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]

[Sikkema & Wojcik, 2001]

Gravity, electric and electromagnetic measurements

Seismic amplitudes

Well Logs

Core samples

Increasing resolution

Interpretation process

Increasing scarcity
Uncertainties in subsurface

- Various data, various resolution

[Sikkema & Wojcik, 2001]

Interpretation process

Increasing resolution

Increasing scarcity

Huge uncertainties

Gravity, electric and electromagnetic measurements

Seismic amplitudes

Well Logs

Core samples

[SGU, 2019]
Uncertainties in subsurface

- Various data, various resolution

Gravity, electric and electromagnetic measurements

Interpretation process

Increasing resolution

Well Logs

Core samples

Increasing scarcity

[Sikkema & Wojcik, 2001]

[SGU, 2019]

Huge uncertainties to represent and analyze them

Stochastic approaches
Uncertainties in subsurface

- Various data, various resolution

[SGU, 2019]

Gravity, electrical, electromagnetic measurements

- Huge uncertainties to represent and analyze them
- Stochastic approaches to reduce them
- Geological concepts
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]
1. Channelized systems
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]
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]

- Analogs
- Seismic
- Wells

Parameters
Curvatures, amplitude, wavelength (…)

Channel morphology
*L*-system

Data conditioning
*Constraints*
How to simulate channels?

- Analogos
- Seismic
- Wells

Parameters
Curvatures, amplitude, wavelength (…)

Channel envelope
NURBS
[Ruiu et al., 2015]

Data conditioning
Constraints

Channel morphology
L-system

G. Rongier's PhD [2016]
Application: turbiditic channels

Constraints:
- The master channel sides
- The probability cube

[Rongier et al, 2017]
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...

Sand probability cube

Realization conditioned to the cube

Sand probability

[Rongier, 2016]
Intermediate Conclusion

L-systems can reproduce a trend...

Sand probability cube

300 m

1475 m

Realization conditioned to the cube

Reality

Sand probability

0

1

Sand probability cube [Deptuck et al., 2003]

[Deptuck et al., 2003]

[Deptuck et al., 2003]

... but not a precise stacking

[Deptuck et al., 2003]

[Rongier, 2016]
Channelized system modelling

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

[Schema by Parquer]

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

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

[Schema by Parquer]

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[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

- 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

- ChaRMigS:
  - Geometrical description of migration process
    - With decomposition in downstream / lateral components
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  - Integration of abandoned meanders in the process

Estimated abandonment ages

[Parquer et al., 2017]

[Google Earth 63°12′2533″N 122°59′5373″E] 1 km
A "mixed" approach for reverse migration

- ChaRMigS:
  - Geometrical description of migration process
  - With decomposition in downstream / lateral components
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One realization

[Parquer et al., 2017]

[Google Earth 63°12′2533″N 122°59′5373″E]
A "mixed" approach for reverse migration

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

A second one...

[Parquer et al., 2017]

Realization 2

[Google Earth 63°12’2533”N 122°59’5373”E] 1 km
The particularities of reverse migration

 Chronology

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

 Abandoned meander facies data point
The particularities of reverse migration

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

Chronology

Simulation

Discrete event simulation

MSc: A. Cayrol
The particularities of reverse migration

- Honoring well data in reverse migration

(a) Point bar facies data
(b) Abandoned meander facies data

[Parquer, 2018]
Data conditioning 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...
2. Salt tectonics
The challenges of modelling salt tectonics

- **Salt modeling challenges** \cite{Collon2016}
  - Handling complex surfaces
  - Varying geometries and topologies
Stochastic salt modeling

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

After Thore et al. (2002)
Stochastic salt modeling

• Reference model
  • Pseudo-distance field $D$
  • Defines a “probability” of being in sediments
• Construction
  • Boundary constraints
  • Interpolation \cite{Irakarama2018}

Seismic image from Jackson and Lewis (2012)

\cite{Clausolles2019}
Stochastic salt modeling

• Perturbation
  • Spatially correlated random field $\varphi$
  • Sequential Gaussian simulation

• Distribution model
  \[ \varphi \sim \begin{cases} 
  0 & \text{if } \varphi < \text{threshold} \\
  1 & \text{if } \varphi \geq \text{threshold}
\end{cases} \]

• Variogram model
  \[ V: 800 \text{m} \]

Seismic image from Jackson and Lewis (2012)

[Clausolles et al., 2019]
Sampling salt bodies

- Definition of the salt boundary
  - 0-Level set of $D_{pert} = D - \varphi$

- Multiple salt boundaries
  - Multiple perturbations $\varphi$

Seismic image from Jackson and Lewis (2012)

[Clausalles et al., 2019]
Stochastic salt modeling

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

[Clauzolles et al., 2019]
Stochastic salt modeling

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

[Clausolles et al., 2019]
Stochastic salt modeling

• 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 $D/\phi$

Seismic image from Jackson and Lewis (2012)

[Clausolles et al., 2019]
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]
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