Application of a Training-Image Library to Reservoir Modeling Using Multi-Point Statistics Based on Quantitative Fluvial Facies Characterization*

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Abstract

Facies modelling seeks to reproduce the geometry and distribution of the reservoir-forming sedimentary bodies in three dimensions to provide a framework for the construction of property and flow models. However, variogram-based facies modelling techniques are not well suited to the reproduction of complex geological shapes (e.g., sinuous fluvial channels), whereas object-based simulations may fail to honour conditioning data (e.g., well data). New workflows have been developed for the generation of fluvial reservoir models with improved geological realism compared to outputs of conventional methods. These workflows are suitable for modelling reservoirs that comprise fluvial meander-belt deposits, and can therefore provide the models of spatial heterogeneity (training images) required to apply simulation techniques based on multi-point statistics (MPS), which are then useful to integrate complex geological patterns. A library of training images from which MPS modelling algorithms replicate geological patterns has been developed using quantitative information derived from a relational database of geological analogues (Fluvial Architecture Knowledge Transfer System, FAKTS), and a forward stratigraphic modelling tool that simulates fluvial meander-bend evolution and resulting point-bar facies organization (PB-SAND). The devised training images incorporate fundamental features of the facies architecture of fluvial point-bar elements and larger meander belts composed of these and related elements. The application of training images has been optimized to three widely used MPS algorithms: SNESIM, DEESSE and FILTERSIM. A quantitative and qualitative quality check of MPS realizations has been performed whereby facies proportions, facies relationships, element geometries, dimensions, control of non-stationarity and runtime are optimized for particular fluvial successions being modelled. The sensitivity of multiple simulation results to input parameters has been analysed to define preferred modelling recipes, paired to each training image and to each MPS modelling algorithm. Research outcomes are the development of an extensive library of training images for MPS simulations of the architecture of subsurface successions deposited by a variety of types of meandering fluvial systems. Devised workflows are applicable to multiple MPS algorithms, and enable off-the-shelf training-image selection for the effective establishment of a hierarchical approach to facies modelling.

Selected References

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Colombera, L., N.P. Mountney, and W.D. McCaffrey, 2012, A relational database for the digitization of fluvial architecture: concepts and example applications: Petroleum Geoscience, v. 18, p. 129–140.

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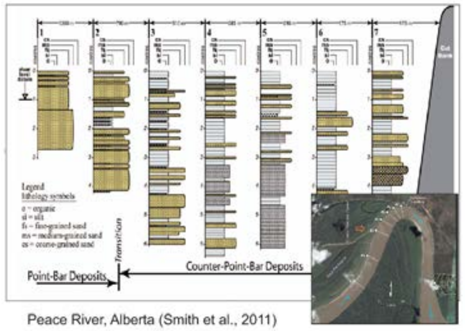
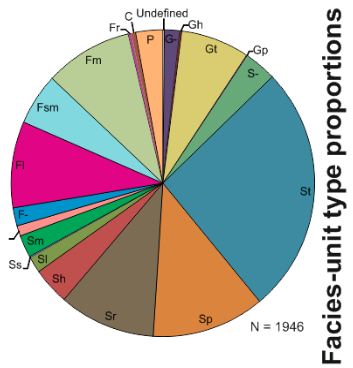
LITERATURE AND FIELD STUDIES



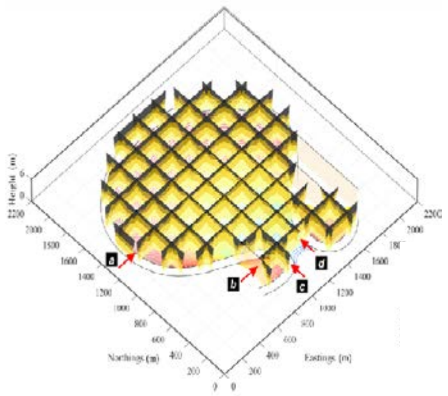
Peace River, Alberta (Smith et al., 2011)

FAKTS (DATABASE)

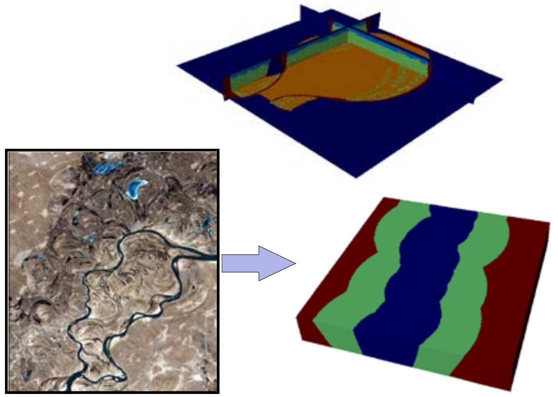
(Fluvial Architecture Knowledge Transfer System)



3D STRATIGRAPHICAL MODELS

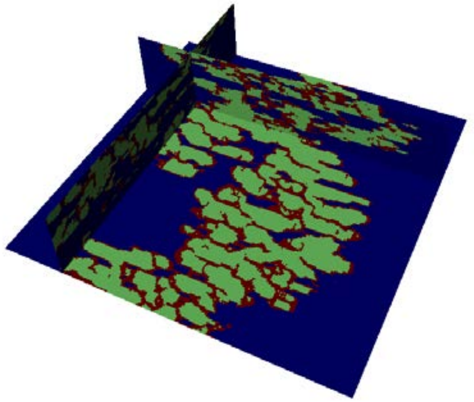


TRAINING IMAGES & AUXILIARY VARIABLE MAPS



FACIES MODELLING

SNESIM & DEESSE



AREVA · AkerBP · bhpbilliton · ConocoPhillips · MURPHY OIL CORPORATION · NERC SCIENCE OF THE ENVIRONMENT · CNOOC · nexen · pds petrotechnical · Saudi Aramco · Shell · TULLOW · woodside · YPF

MAIN POINTS AND AIM OF THE PROJECT

OUTLINE

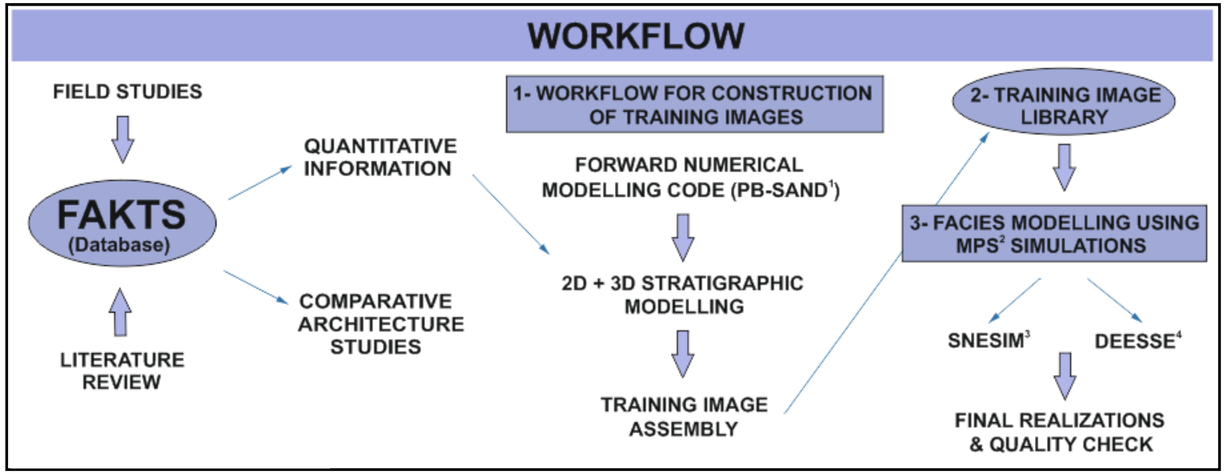
1- What are facies models? Why do they need to be improved?

2- Multipoint statistical simulation introduction (MPS)

3- A novel facies modelling workflow for fluvial meandering system

- FAKTS analogue database
- PB-SAND program for forward stratigraphical models
- Training Image Library

4- Applications to SNESIM and DEESSE (Multipoint Statistical simulation)



AIMS

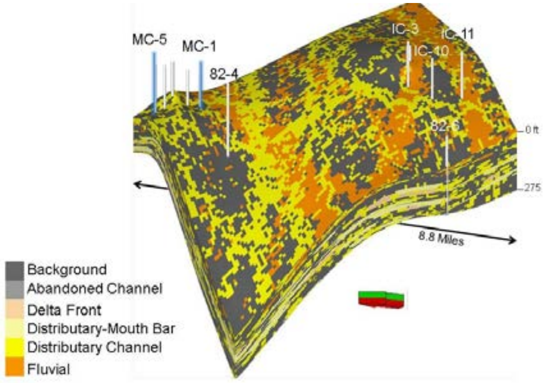
- Deliver an effective and fast methodology by which training-image building can be informed quantitatively
- A workflow for facies modelling using MPS applicable in the oil and gas industry, geothermal and hydrogeology

WORKFLOW AND GEOSTATISTICAL METHODS

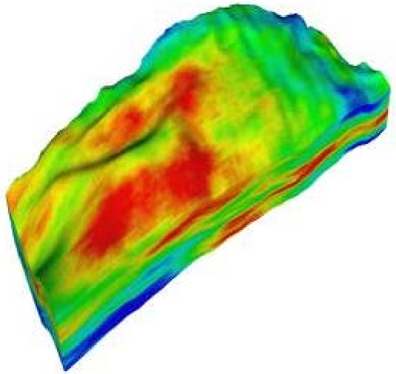
Why does facies modelling matter?

Why do facies models need to be improved?

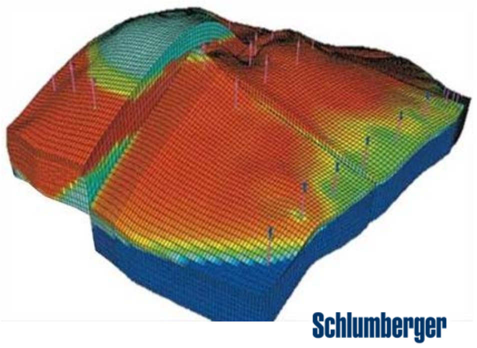
Facies models



Property models
(Vcl,Φ,Ꝁ, Sw…)

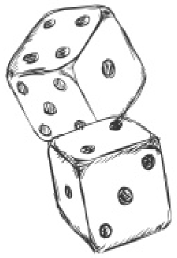


Flow Models

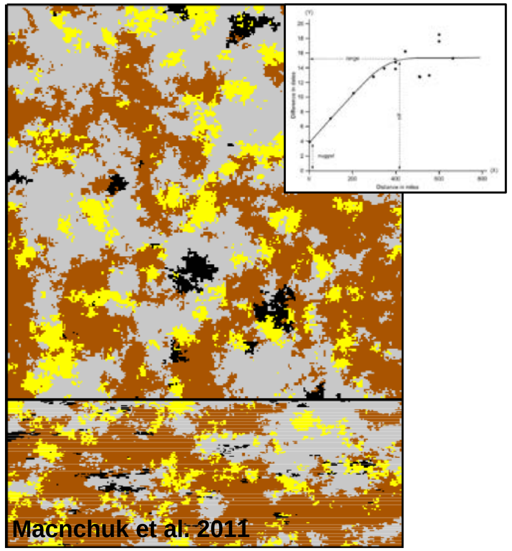


Lack of data
(Well data, core data, seismic data)

Geostatistical methods
“The need to fill the gaps”

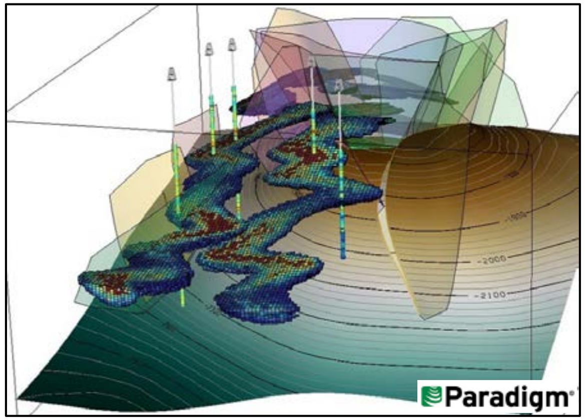


1- Pixel-based methods (I.e., SIS)



- Does not reproduce curvilinear shapes
- Relies on variograms…

2- Object-based methods



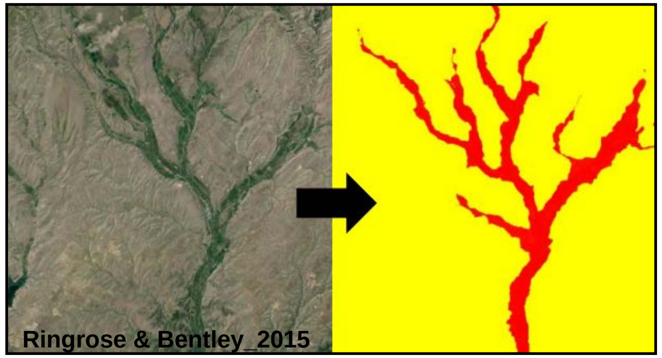
- Not good at honouring hard data

MULTIPOINT STATISTICAL SIMULATIONS (MPS)

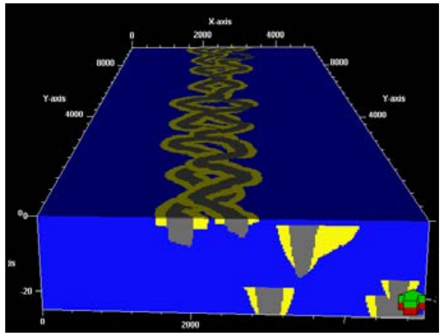
Multipoint statistical simulations combines both the capability of honouring hard data and the ability to reproduce complex geological shapes

Needs a TRAINING IMAGE → **The digital representation of the heterogeneities of the reservoir rock.**

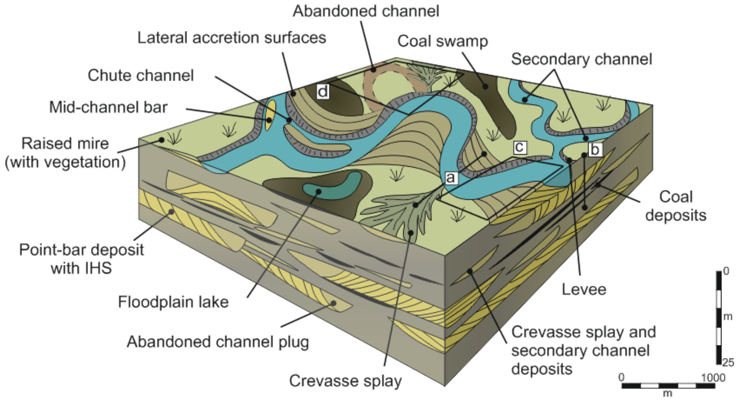
- **The training image substitutes the variograms.**



Satellite image



Object-based generated 3D realization



"Shiers (2017) and Ghazi and Mountney (2009)"

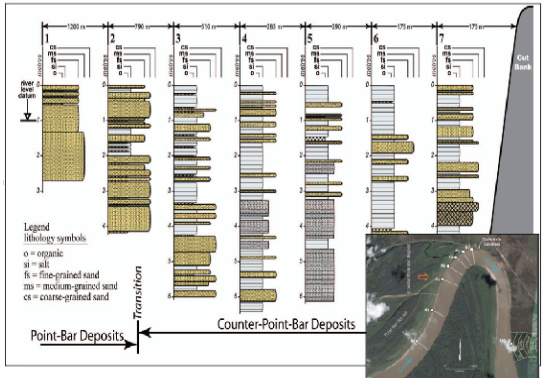
Facies models based on outcrop studies

Need to be "stationary"

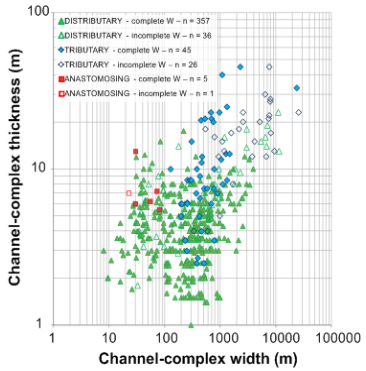
- **1: Patterns are reasonably homogeneous in the Training Image**
- **2: Patterns should be repeated in the Training Image**
- **3: Patterns should not be confined to specific locations in the Training Image**

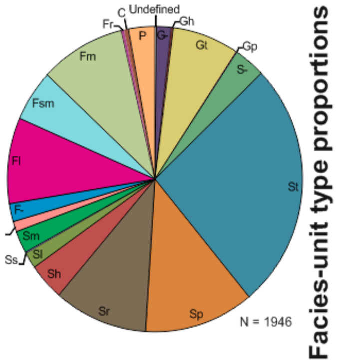
COLLATION OF QUANTITATIVE DATABASE OF APPROPRIATE CASE STUDY EXAMPLE

COLLATION OF QUANTITATIVE DATABASE OF APPROPRIATE CASE STUDY EXAMPLE



Peace River, Alberta (Smith et al., 2011)

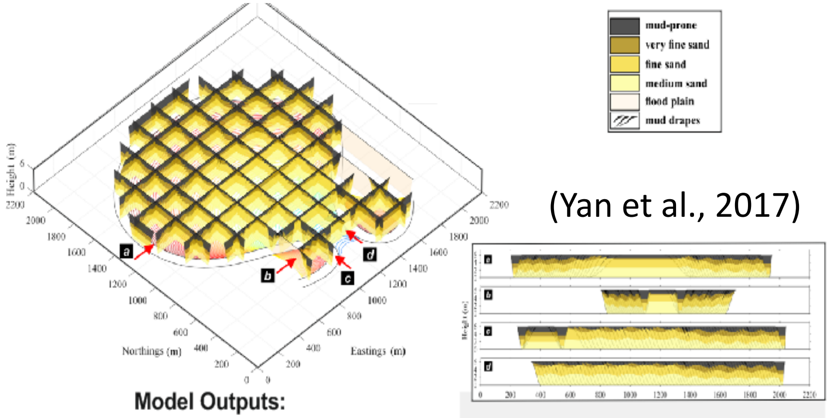




(Colombera et al., 2013)

FORWARD NUMERICAL SIMULATION OF FLUVIAL POINT-BAR EVOLUTION

		Mean	Min	Max	Std.
	bar thickness (m)	6			
	channel width (m)	74			
mud drape	thickness (m)	0.20	0.06	0.66	0.18
	length along accretion surfaces (m)	7.80	1.60	19.00	4.56
	spacing (m)	5.74	1.90	10.20	2.56
	position (to the top) (m)	1.35	0.28	3.30	0.79
	position (to the top)	23 %	5 %	55 %	13 %
facies	mud-prone	11 %			
	very fine sand	7 %			
	fine sand	37 %			
	medium sand	45 %			



(Yan et al., 2017)

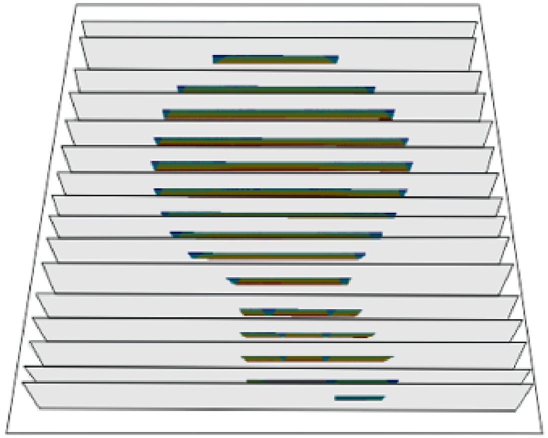
Model Components:

- Morphological Evolution
- Vertical Cross-Sections
- Stacking Patterns
- Bounding surfaces

Model Outputs:

- Facies Transections
- High resolution morphology
- Prediction of 3D architecture
- Probability of possible scenarios

TRAINING IMAGE IMAGE ASSEMBLY

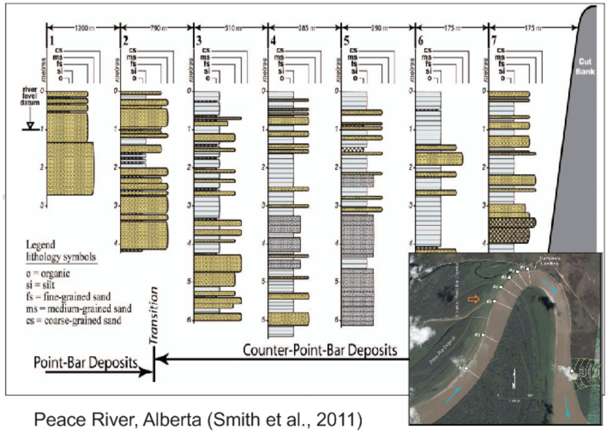


Training Image Components:

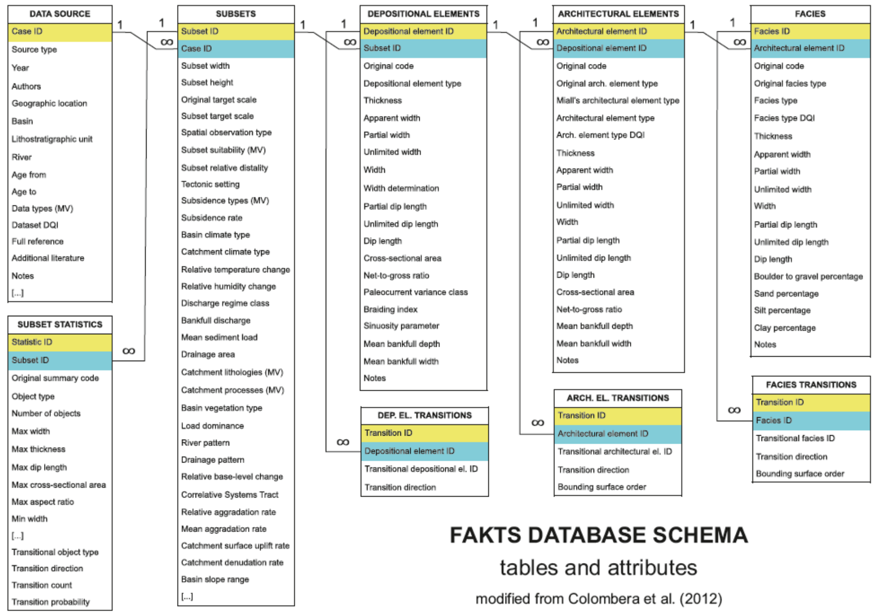
- Transects transformed from RGB to facies
- Stationary and non-stationary Training Images
- From .png to .gslib files.

FAKTS (Fluvial Architecture Knowledge Transfer System)

LITERATURE AND FIELD STUDIES



Peace River, Alberta (Smith et al., 2011)

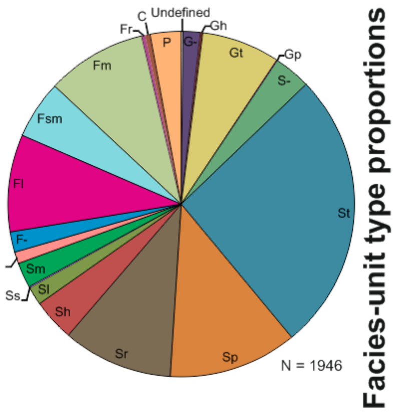


FAKTS DATABASE SCHEMA

tables and attributes

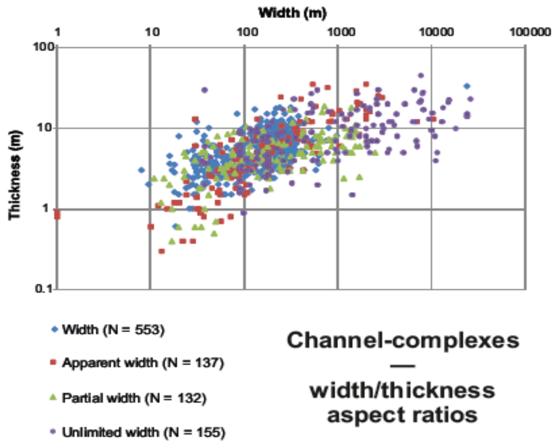
modified from Colombera et al. (2012)

Facies Proportions



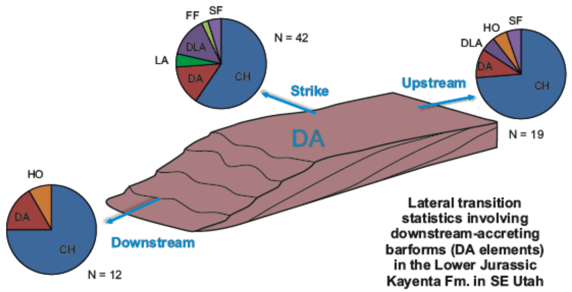
(Colombera et al., 2013)

Facies Geometries



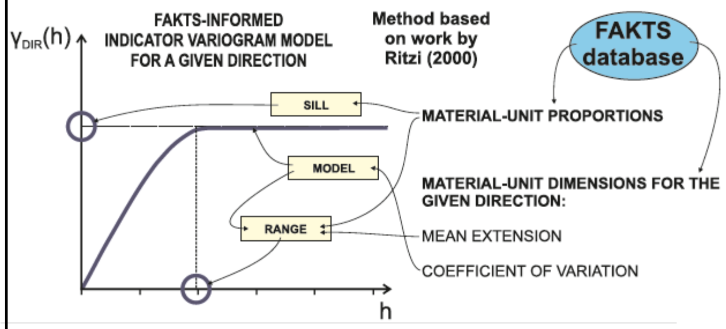
Channel-complexes
—
width/thickness aspect ratios

Facies transition statistics



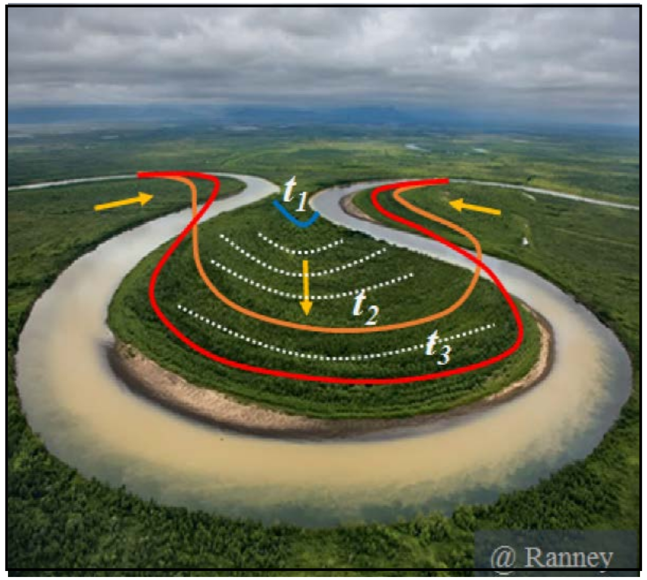
Lateral transition statistics involving downstream-accreting barforms (DA elements) in the Lower Jurassic Kayenta Fm. in SE Utah

Reservoir Modelling Constraints



FORWARD STRATIGRAPHIC MODELLING OF FLUVIAL POINT-BAR ELEMENTS USING PB-SANDS

EXPANSIONAL MEANDER EXAMPLE



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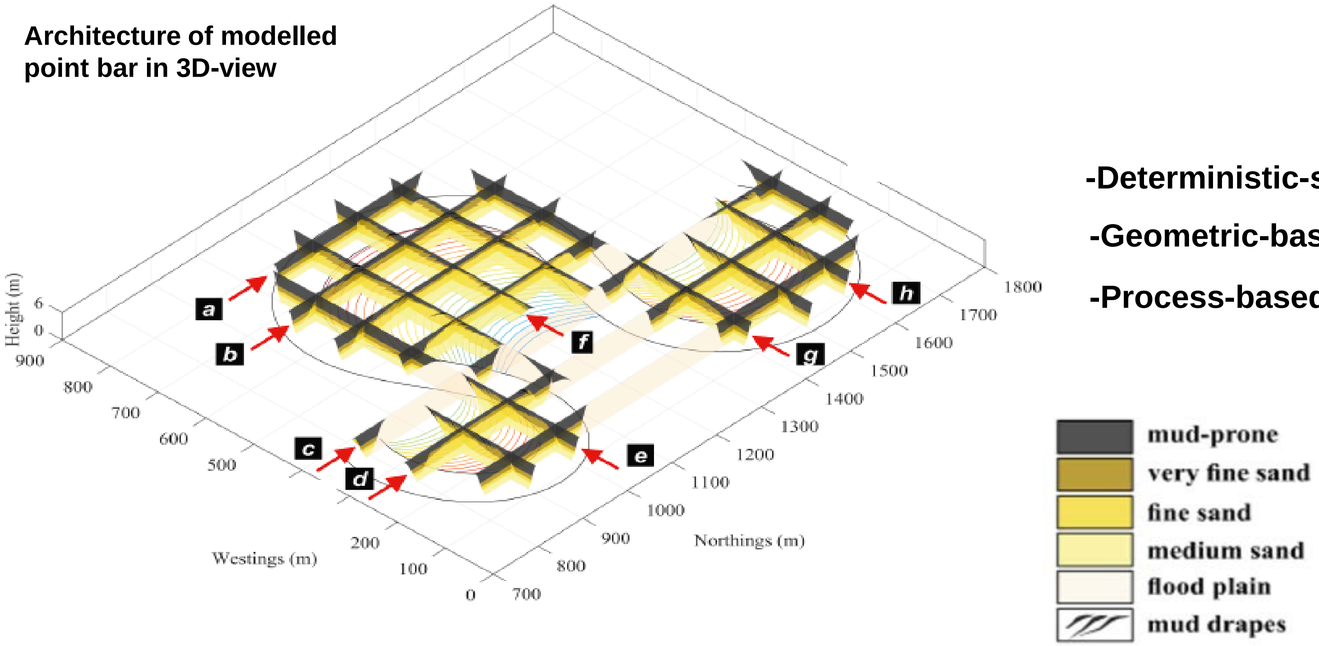
Yan et al., 2017. Computers & Geosciences, 105, 65-80

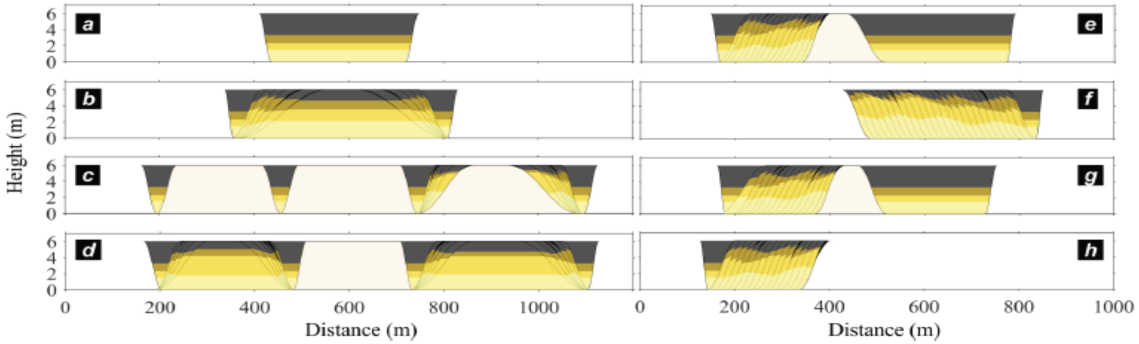
3D STRATIGRAPHICAL MODELS

Architecture of modelled point bar in 3D-view

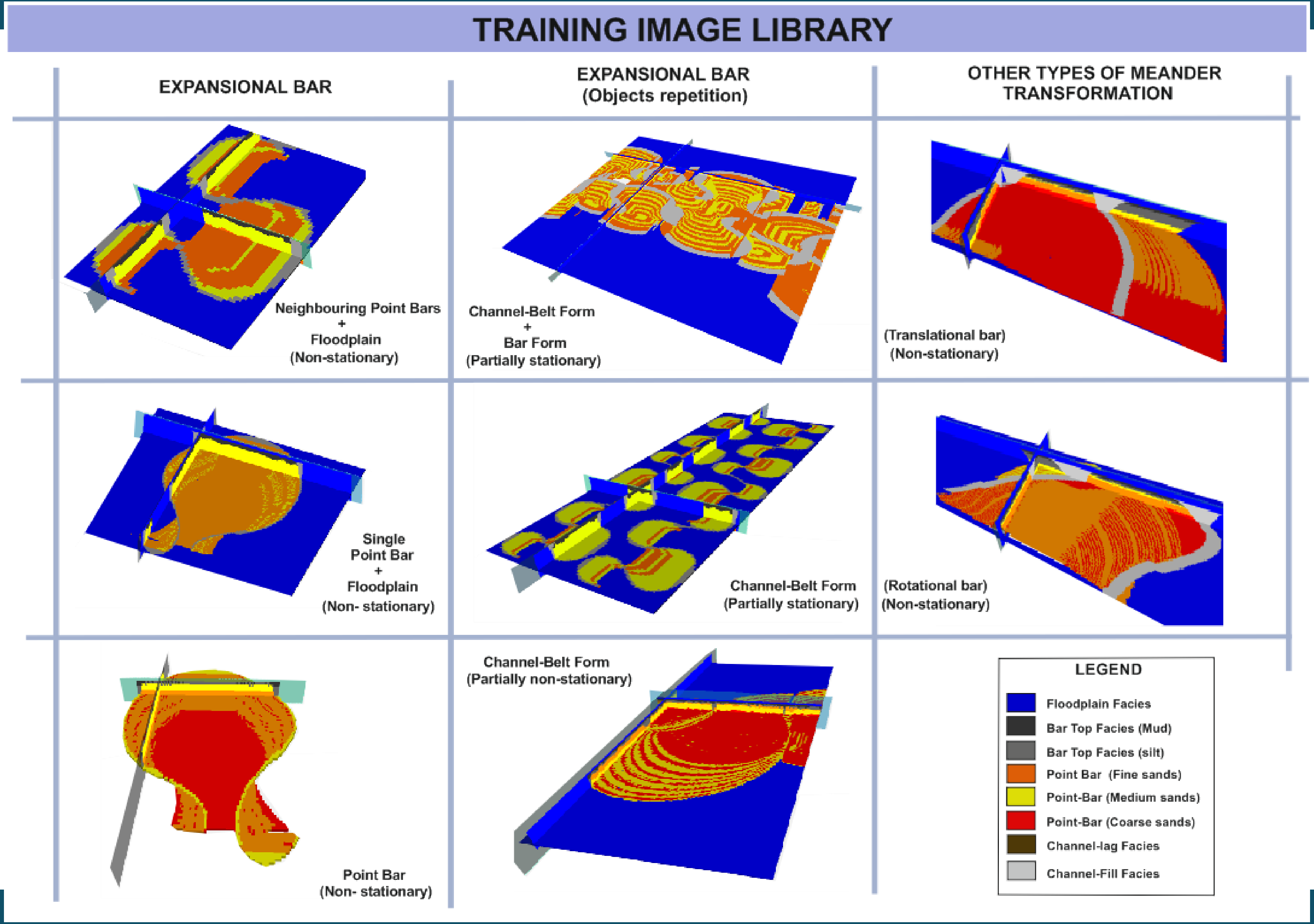


- Deterministic-stochastic mixed
- Geometric-based
- Process-based

Cross-sections examples

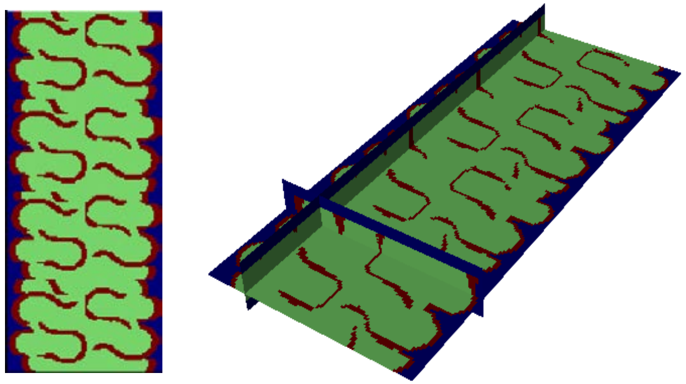


TRAINING IMAGE LIBRARY

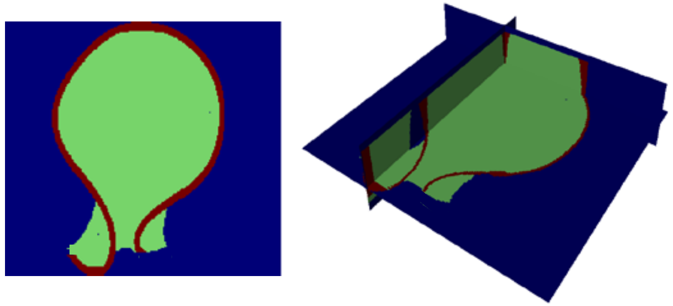


2 CASE STUDY (EXAMPLE 1 and 2)

EXAMPLE 1
EXPANSIONAL BAR
(Partially STATIONARY EXAMPLE)



EXAMPLE 2
EXPANSIONAL BAR
(NON-STATIONARY EXAMPLE)

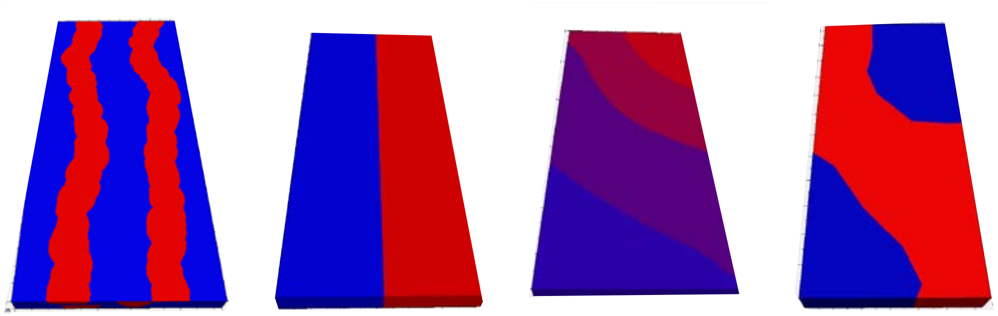


2 algorithm will be tested and compared:

SNESIM (Strebelle, 2002)	**DEESSE** (Mariethoz et al. 2010)
-Search Template Geometry	-Search Window
-Number of nodes	-Number of nodes
-Number of replicates	-Search distance
-Servosystem	-Fraction
-Multigrids	-Support Radius
-Subgrids	-Deactivation Threshold

AUXILIARY VARIABLE MAPS

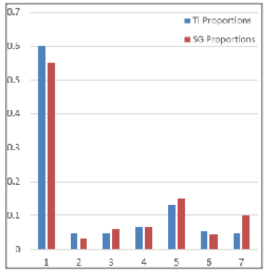
(Handling non-stationarity and include trends)



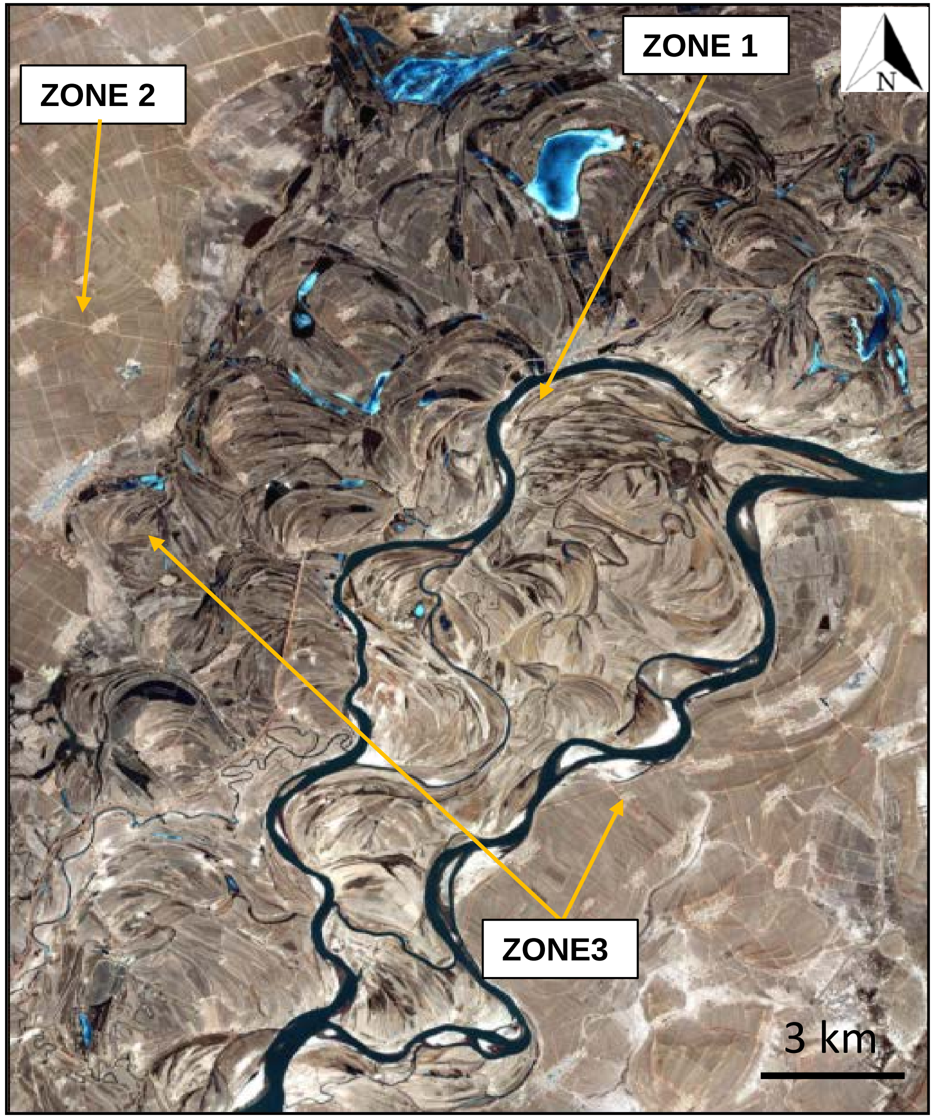
Probability **Rotation** **Scaling** **Regions**

QUALITY CHECK:

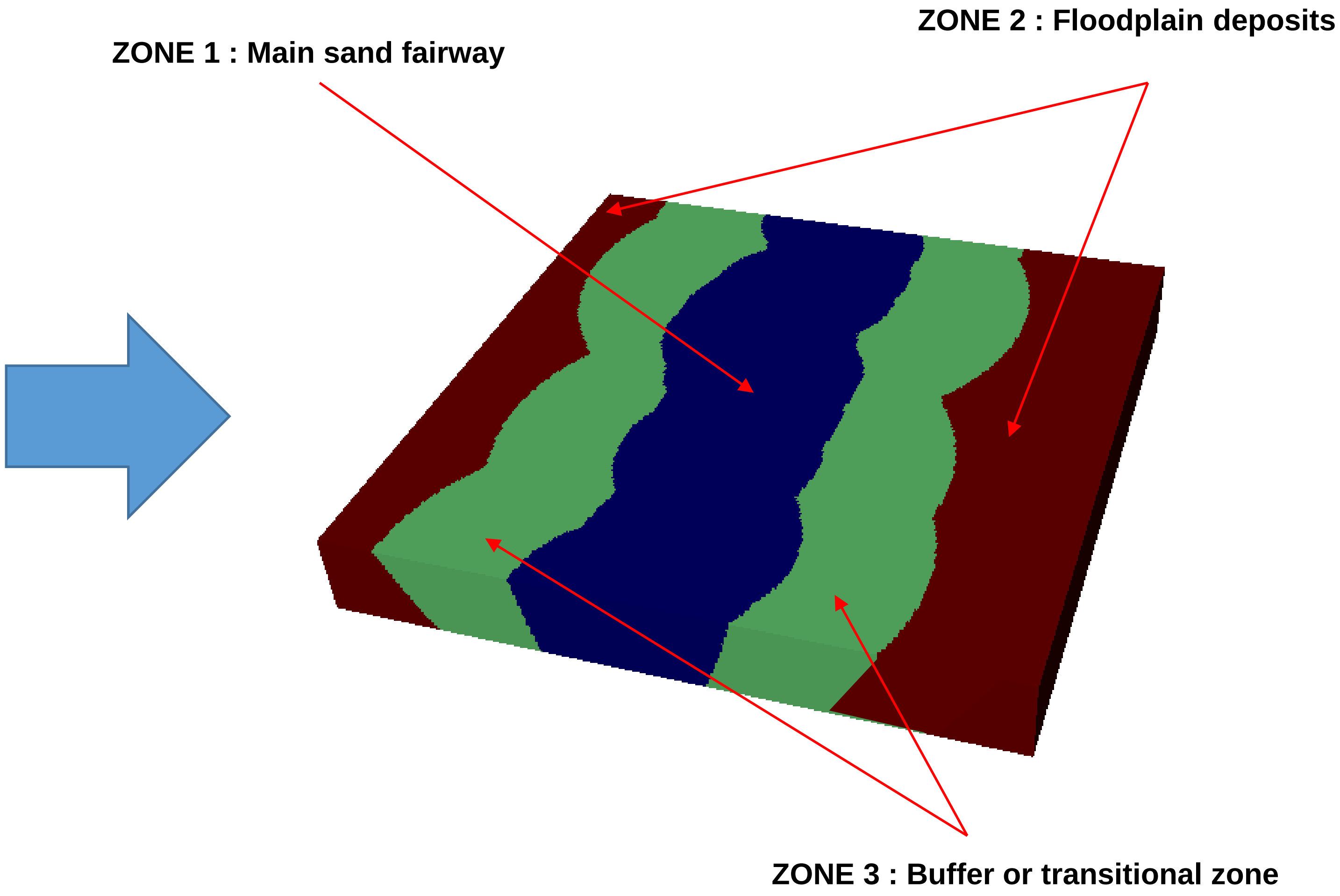
- -Geometries
- -Proportions
- -Trends
- -Run-Time
- -Noise
- -Stationarity



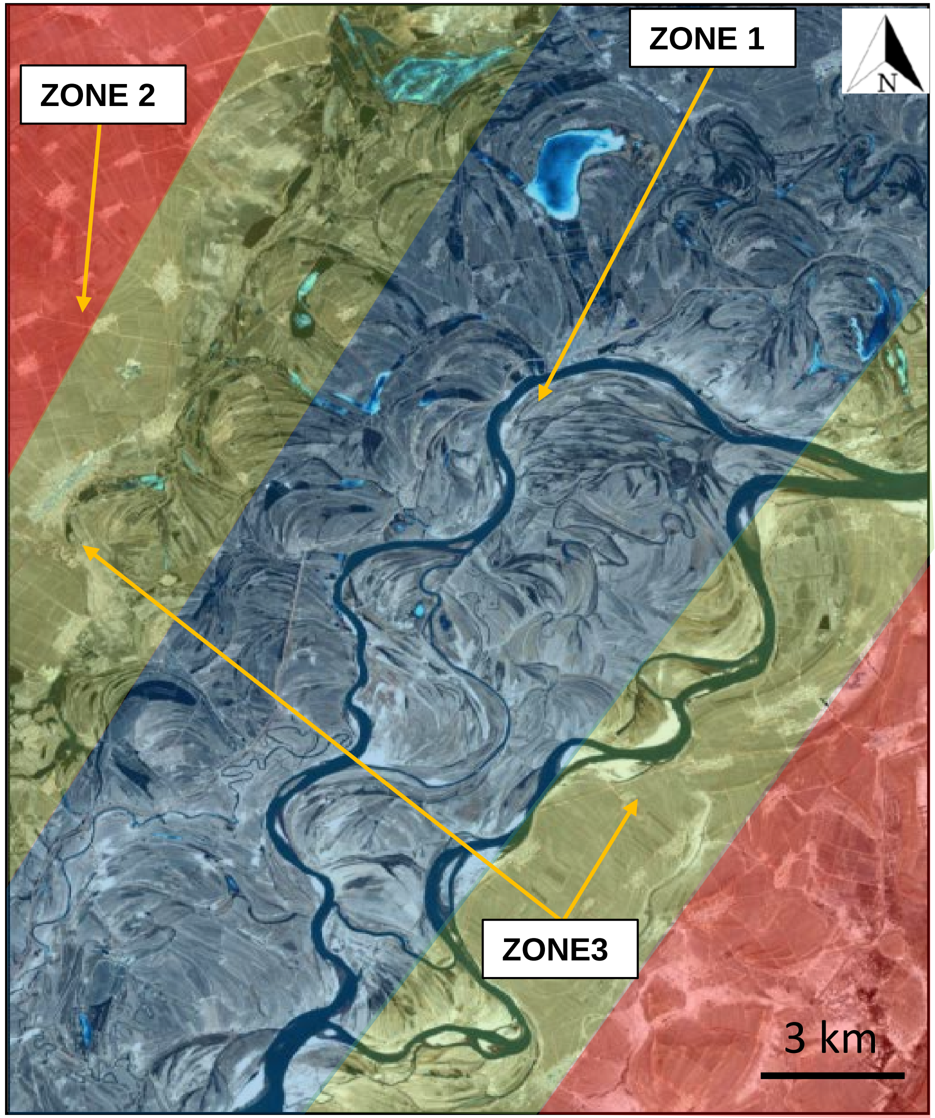
AUXILIARY VARIABLE MAPS (PROBABILITY MAPS CONSTRUCTION)



Songhua River, China (NASA)



AUXILIARY VARIABLE MAPS (PROBABILITY MAPS CONSTRUCTION)



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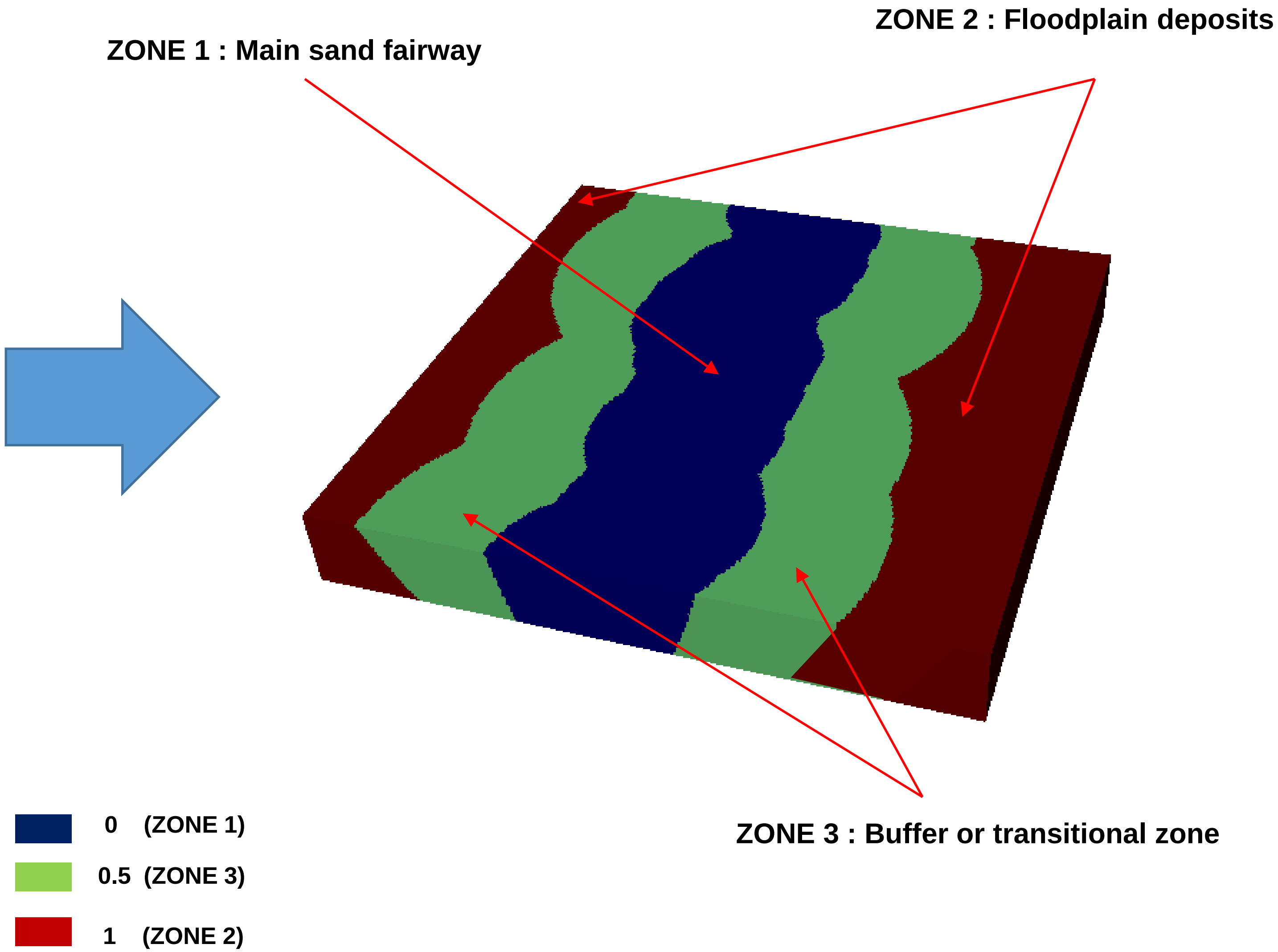
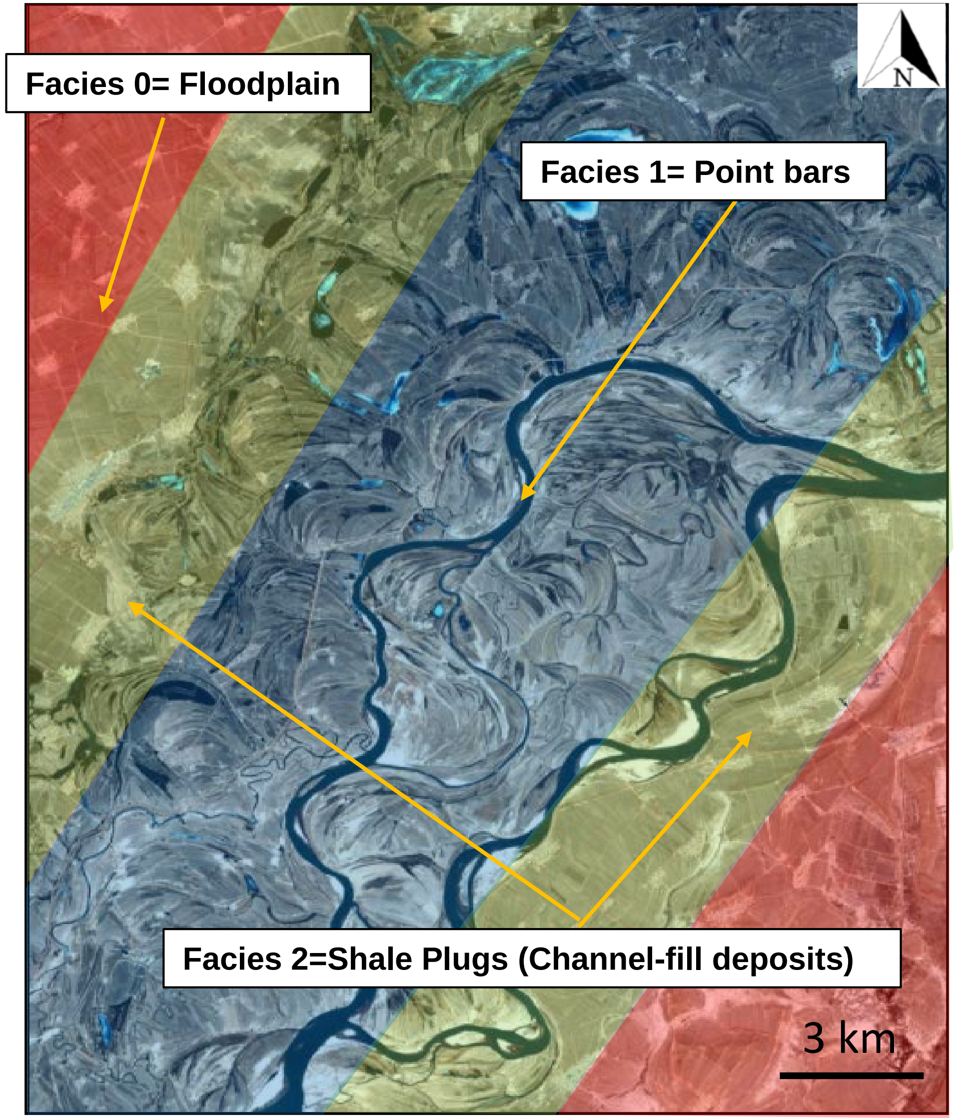


AUXILIARY VARIABLE MAPS (PROBABILITY MAPS CONSTRUCTION)



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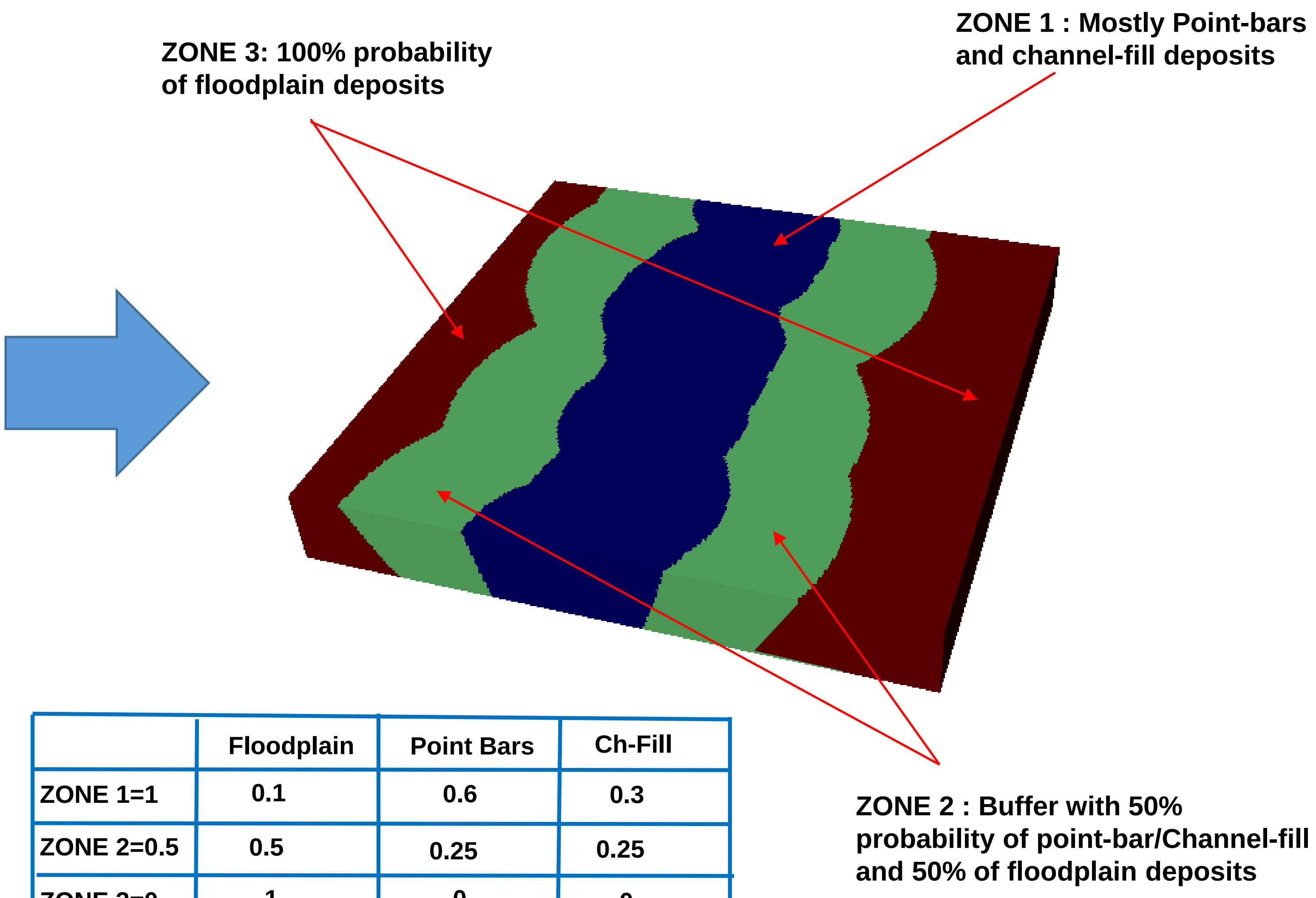
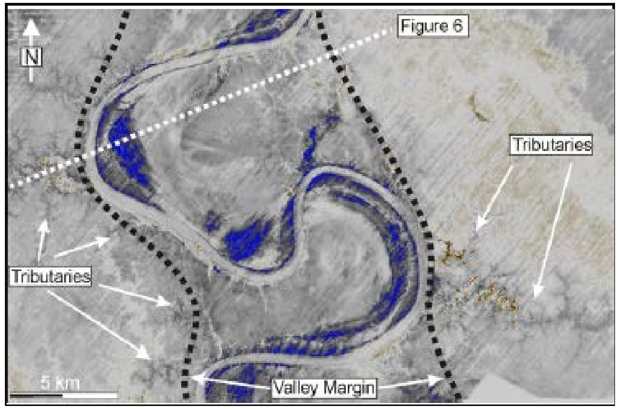
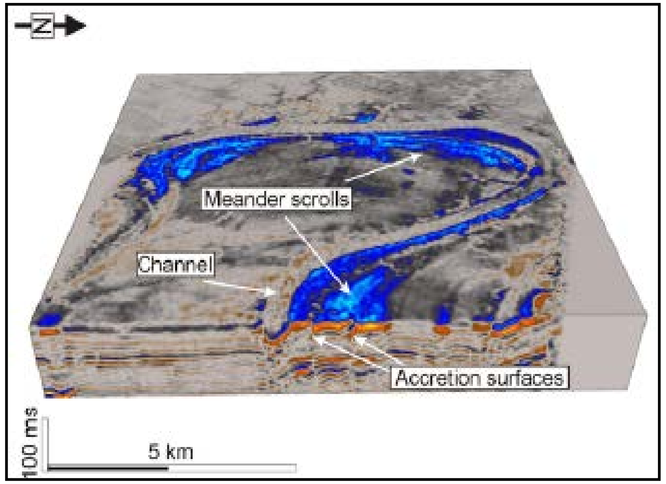


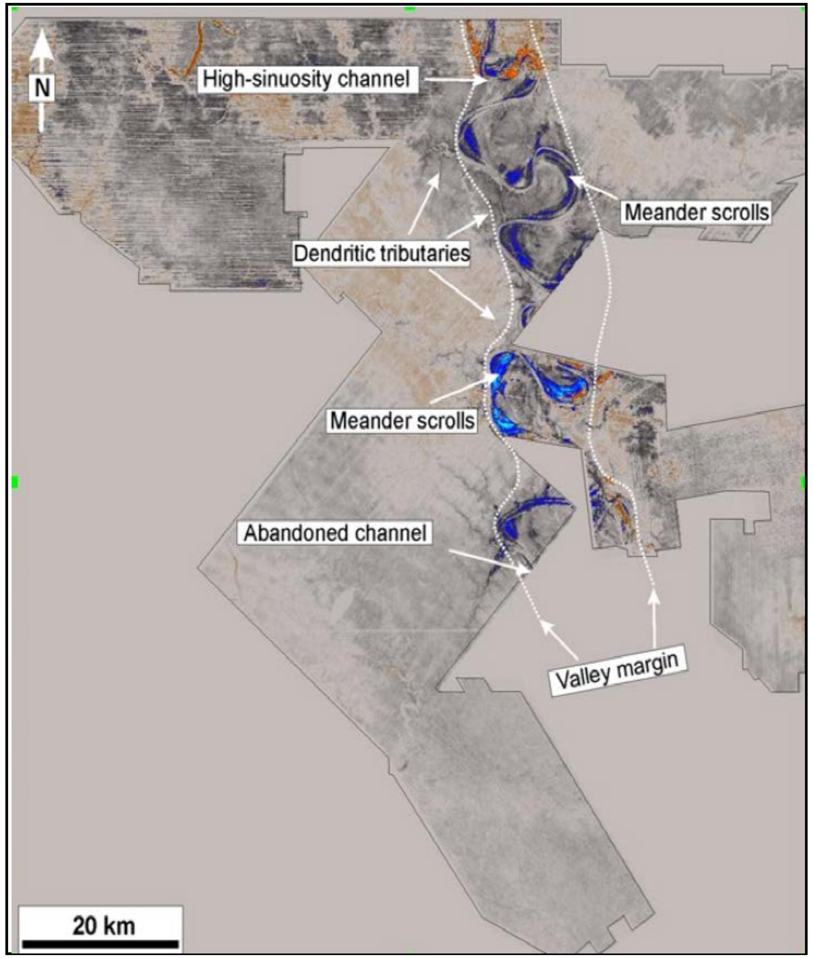
	Floodplain	Point Bars	Ch-Fill
ZONE 1=1	0.1	0.6	0.3
ZONE 2=0.5	0.5	0.25	0.25
ZONE 3=0	1	0	0

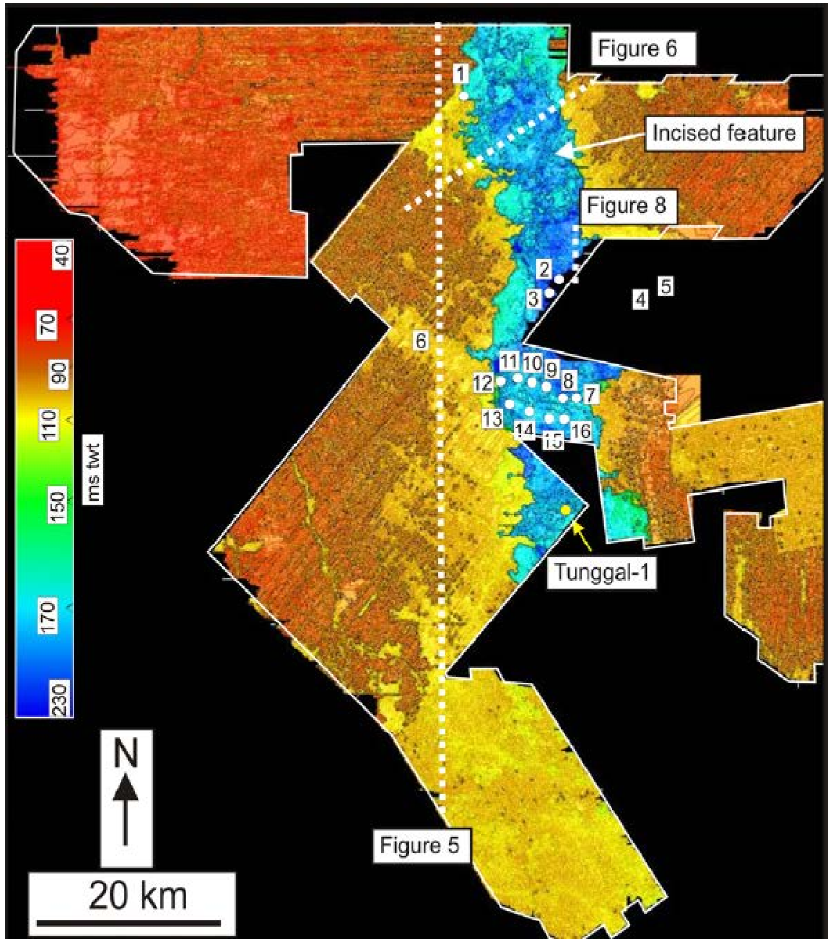
AUXILIARY VARIABLE MAPS (PROBABILITY MAPS CONSTRUCTION)

1- Based on SOFT DATA



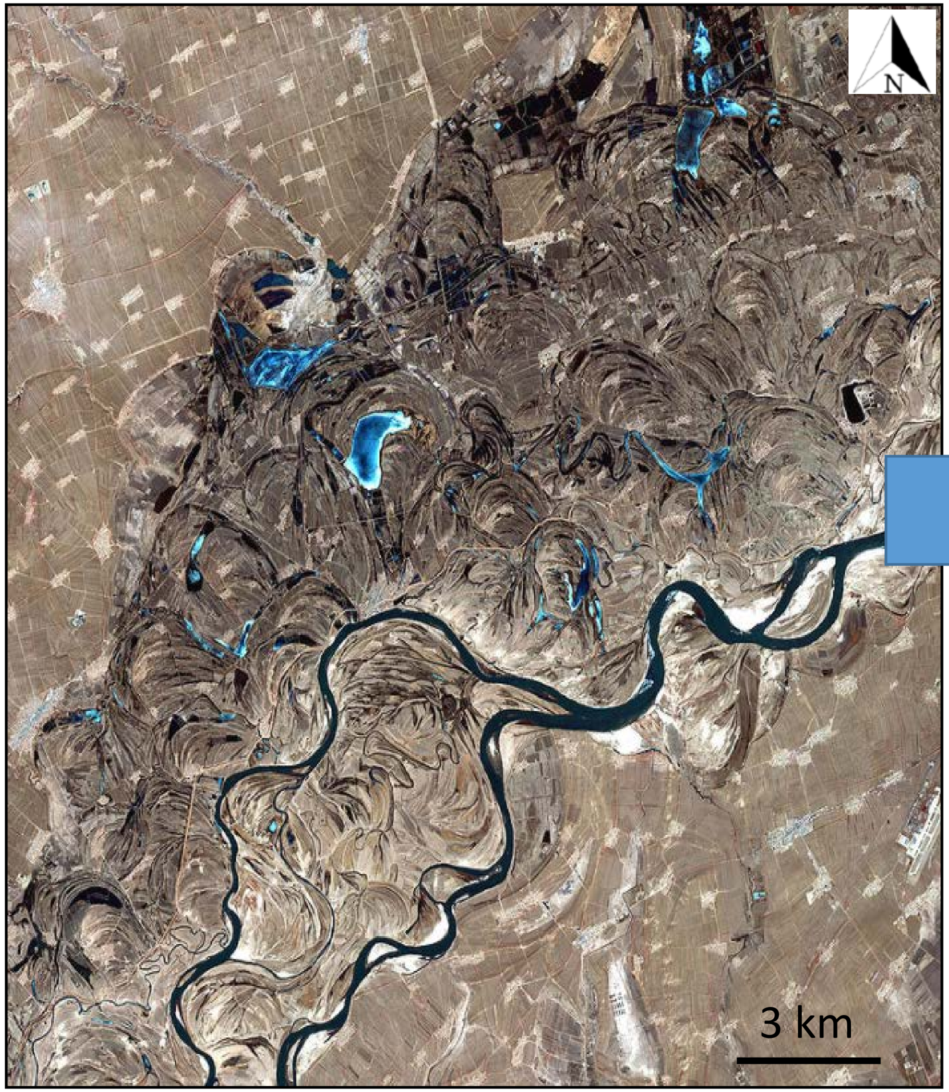






Alqahtani A. et al. 2015. Sedimentology 62, 1198-1232

AUXILIARY VARIABLE MAPS (PROBABILITY MAPS CONSTRUCTION)



Songhua River, China (NASA)

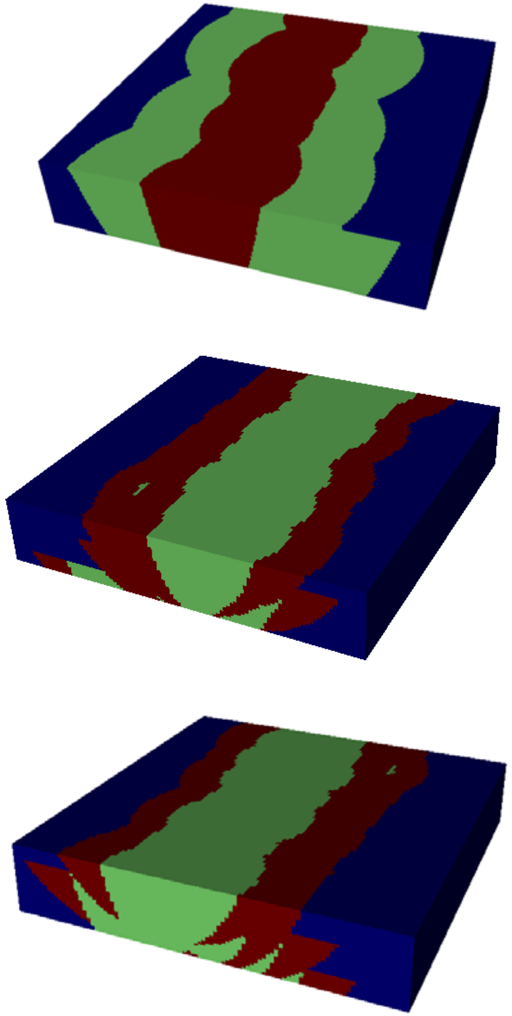
2- Based on FAKTS estimates (Channel-belt case)

- Sedimentological analysis at a BIG SCALE required to interpret the fluvial geological setting.

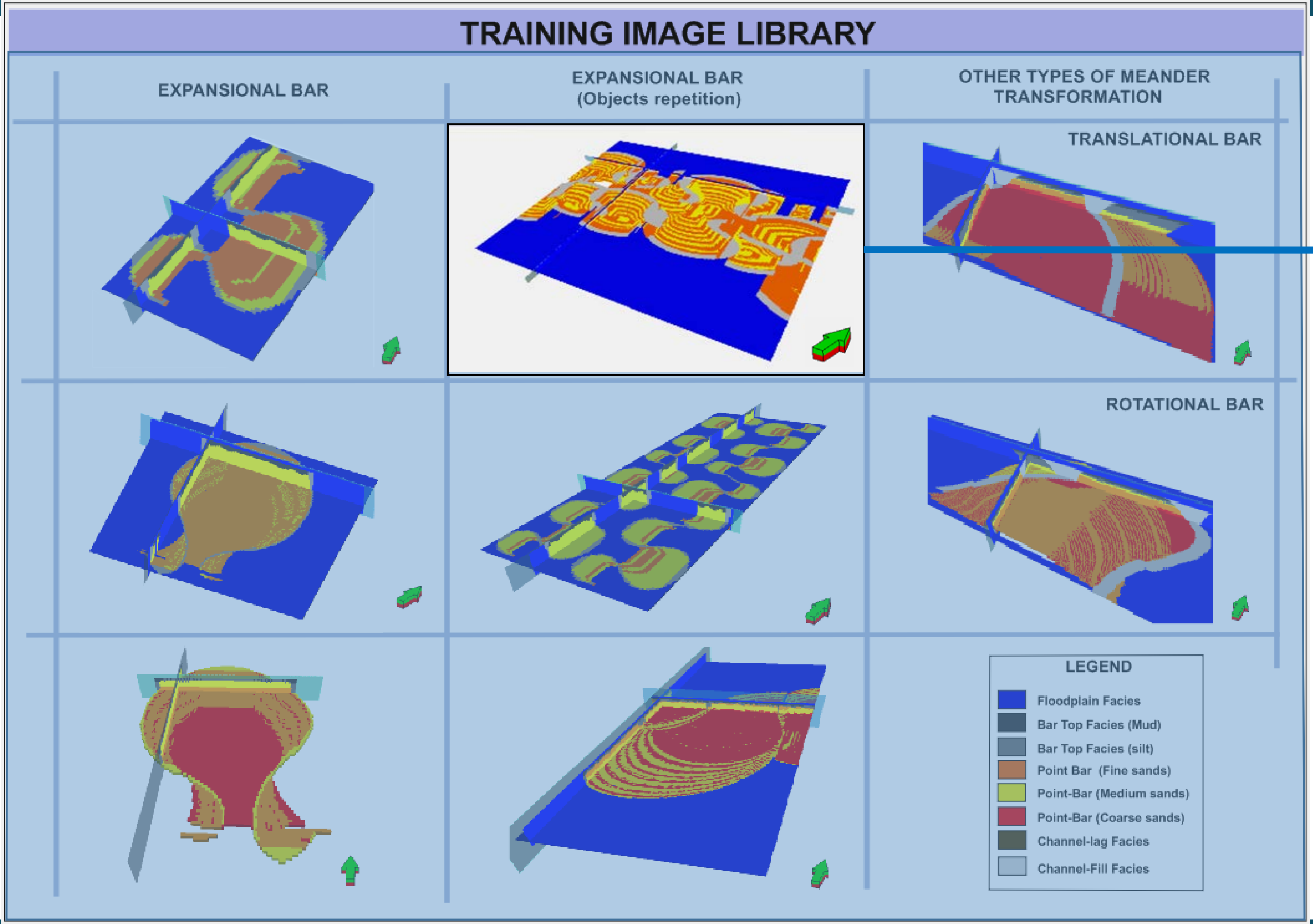
- Channel-belt estimates can be easily obtained using FAKTS:

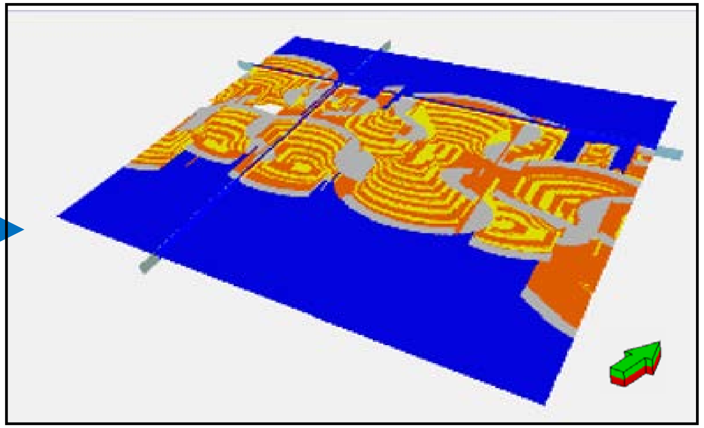
  - Facies Proportions
  - Geometries size
  - Net to gross (Shale/sand proportions)

- Different solutions can be created stochastically with an object-based algorithm.



EXAMPLE-1: EXPANSIONAL BAR (STATIONARY EXAMPLE)



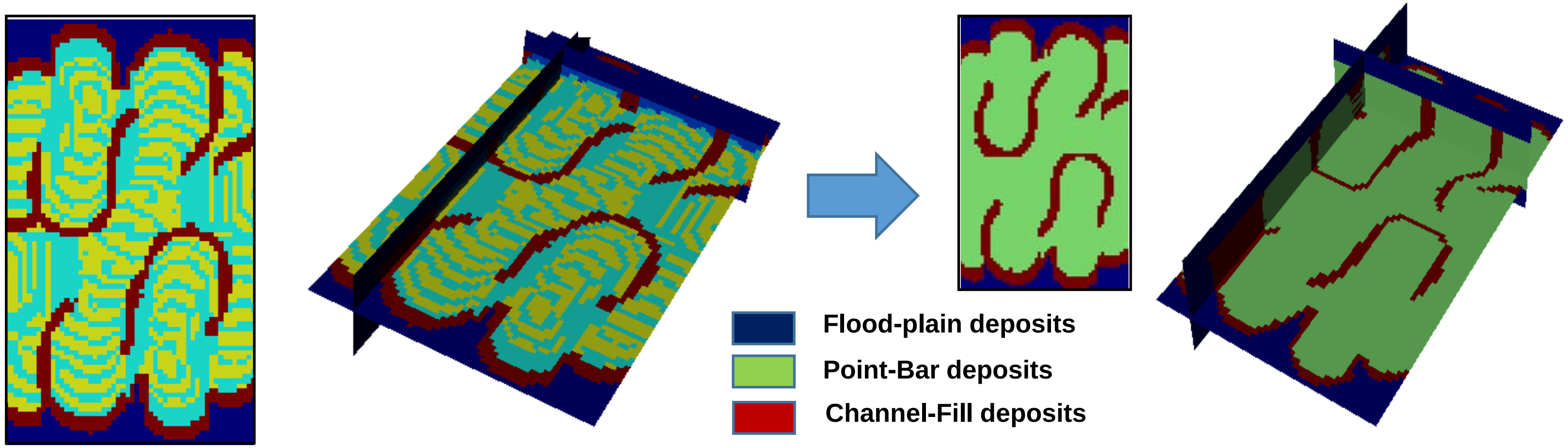


EXPANSIONAL BAR CASE
(PARTIALLY STATIONARY
TRAINING IMAGE)

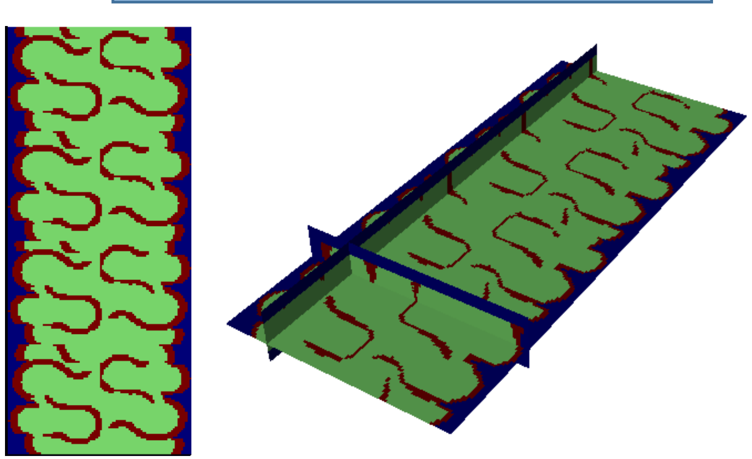
- **Homogeneous Patterns**
- **Repeated objects**
- **Only One single channel belt**

EXAMPLE-1. SIMULATION WORKFLOW

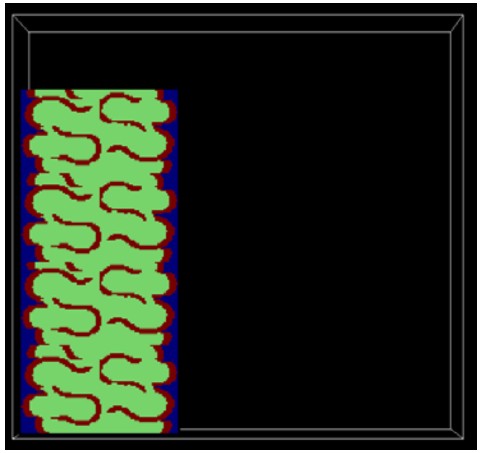
STEP 1: Category reduction (From 5 to 3 facies)



STEP 2: Adding Stationarity



STEP 3:Upscaling / Downscaling



SIMULATION GRID
X: 250
Y: 250
Z: 50

Training Image
Number of Cells
X: 90
Y: 210
Z: 33

CELL SIZE
X: 20
Y: 20
Z: 0.25

STEP 4: Sensitivity Phase

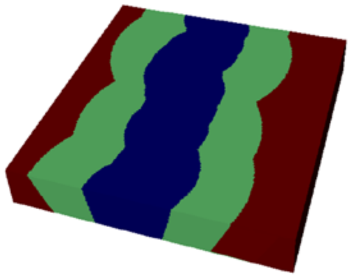
SNESIM (Strebelle, 2002)

-Search Template Geometry
-Number of nodes
-Number of replicates
-Servosystem

DEESSE (Mariethoz et al. 2010)

-Search Window
-Number of nodes
-Search distance
-Fractions

STEP 5: Auxiliary Variable Maps



	Facies 0	Facies 1	Facies 2
AREA 1	0.1	0.55	0.35
AREA 2	0.5	0.25	0.25
AREA 3	1	0	0

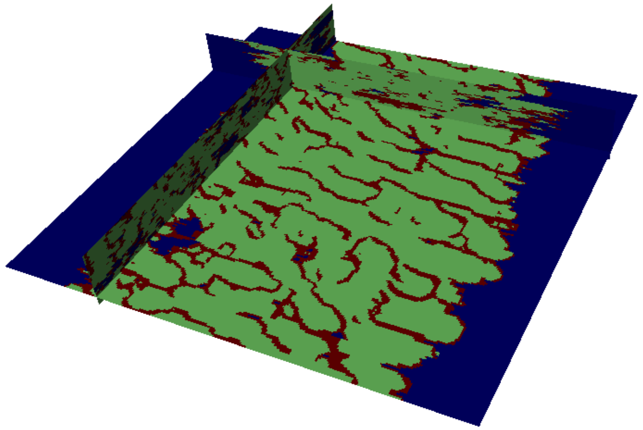
-TAU model probability for SNESIM

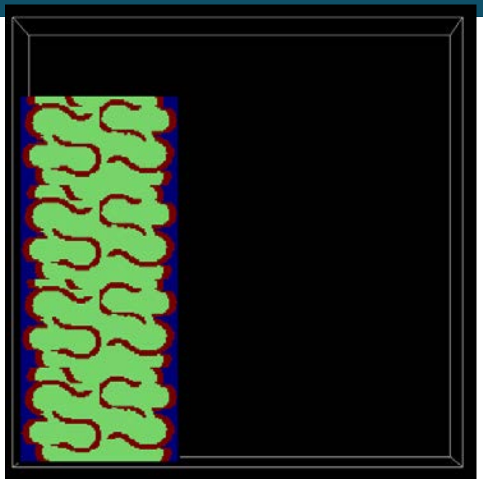
-Support radius and Deactivation threshold for DEESSE.

EXAMPLE-1. STATIONARY TRAINING IMAGE REALIZATIONS (3 facies)

Flood-plain deposits
Point-Bar deposits
Channel-Fill deposits

SNESIM Runtime <2 min/realization



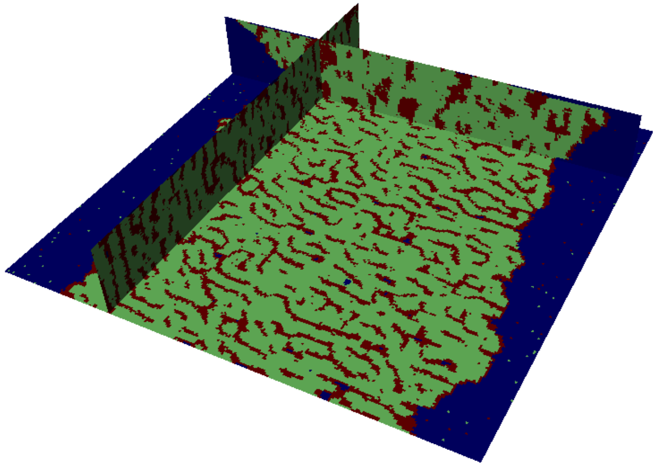


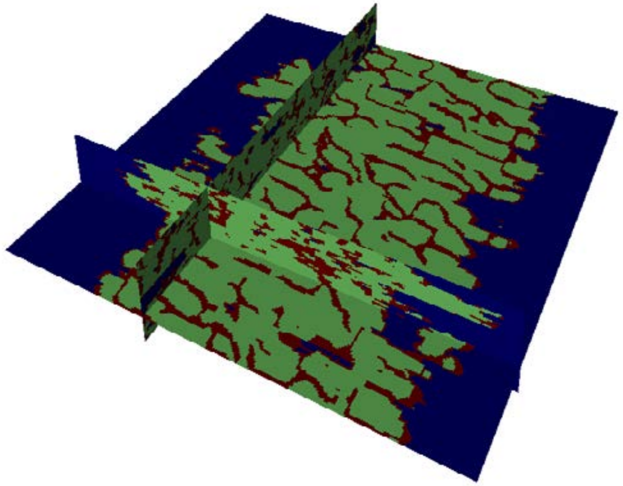
SIMULATION GRID
X: 250
Y: 250
Z: 50

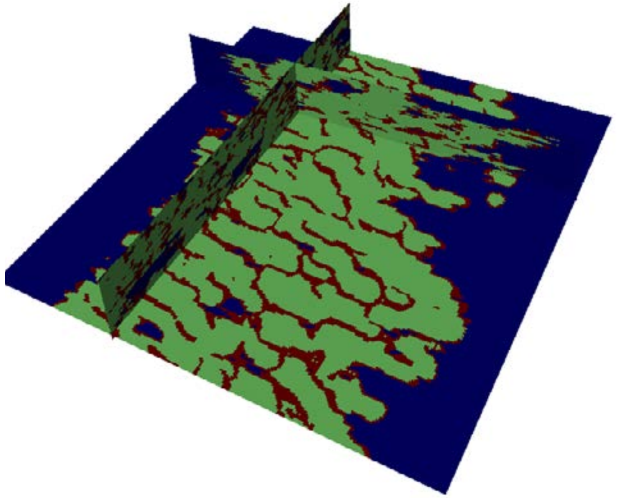
TI Number of Cells
X: 90
Y: 210
Z: 33

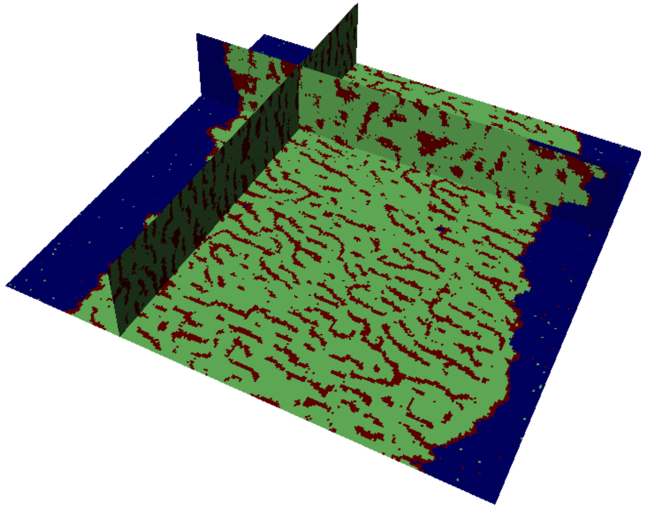
CELL SIZE
X: 20
Y: 20
Z: 0.25

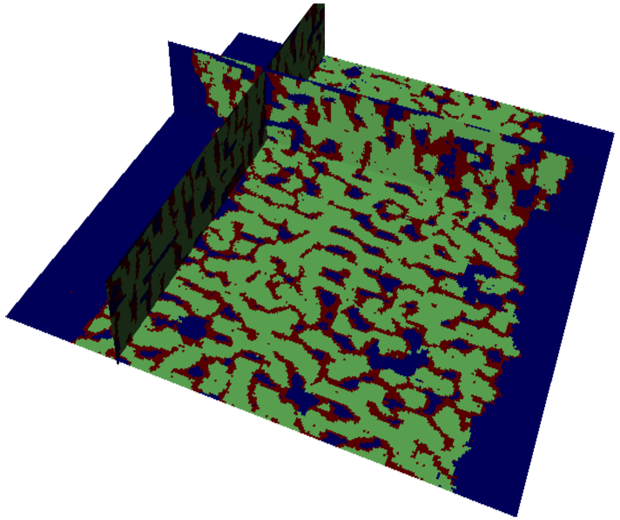
DEESSE Runtime <2 min/realization











Parameters:

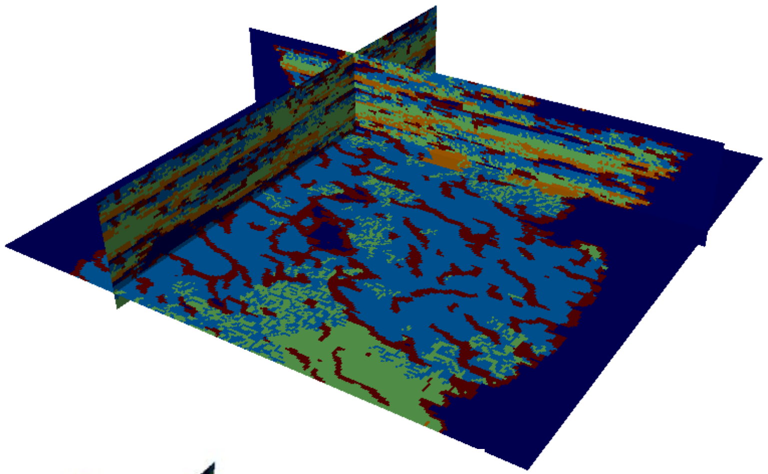
Search Radius: 4000x4000x15, N=70, Replicates=20, Serv=1, Multigrids=4
Condition to Auxiliary Probability (TAU MODEL 2 1)

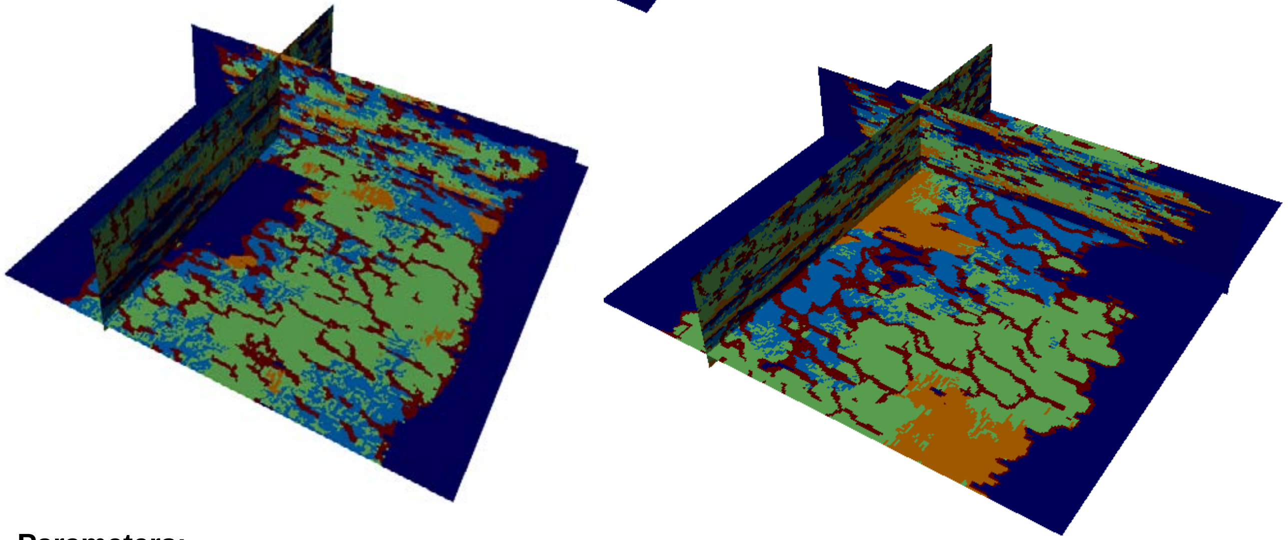
Parameters:

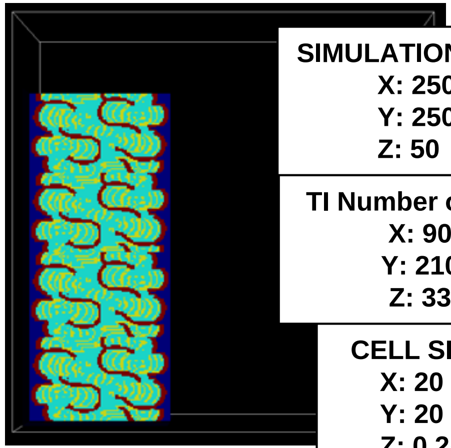
Search Window: 20x20x8, N=35, Distance=0.25, Radius=10, Deact. Threshold=5
Condition to Auxiliary Probability and Rotation map

EXAMPLE-1. STATIONARY TRAINING IMAGE REALIZATIONS (5 facies)

SNESIM Runtime <5 min/realization





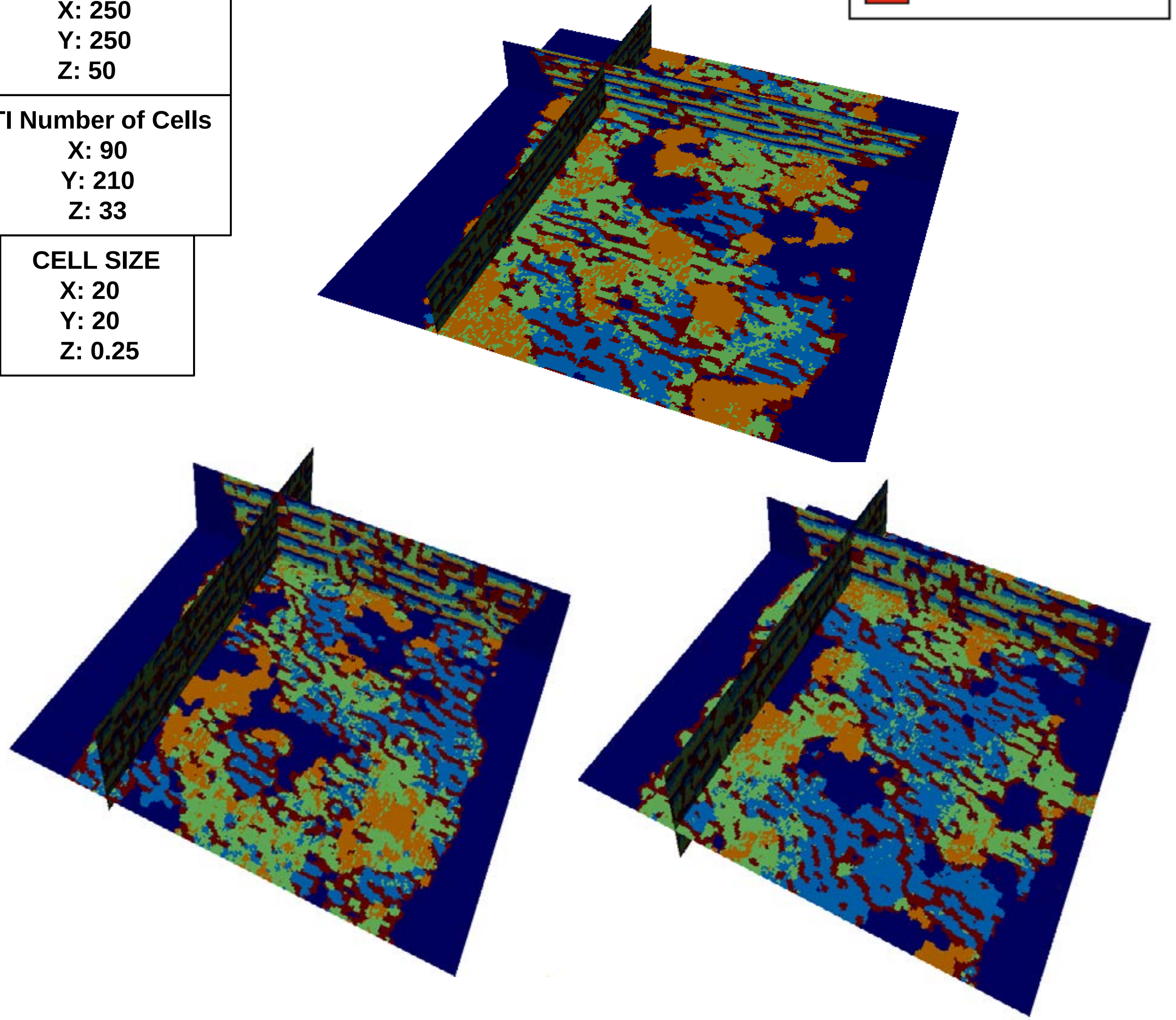


SIMULATION GRID
X: 250
Y: 250
Z: 50

TI Number of Cells
X: 90
Y: 210
Z: 33

CELL SIZE
X: 20
Y: 20
Z: 0.25

DEESSE Runtime <5 min/realization

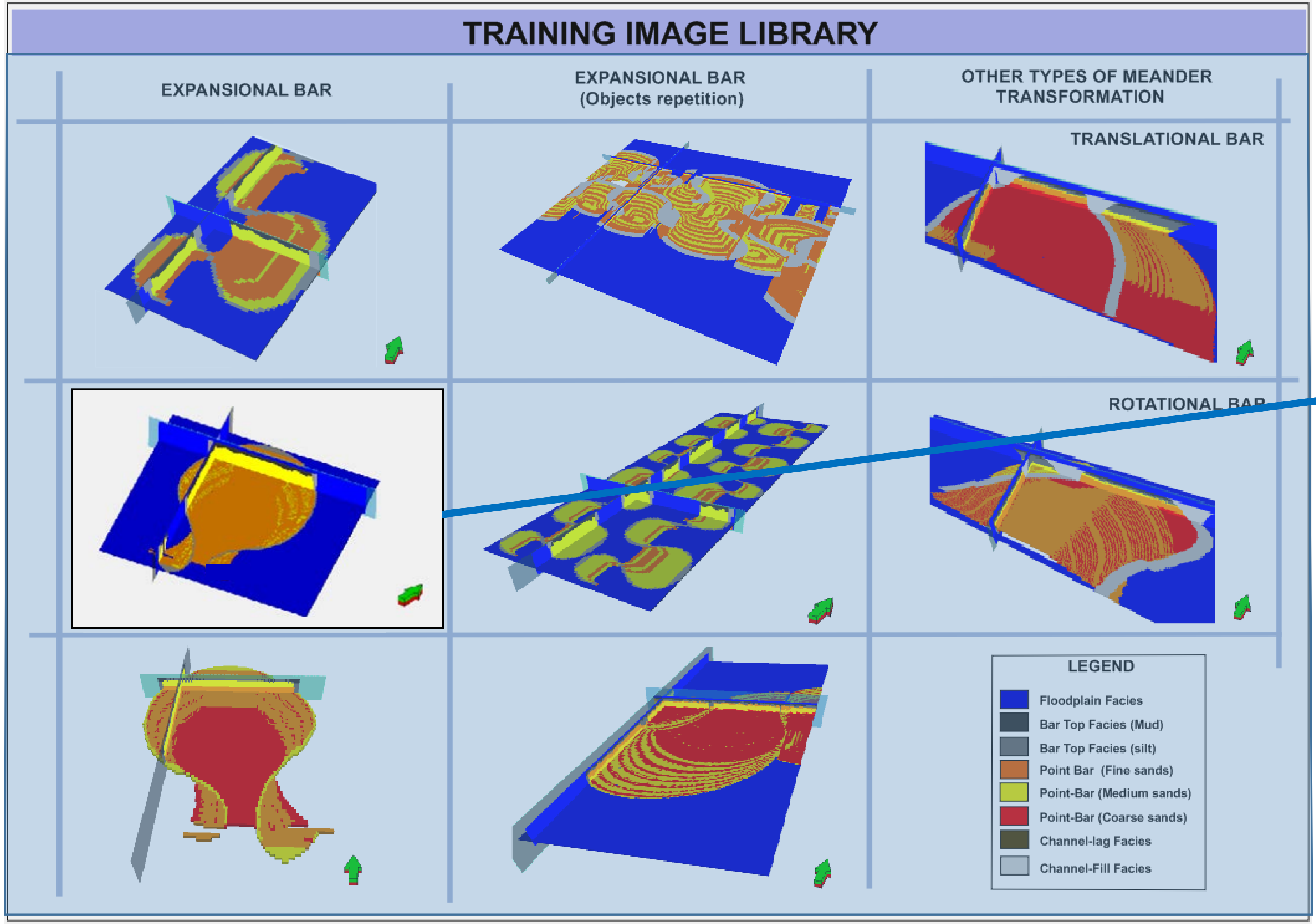


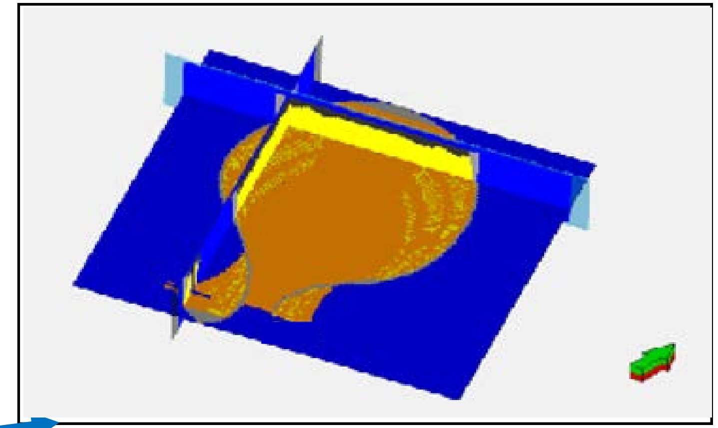
LEGEND
- Floodplain Facies
- Bar Top facies
- Point Bar (Sands)
- Point Bar (Coarse sands)
- Channel-Fill Facies

Parameters:

Search Radius: 4000x4000x30, N=70, Replicates=20, Serv=1, Multigrids=4
Condition to Auxiliary Probability (TAU model 2 1)

EXAMPLE-2. EXPANSIONAL BAR (NON-STATIONARY EXAMPLE)



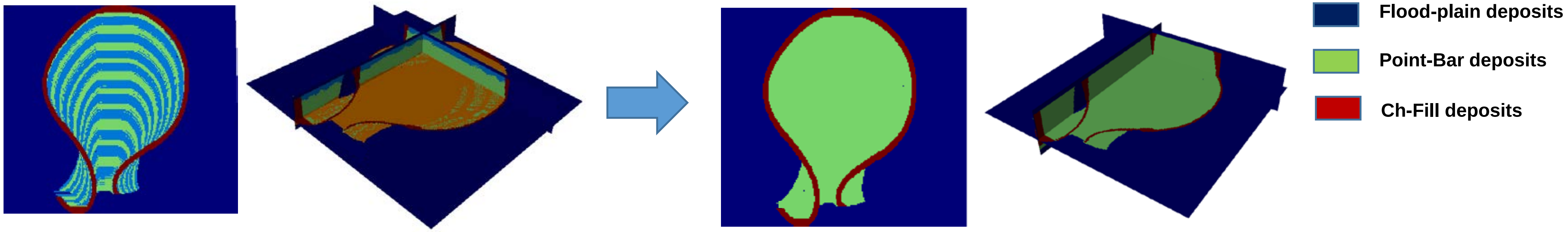


EXPANSIONAL BAR CASE
(NON-STATIONARY
TRAINING IMAGE)

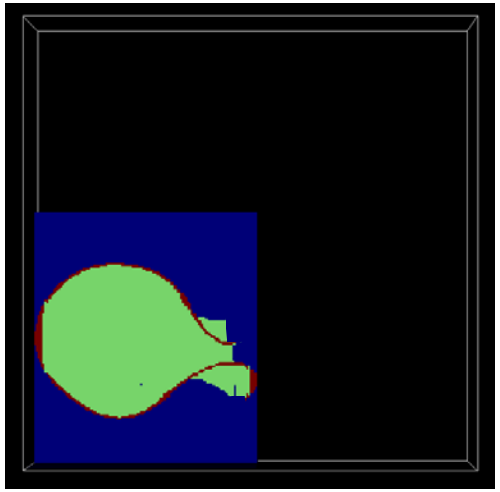
- No repetition of patterns
- Patterns confined to specific locations

EXAMPLE-2. SIMULATION WORKFLOW

STEP 1: Category reduction (3 facies)



STEP 2: Upscaling / Downscaling



SIMULATION GRID
X: 250
Y: 250
Z: 50

Training Image
Number of Cells
X: 128
Y: 144
Z: 39

CELL SIZE
X: 20
Y: 20
Z: 0.25

STEP 3: Sensitivity Phase

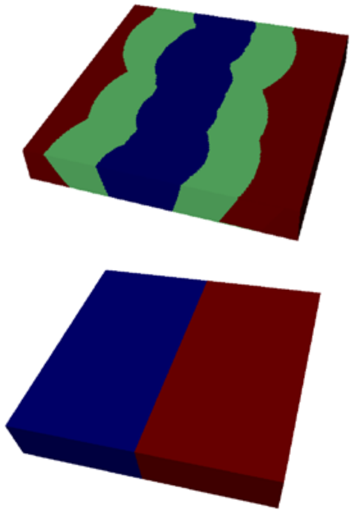
SNESIM (Strebelle, 2002)

- -Search Template Geometry
- -Number of nodes
- -Number of replicates
- -Servosystem

DEESSE (Mariethoz et al. 2010)

- -Search Window
- -Number of nodes
- -Search distance
- -Fractions

STEP 4: Auxiliary Variable Maps



	Facies 0	Facies 1	Facies 2
AREA 1	0.1	0.55	0.35
AREA 2	0.5	0.25	0.25
AREA 3	1	0	0

-TAU model probability for SNESIM

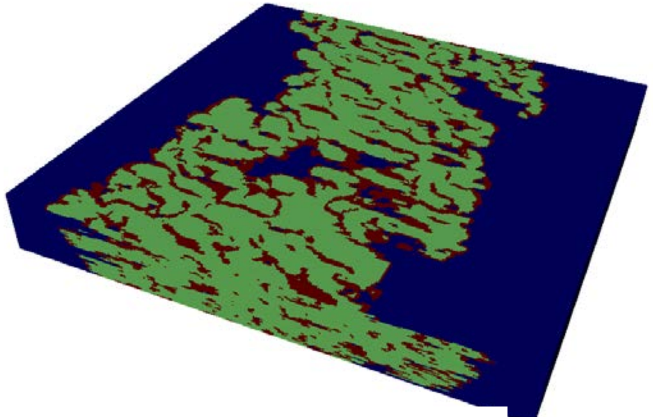
-Support radius and Deactivation threshold for DEESSE.

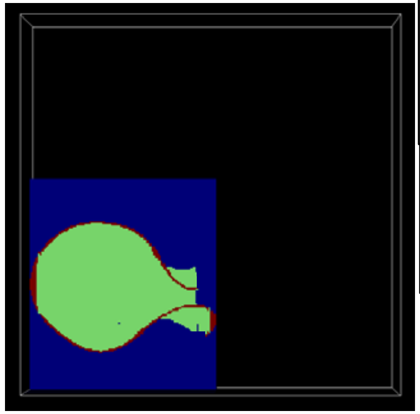
-Rotation Map (blue:0°, Red: 180°)

EXAMPLE-2. NON-STATIONARY TRAINING IMAGE REALIZATIONS (3 facies)

Flood-plain deposits
Point-Bar deposits
Channel-Fill deposits

SNESIM Runtime <2 min/realization



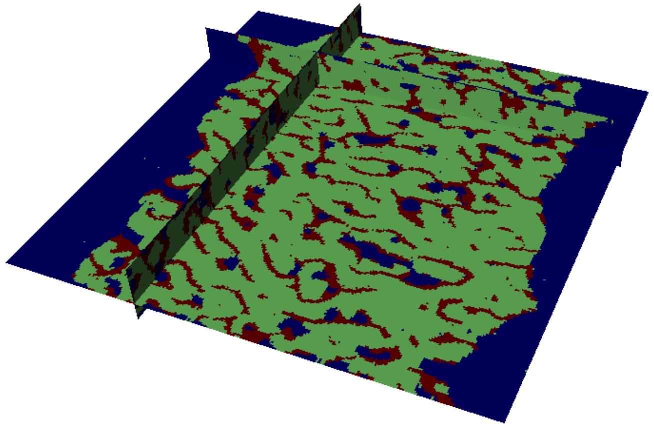


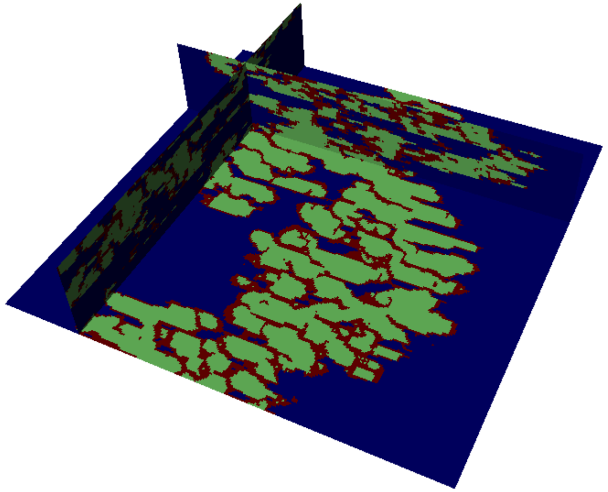
SIMULATION GRID
X: 250
Y: 250
Z: 50

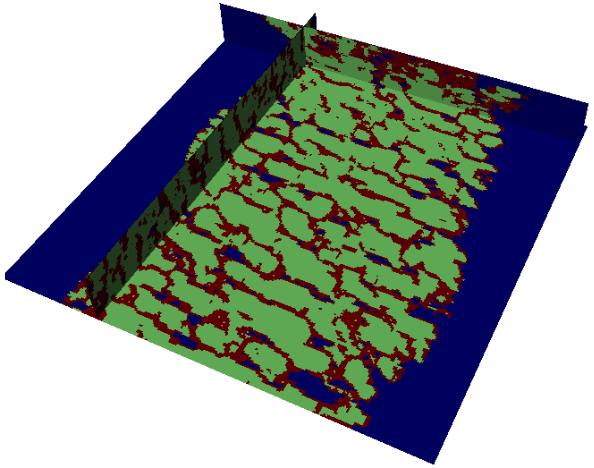
TI Number of Cells
X: 128
Y: 144
Z: 39

CELL SIZE
X: 20
Y: 20
Z: 0.25

DEESSE Runtime <2 min/realization

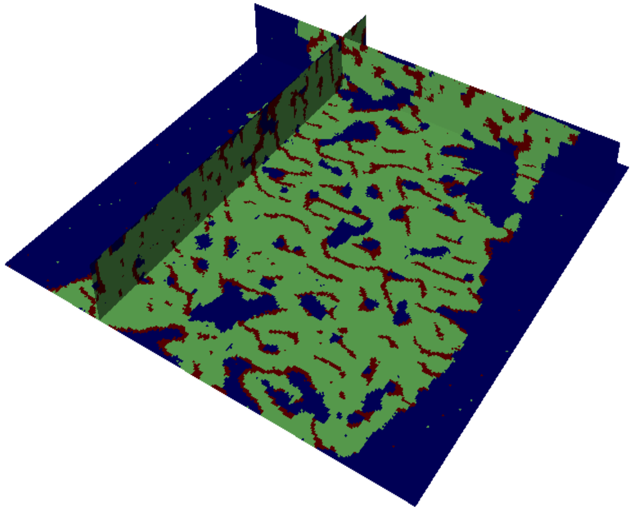


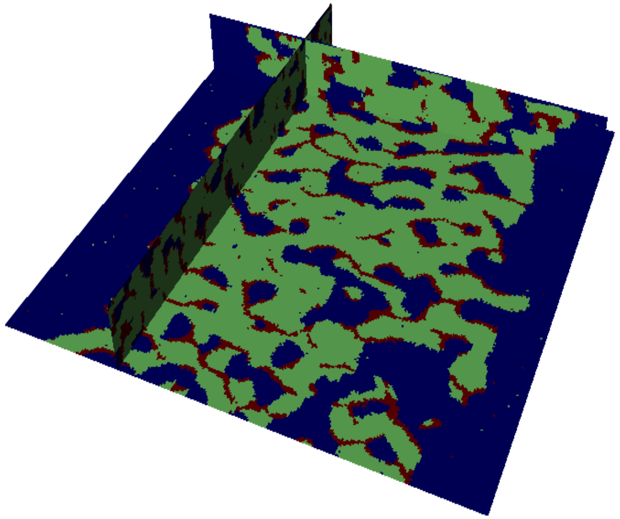




Parameters:

Search Radius: 2000x2000x15, N=60, Replicates=20, Serv=1, Multigrids=4
Condition to Auxiliary Probability and Rotation map

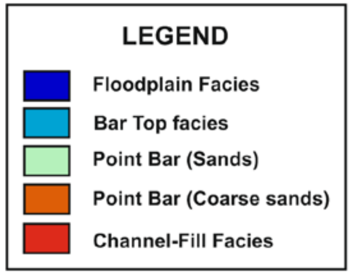




Parameters:

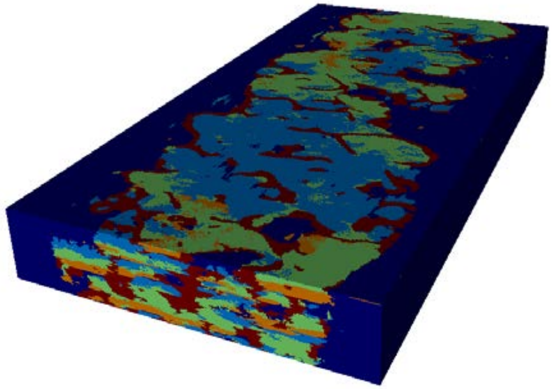
Search Window: 25x25x10, N=35, Distance=0.25, Radius Threshold=4
Condition to Auxiliary Probability and Rotation map

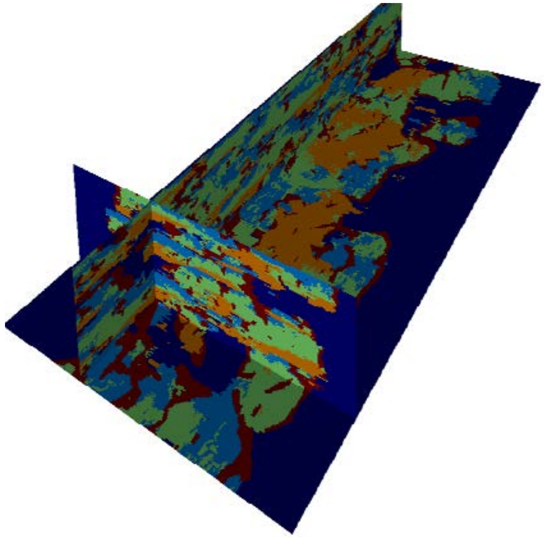
EXAMPLE-2. NON-STATIONARY TRAINING IMAGE REALIZATIONS (5 facies)

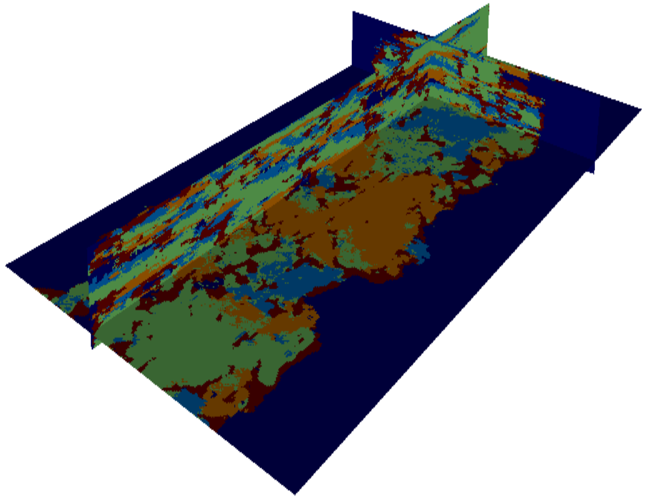


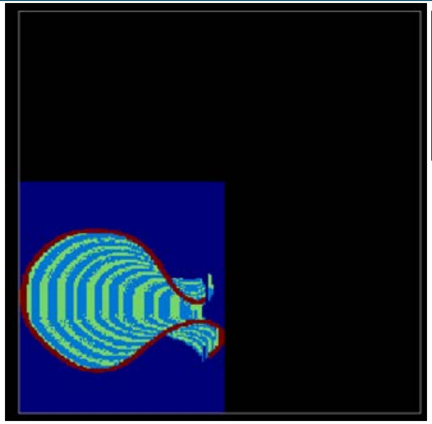
SNESIM

Runtime <20 min/realization









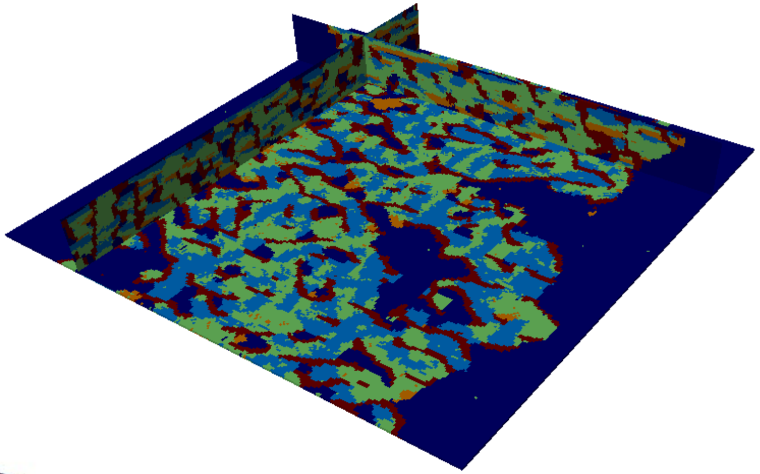
SIMULATION GRID
X: 250
Y: 250
Z: 50

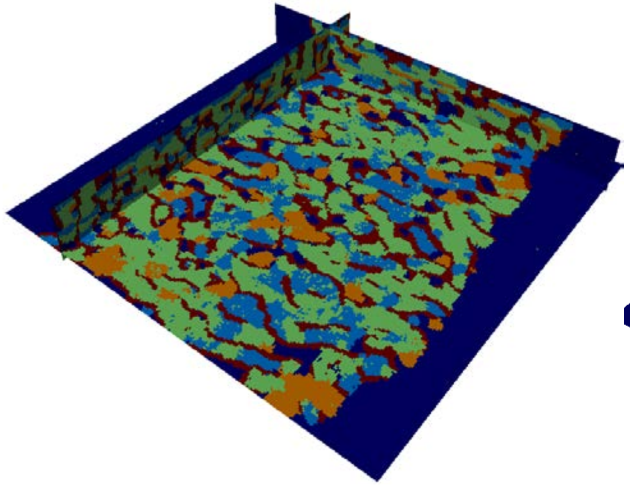
TI Number of Cells
X: 128
Y: 144
Z: 39

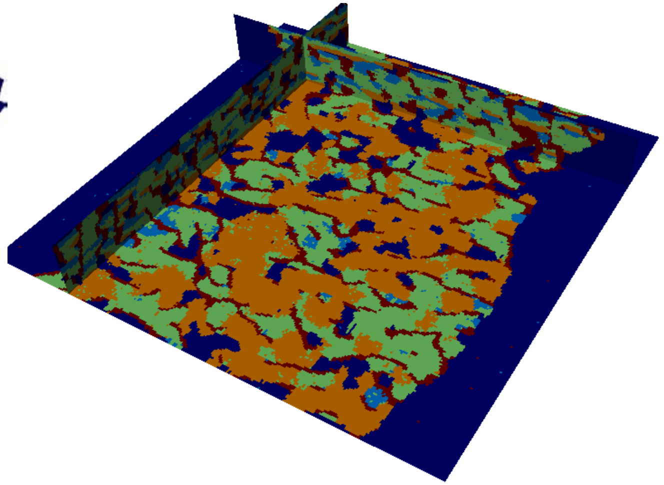
CELL SIZE
X: 20
Y: 20
Z: 0.25

DEESSE

Runtime <20 min/realization







Parameters:

Search Radius: 2000x2000x15, N=60, Replicates=20, Serv=1, Multigrids=4
Condition to Auxiliary Probability and Rotation map

Parameters:

Search Window: 25x25x10, N=35, Distance=0.25, Radius=5, Deact. Threshold=4
Condition to Auxiliary Probability and Rotation map

CONCLUSIONS AND FUTURE WORKS

FRG ERG

CONCLUSIONS

Realizations performed following this workflow attempted to model the sedimentary architecture of fluvial meandering systems, at bar and facies scales.

Training images with different levels of non-stationarity can be handled by the use of probability maps.

FUTURE RESEARCH

Apply the workflow to a real-case scenario where:

-Training images can be built based on analogue data;

-Well data can be used to define training-image lithotypes;

-Soft data (e.g., seismic attributes) can be used to create probability maps;

-A connectivity study can be performed to compare results with those of other pixel- and object-based methods.

AKNOWLEDGEMENTS

The Fluvial Research Group (FRG) gratefully acknowledges the Randlab Group (University of Neuchâtel) for providing DEESSE code licenses and our sponsors for financial support.

AREVA AkerBP bhpbilliton ConocoPhillips MURPHY OIL CORPORATION NERC SCIENCE OF THE ENVIRONMENT nexen pdspetrotechnical Saudi Aramco TULLOW woodside YPF