Reproduces geological features (through parameter tuning)





Halokinetic sequences





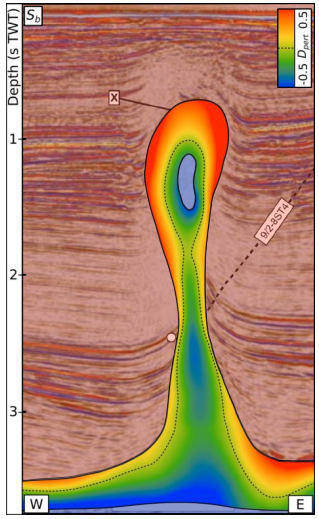
Christmas trees

[Clausolles et al., 2019]

Stochastic salt modeling

➔ N. Clausolles's PhD [2020]

- Assessment of the proposed method
  - Simulates salt bodies and their connectivity
    - Integrates punctual data (about boundary and weld)
    - Reproduces geological features (through parameter tuning)
  - Limitations
    - Extraction of 3D welds
    - Generation of the uncertainty envelope
    - Validation of the simulated models
    - Parameter choice/inference, relations D/φ



Seismic image from Jackson and Lewis (2012)

[Clausolles et al., 2019]

Introduction

1. Simulating connected linear objects

2. Modelling channelized system architecture

3. From “skeletons” to volume representations

Conclusions and perspectives

Conclusions and perspectives

- **Contributions:**
  - **Numerous ideas are investigated**
  - **Integrating geological knowledge ➔ natural system studies** ***(e.g. Mississippi, karst network database)***
  - **Pragmatic approach ➔ from available observations and data**
  - **Stochastic methods ➔ uncertainties and irreversibility of processes**

Conclusions and perspectives

- **Modelling perspectives:**
  - **Better conditioning to data (net-to-gross, lobes)**
  - **Application to real data (we are looking for...)**
  - **Go back into a wider context of subsurface modelling: petrophysical simulations, flow impact assessment …**
  - **Integrating into an inverse procedure**
- **More and more sophisticated models:**

  ➔ how to compare realizations?

  A problem taken up in :
  - ***[Rongier et al., 2016]* : Metrics to compare connected structures in realizations**

  ➔ Now a requirement to compare the associated dynamic impact

Perspectives

[©S. Leone, 1966]

Models presented here were realized with RING-plugins:

Connecto GoNurbs GoScope

Thank You !

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+ 140 universities

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