Directional Permeability in Geological Modelling

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Directional Permeability in Geo-Modelling

OBJECTIVES OF ESTIMATING PERMEABILITY

CORE PLUG SAMPLING, THIN SHALES, Kh, Kv

GEOLOGY OUTCROP OBSERVATIONS

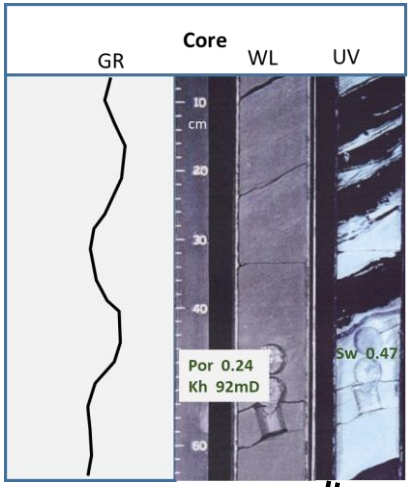
LARGE-SCALE MODEL OF THE ARCHITECTURE

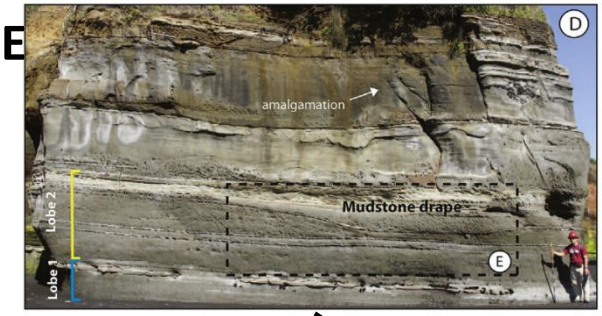
LITHOFACIES ASSOCIATION MODELLING

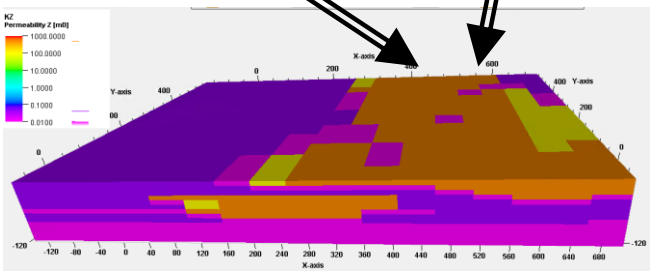
FULL-FIELD MODELLING WITH BAFFLES

DIRECTIONAL PERMEABILITY EXAMPLE

CONCLUSIONS

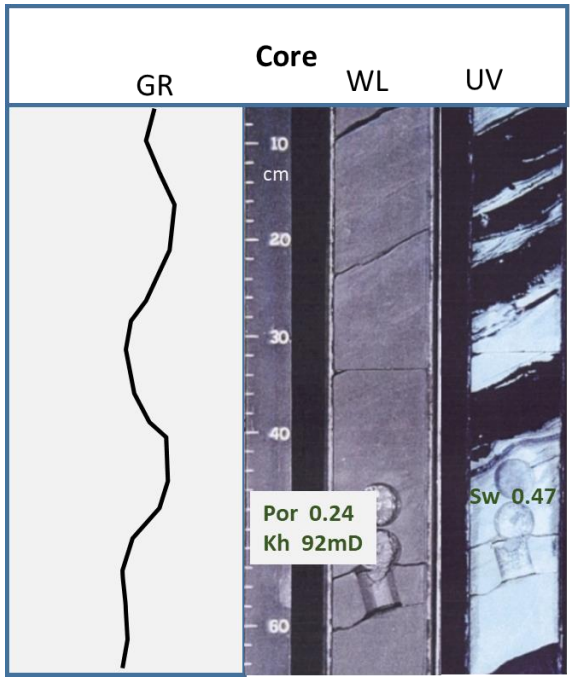






Objectives of the Permeability Estimates

- In dynamic reservoir modelling, we typically need to understand fluid flow on a km-scale to plan wells and estimate recovery
- Petrophysicists and geologists spend a lot of time analysing cross plots and well logs to derive a poro-perm relationship
- However, reservoir engineers often have to invoke directional permeability modifiers in the simulator to match production behaviour and pressures
- In some cases this is because the baffles and facies architecture has not been captured in the static model



As we know, some lithologies are not sampled by core plugs or are below log resolution, for example extensive thin shales or laminated facies

So how do we translate the geological features into relatively large simulation cells?

Core Samples in Turbidites

Core Plugs

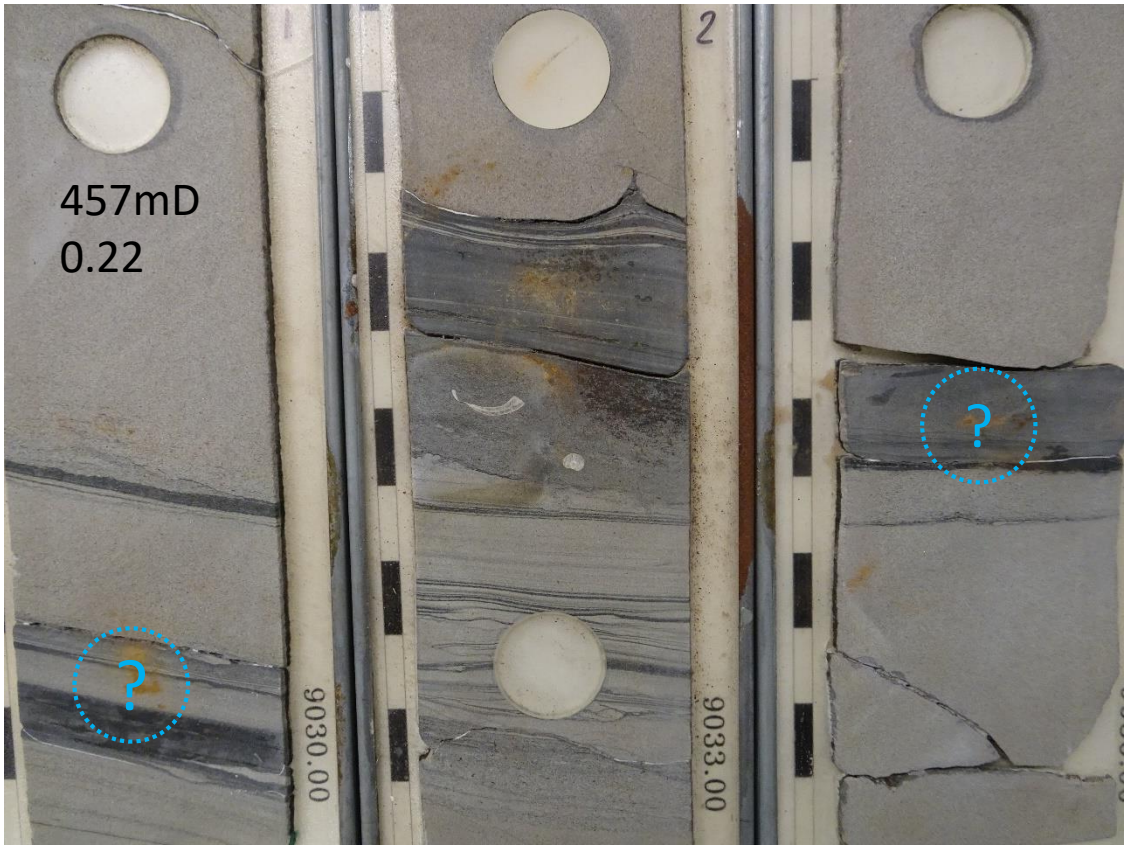
Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm



Kh

Kv ?

Most of the samples are in the sandstone
The poor-quality facies are poorly sampled and difficult to measure
Can we use the vertical permeability from core?

Plug Sampling Bias

Core Plugs

Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm

Poor quality facies and mudstone rarely sampled

Por-Perm Cross Plot

Core Plugs

Outcrops

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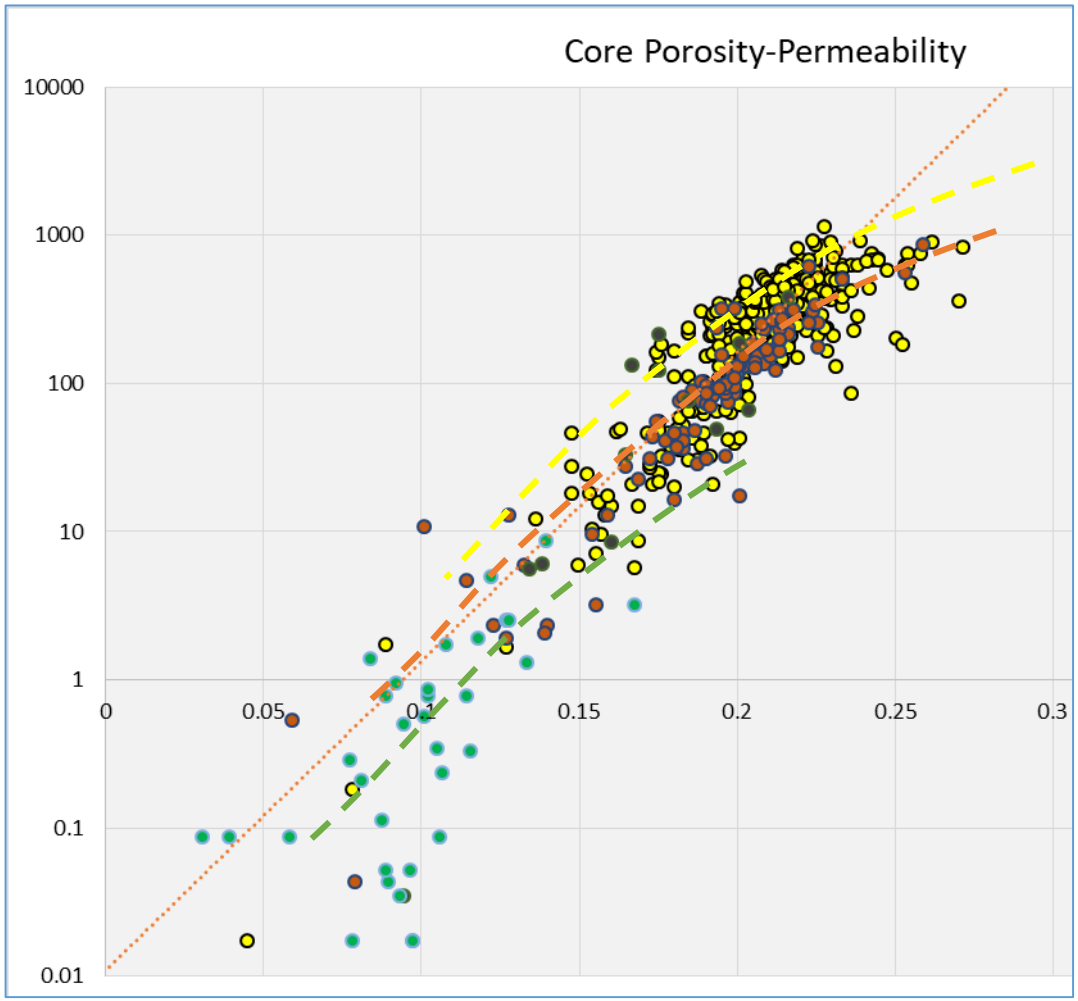
Directional Perm



Reasonable K-Phi relationships at greater than 10mD

Some scatter below 1mD

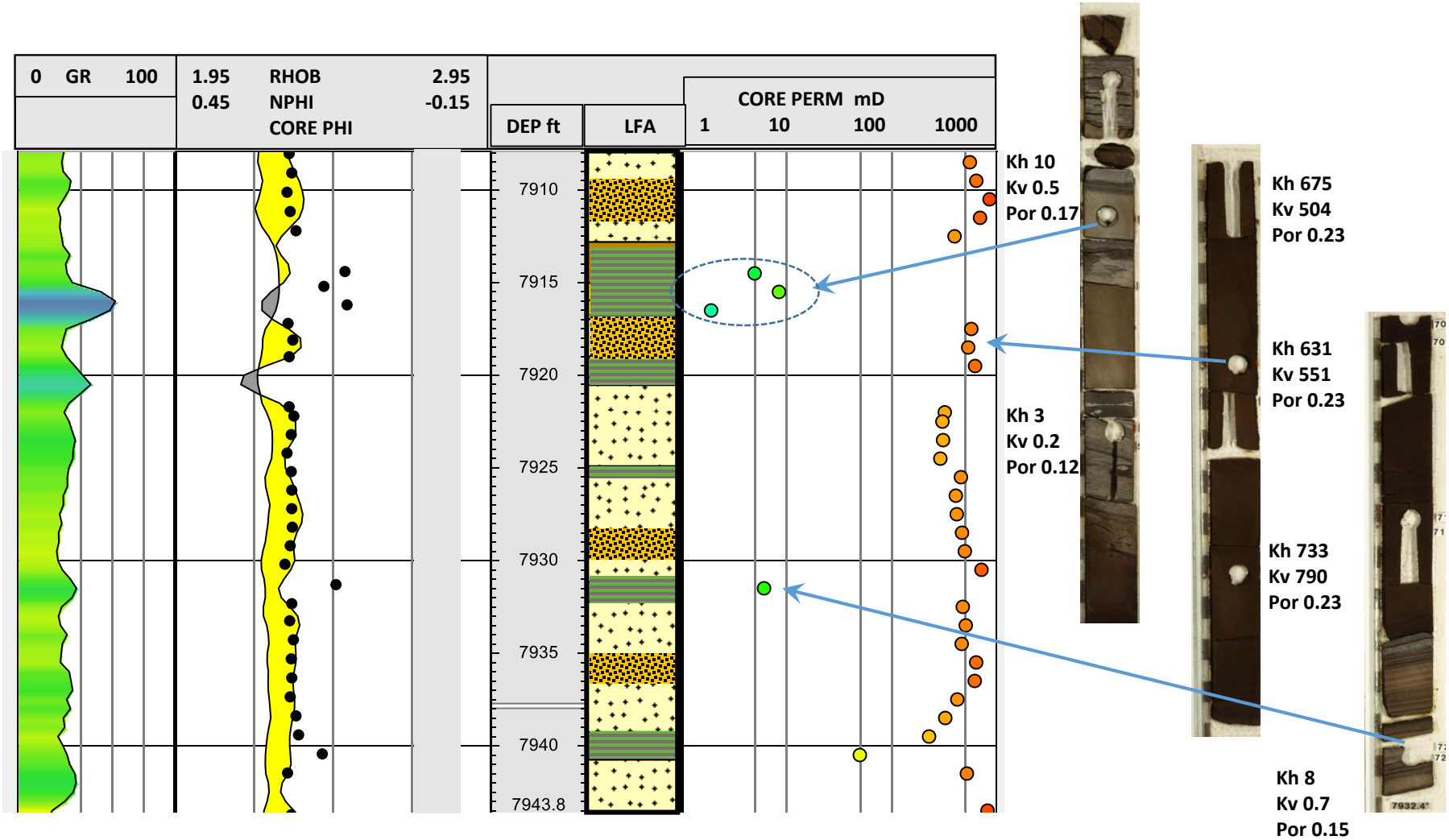
Fine sst

vfine sst

Silty lam

Core Plug Permeability Kh and Kv

1. We do not want to include the poor quality samples in the Kh
2. We can make some vertical permeability estimates from the silty samples



Vertical Permeability in the poor facies

Core Plugs

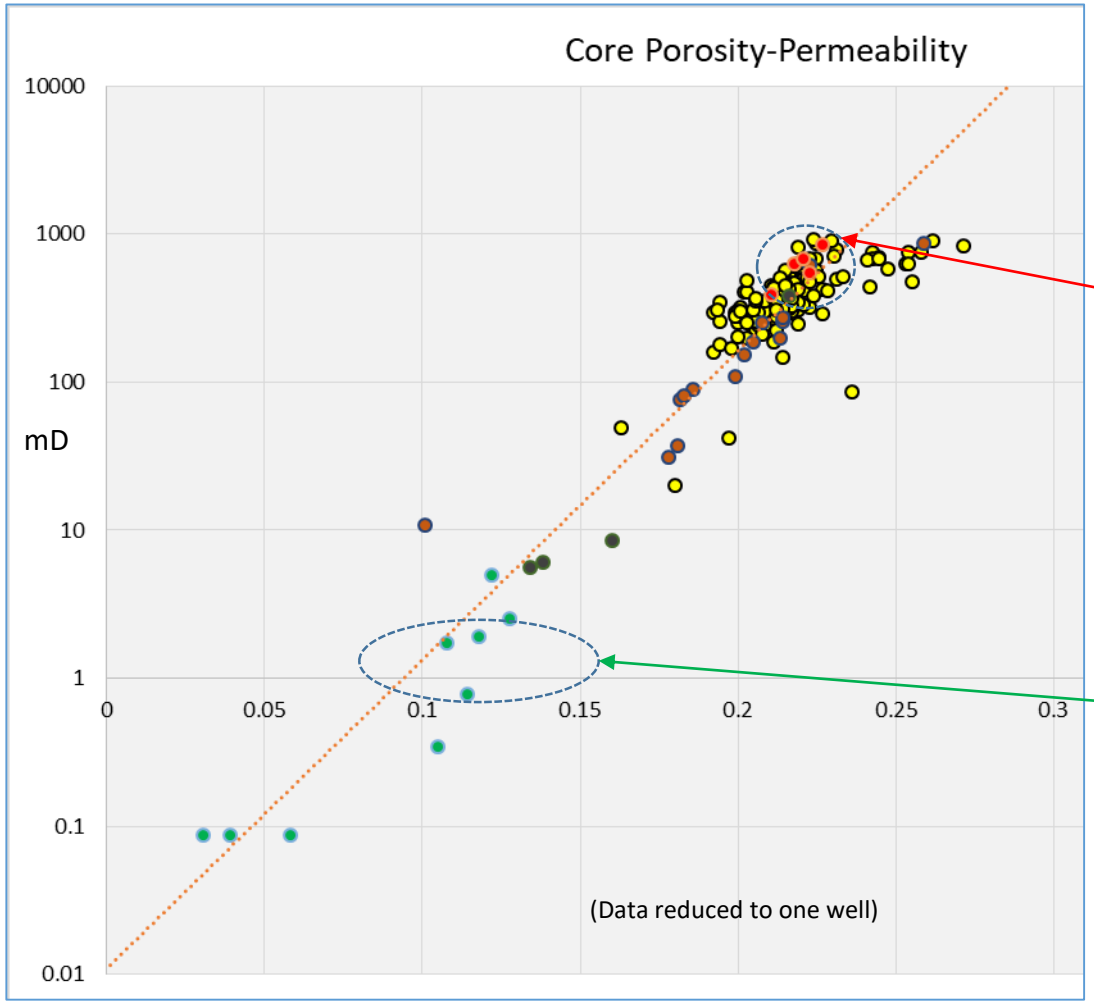
Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm



Most of the sandstone plugs represent Kh

Por	Kh	Kv	Kv/Kh
0.23	654	388	0.59
0.23	753	815	1.08
0.24	985	613	0.62
0.23	817	790	0.97
0.22	468	508	1.09
Average:	**735**	**623**	**0.87**

Some selected silty plugs:

Por	Kh	Kv	Kv/Kh
0.17	10.0	0.50	0.05
0.12	3.0	0.20	0.07
0.15	8.0	0.70	0.09
Average:	**7.0**	**0.47**	**0.07**

Just from these observations, we have some estimate of Kv and Kh

Outcrop Information

Outcrop characterization of a submarine channel-lobe complex: The Lower Mount Messenger Formation, Taranaki Basin, New Zealand.
Larisa U. Masalimova, Marine and Petroleum Geology 71 (2016)

Objectives

Core Plugs

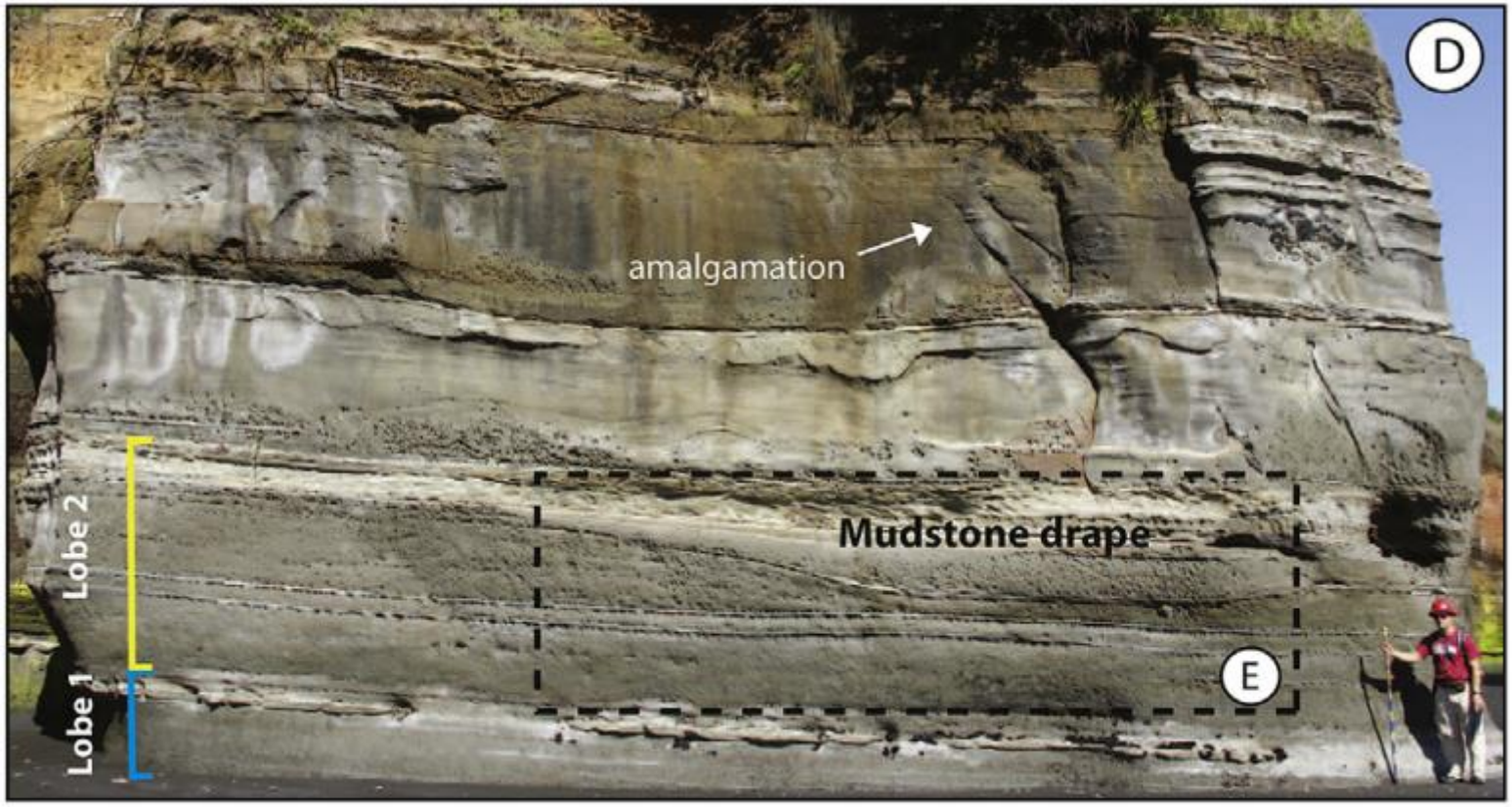
Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm

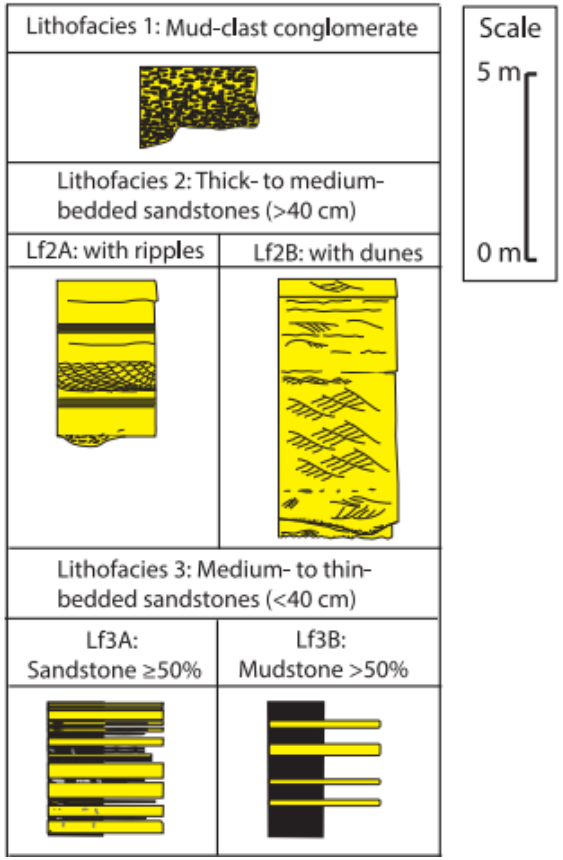


High NTG, but thin shales and silts will reduce vertical permeability
These are thinner than any cell we could place in a model

Frequency of Mudstone Beds

- Objectives
- Core Plugs
- **Outcrops**
- Facies bed-scale
- Full-Field Model
- Model Baffles
- Directional Perm

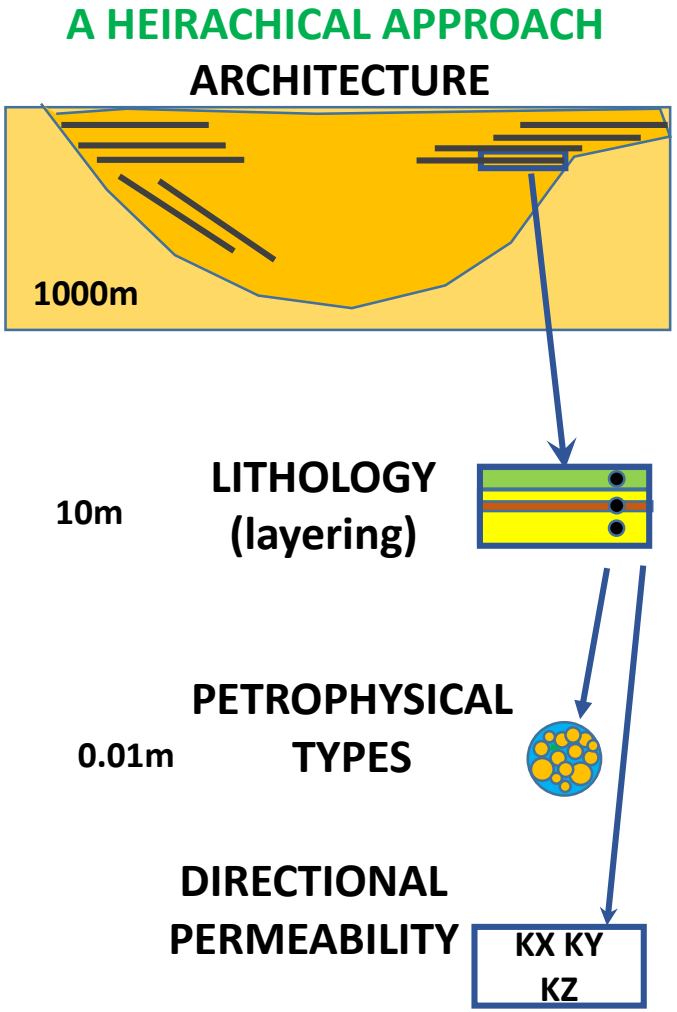
Litho-Facies Associations



The mudstone and silt beds may extend several 100 metres
A facies classification can be developed

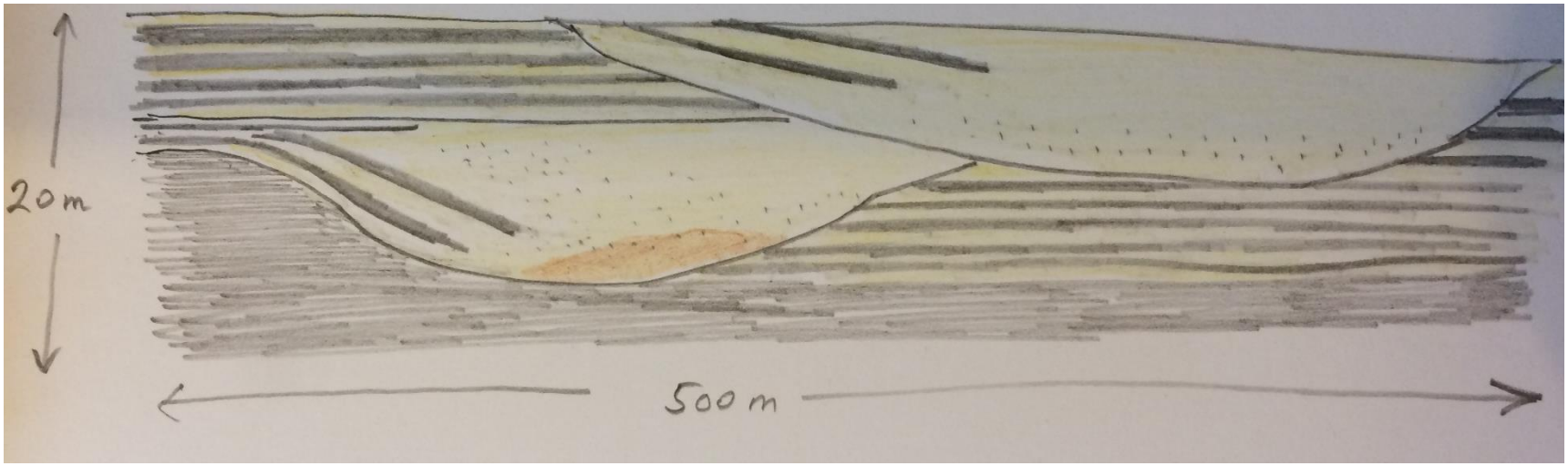
Scale in Reservoir Simulation Models

- Aim to build 3D model at dynamic simulation scale
- The directional permeability on a simulation scale can be captured more effectively by combining lithologies into Lithofacies Associations
- A particular LFA is a combination of:
  - Lithologies (e.g. sand shale)
  - Small-scale geometry (e.g. thin beds)
  - Petrophysical pore types (e.g. primary or secondary)
- Using typical properties, a set of fine and coarse single cell models are built for each LFA to represent the range in directional permeability



Modelling Workflow

Field Outcrop Example Sketch



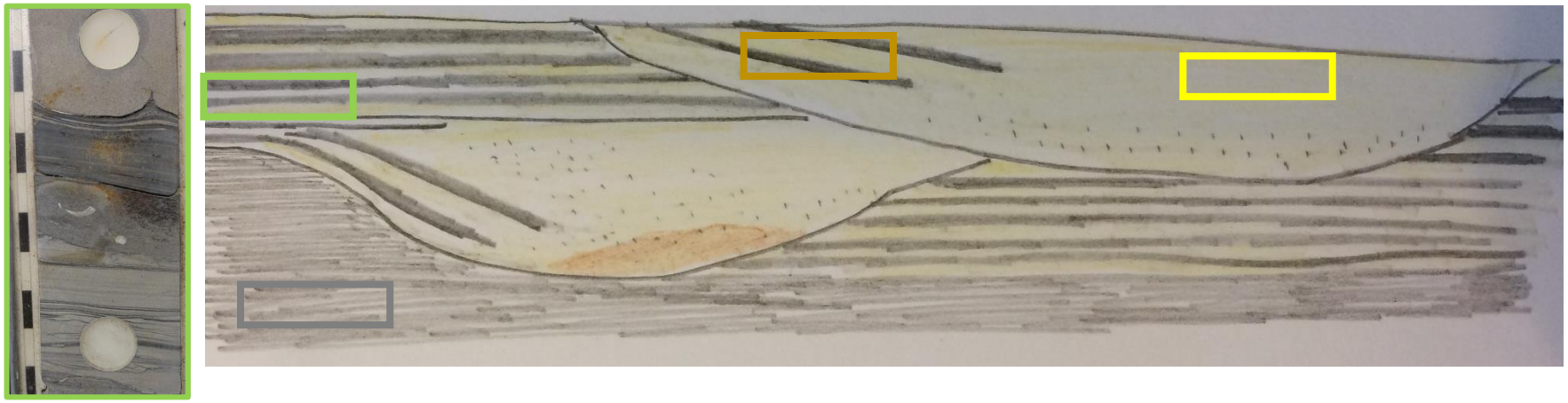
Outcrop Example from
Mount Messenger, Taranaki Basin, New Zealand
Depositional environment: Median Fan Turbidite Lobes

Width:Thickness ratio 1:50 to 1:200
Compensational stacking
Moderate NTG
Variable amalgamation ratio
and vertical connectivity

Making the sketch makes us think about the larger-scale geometry

LithoFacies Associations

- As a starting point, lets define the term LFA as meaning sedimentary facies
  - A sedimentary bed or bed-set
  - Something deposited at almost the same time by a particular depositional process
  - Typically extends at least 50m laterally
- LFA should be defined from core together with outcrop information



Character of four Litho-Facies Associations

- The LFA can be a combination of petrophysical rock types
- Not attempting to define every thin bed

Core Plugs

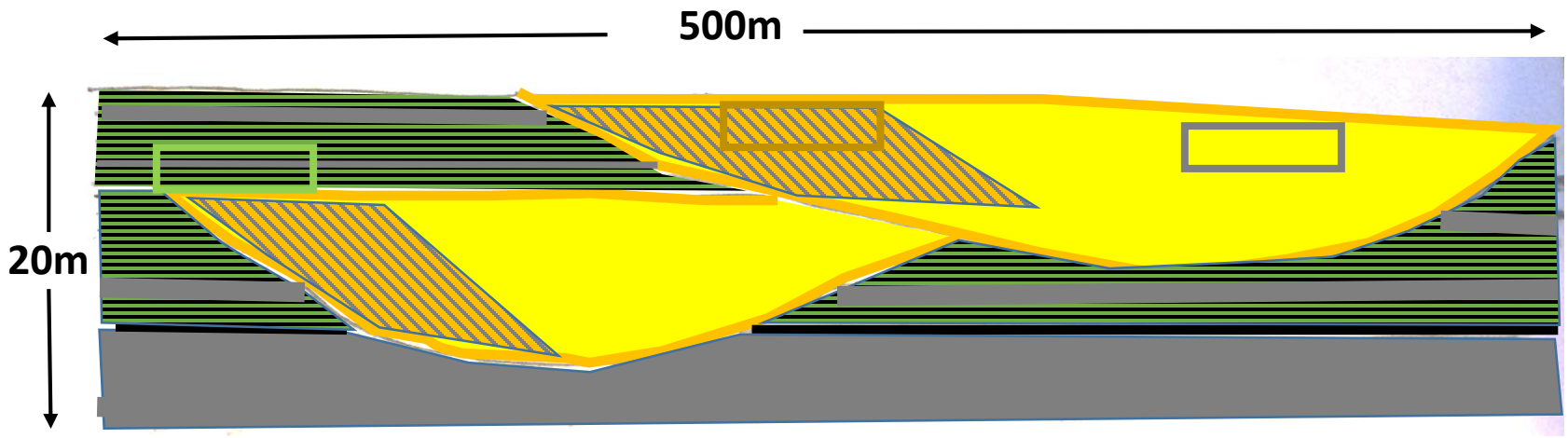
Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm



LFA	Description	Grain size	Bed thickness	NTG (proportion oil)	Vertical Perm
LFA1	Medium bedded sandstone	vf-f	20 – 50cm	1	= horizontal
LFA2	Thin bedded rippled sandstone with silt lam.	vf-silt	<20cm	0.8	Low
LFA3	Interbedded vf-fine sand and silt, shale lam	vf / silt-mud	<20cm	0.5	Very low
LFA4	Shale	mud	<50cm	0	Very low

Build bed-scale model for each LFA

(5 x 5 cells x 20 layers)

Core Plugs

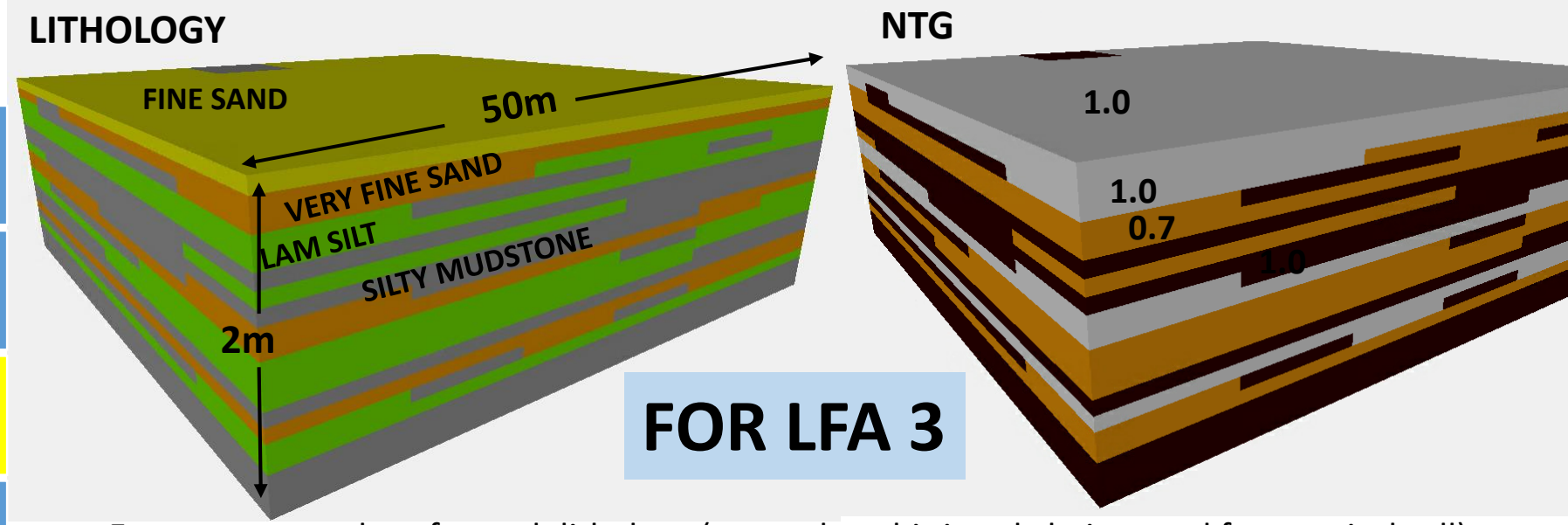
Outcrops

Facies bed-scale

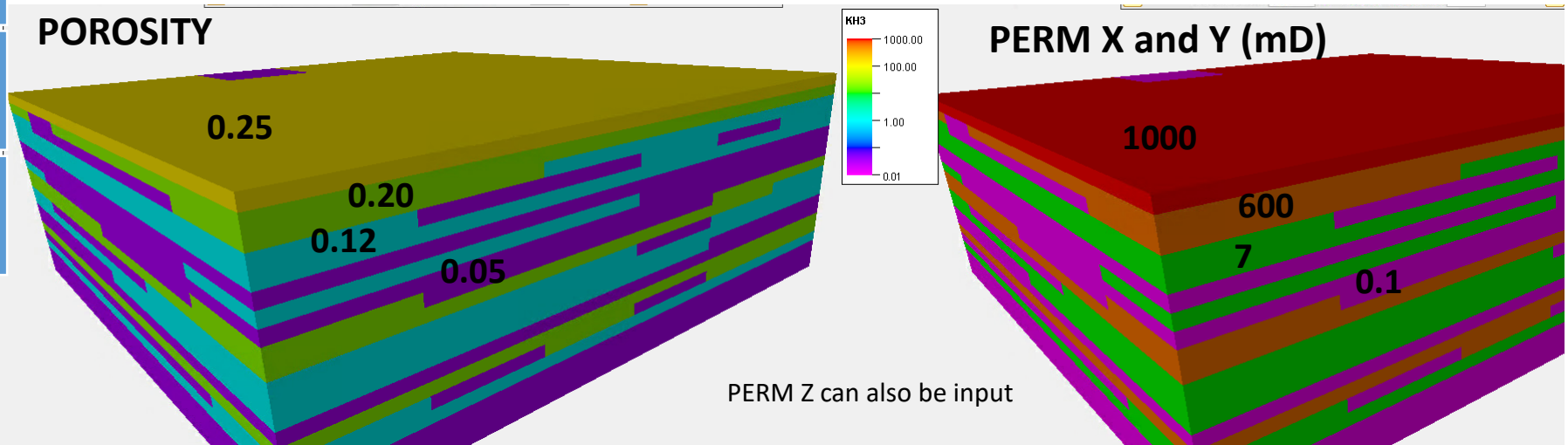
Full-Field Model

Model Baffles

Directional Perm



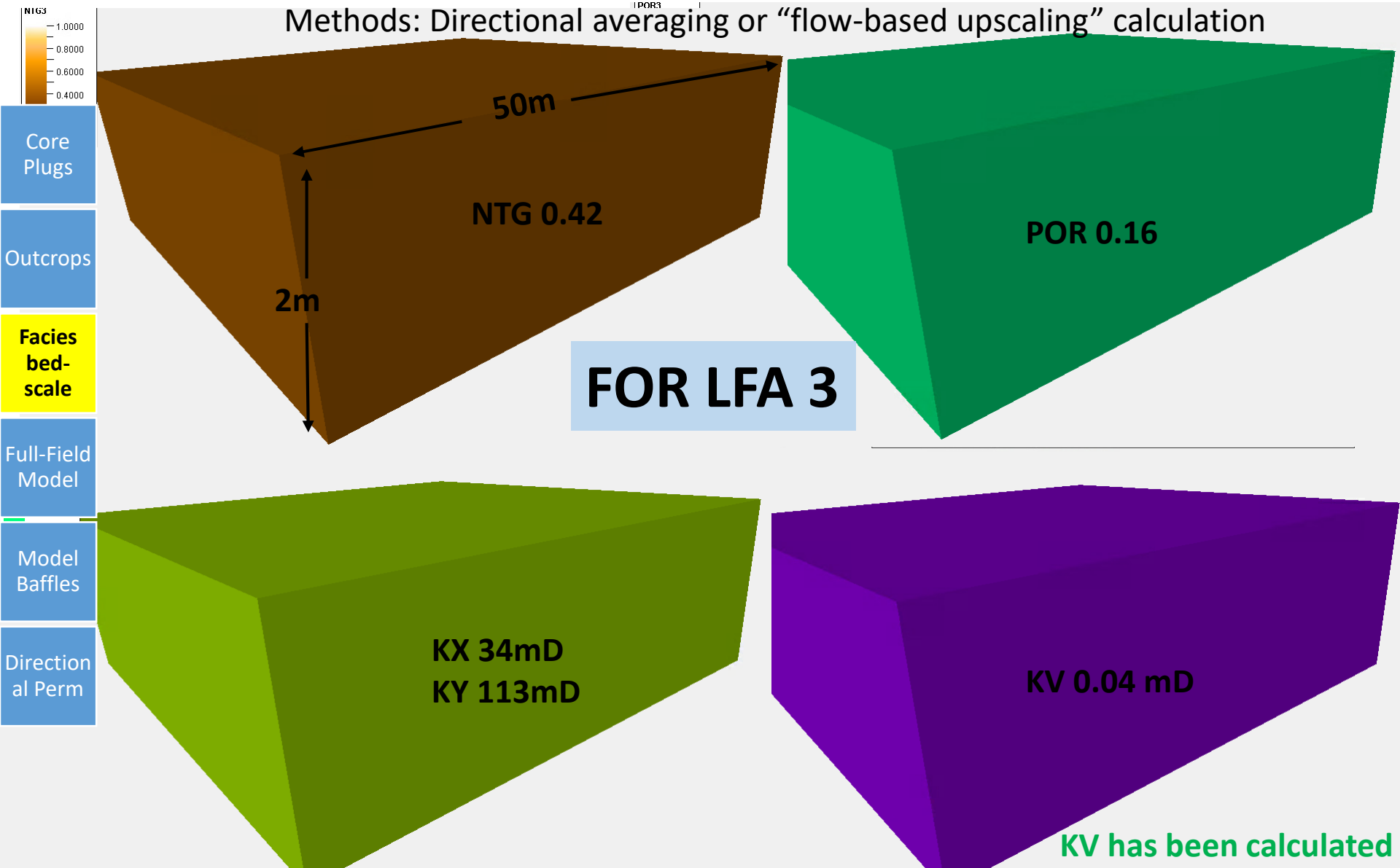
Enter average values for each lithology (remember this is only being used for a typical cell)



PERM Z can also be input

Upscale into the single Simulation cell

Methods: Directional averaging or “flow-based upscaling” calculation



Core Plugs

Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm

FOR LFA 3

KV has been calculated

Large-Scale Architecture

Geological observation and Interpretation:
The sedimentology is organised and hierarchical

Core Plugs

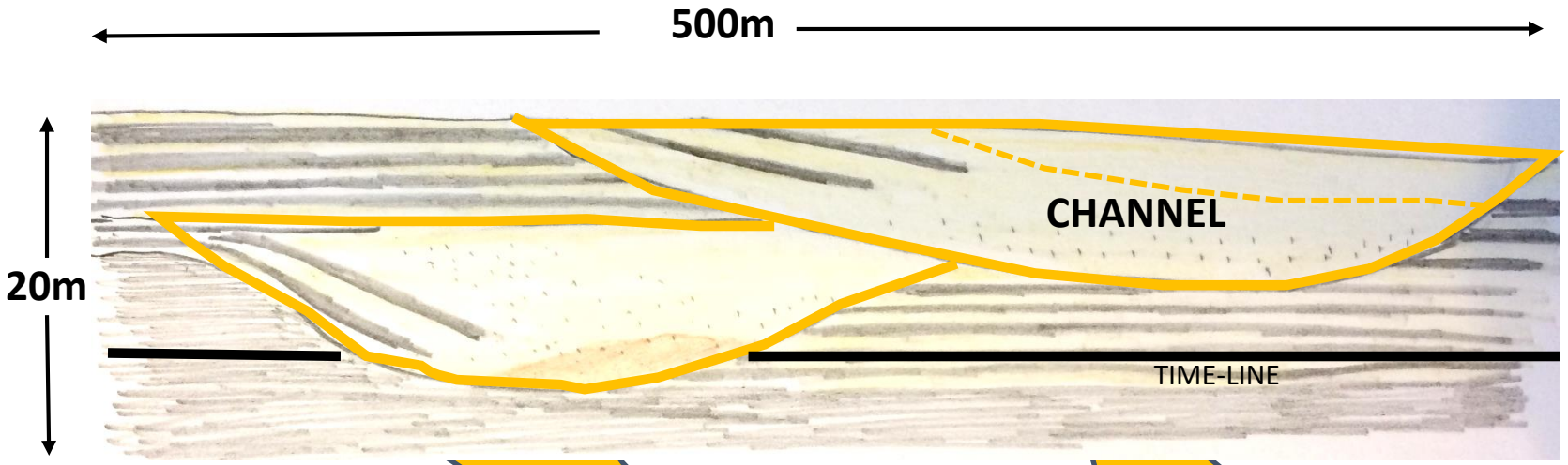
Outcrops

Facies bed-scale

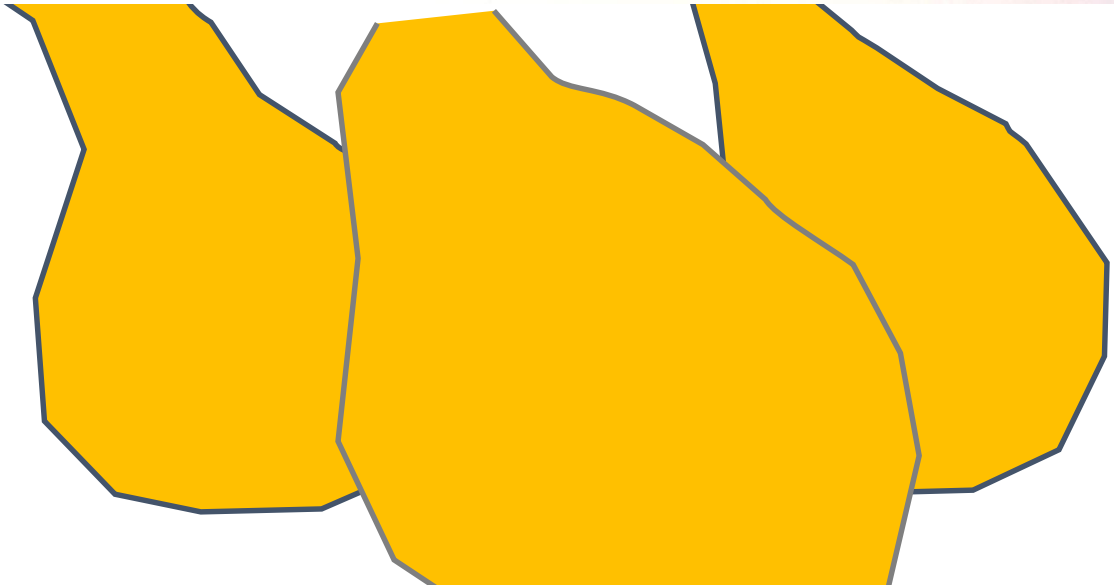
Full-Field Model

Model Baffles

Directional Perm



Environment:
Median to upper basin-floor fan



Simple Model of the Architecture

Channel / non-channel well logs

Core Plugs

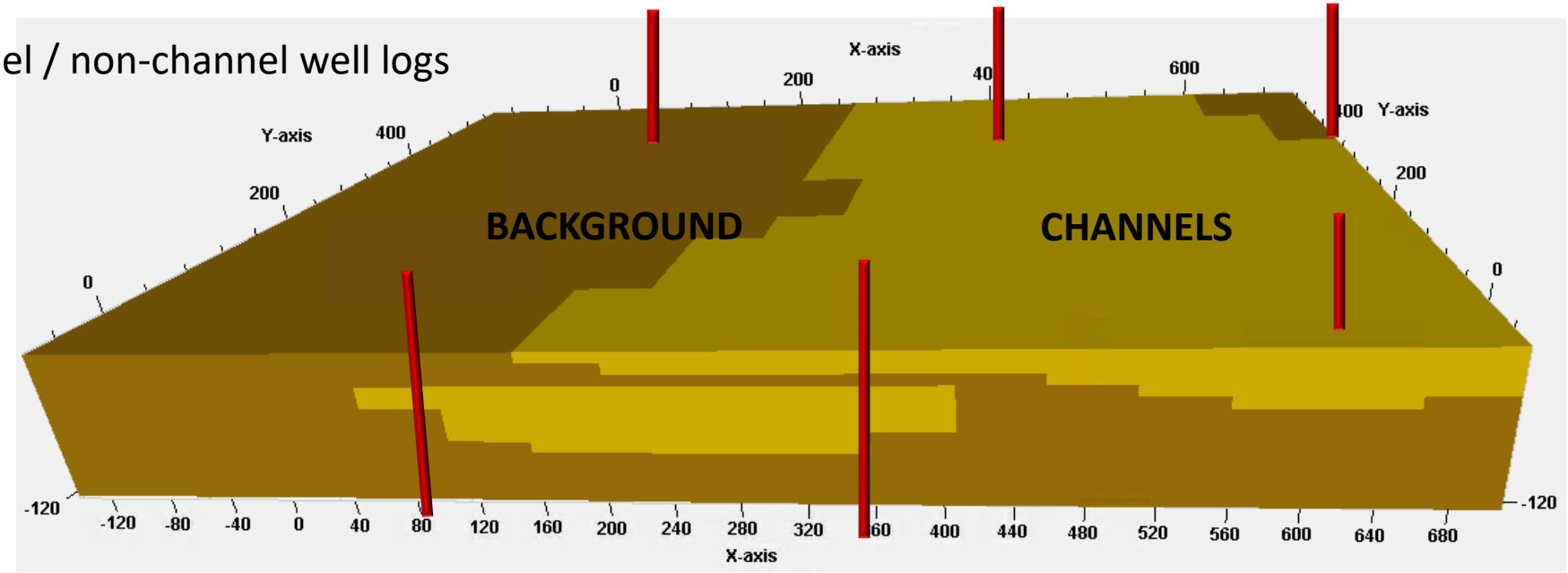
Outcrops

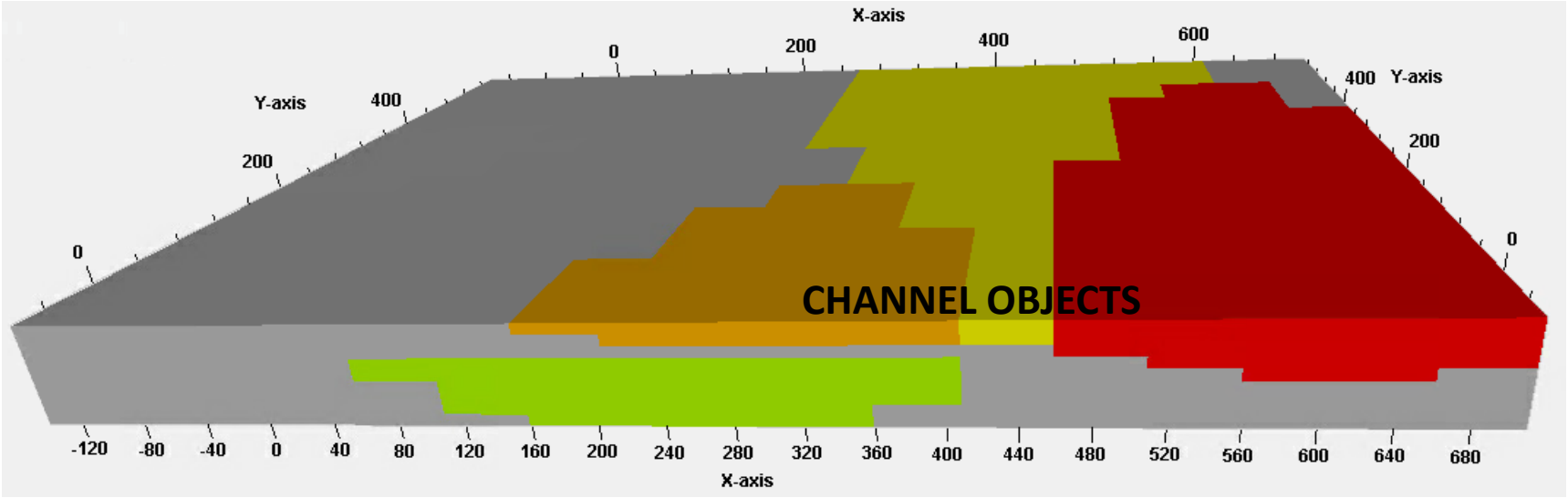
Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm





Build Full-field Facies Model (LFA)

LFA model is built using the proportions in the channel and the background together with some basic trends

Core Plugs

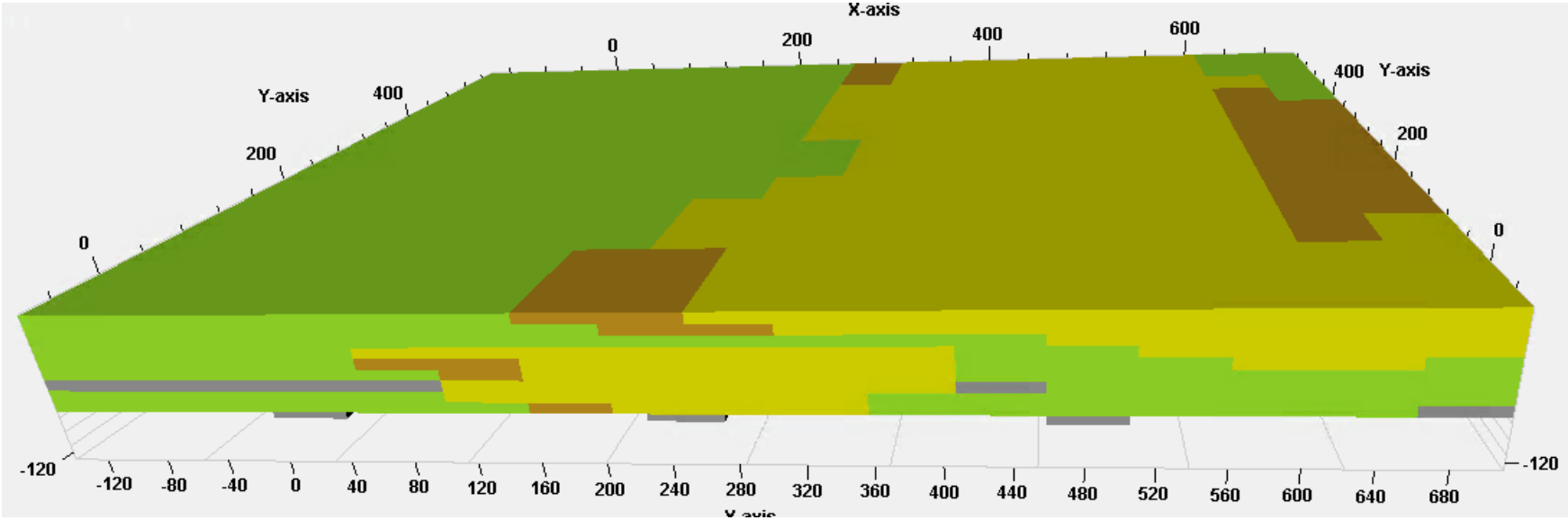
Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm



Archi	LFA	Proportion	Dimensions (av)	Orient.	Bias
Chan	**LFA1**	0.7	From channels		
	LFA2	0.3	500 x 150 x 1	From chan	edges
Non chan	**LFA3**	0.6	2000 x 1000 x 1	na	
	LFA4	0.4	2000 x 1000 x 1	na	

Full-Field Trend Model for Properties

Core Plugs

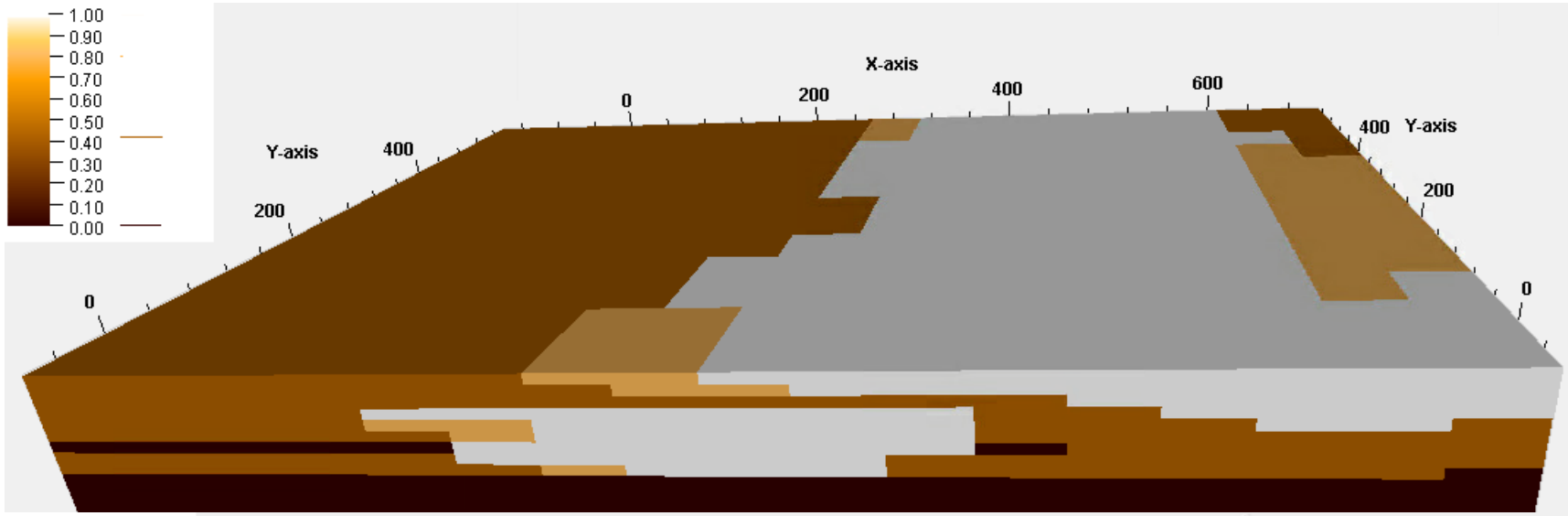
Outcrops

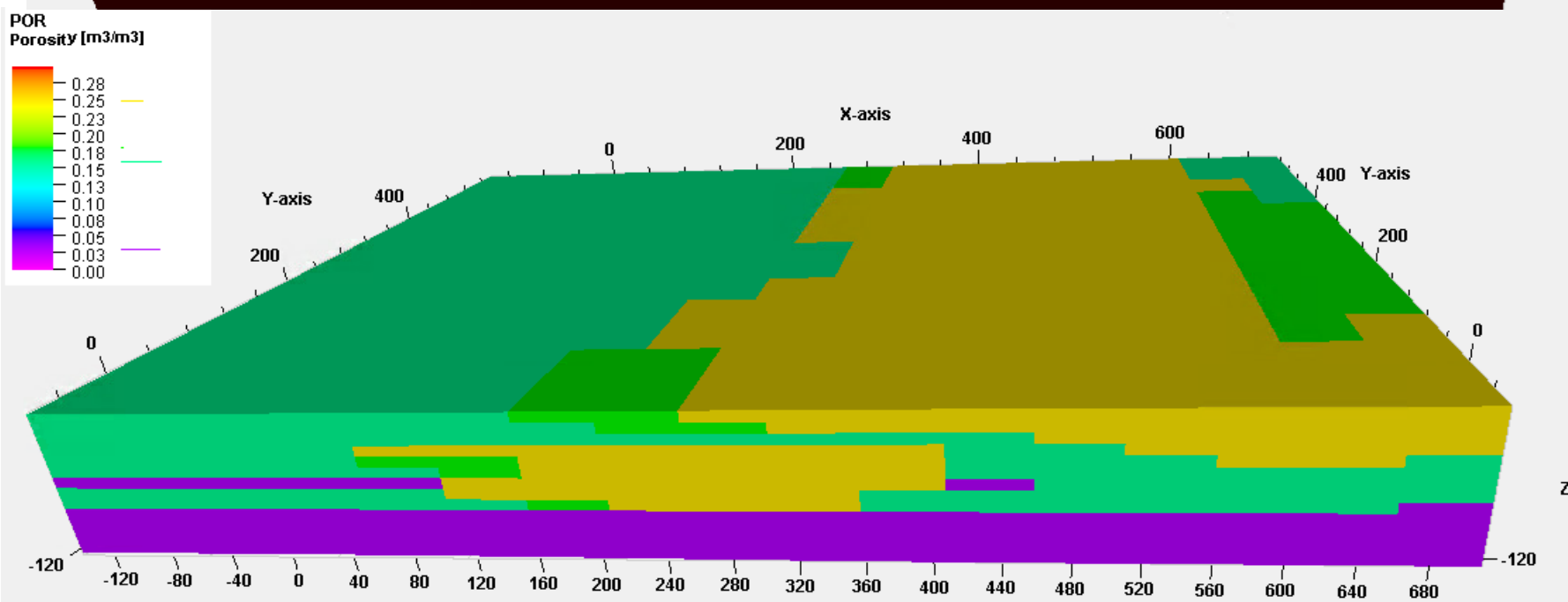
Facies bed-scale

Full-Field Model

Model Baffles

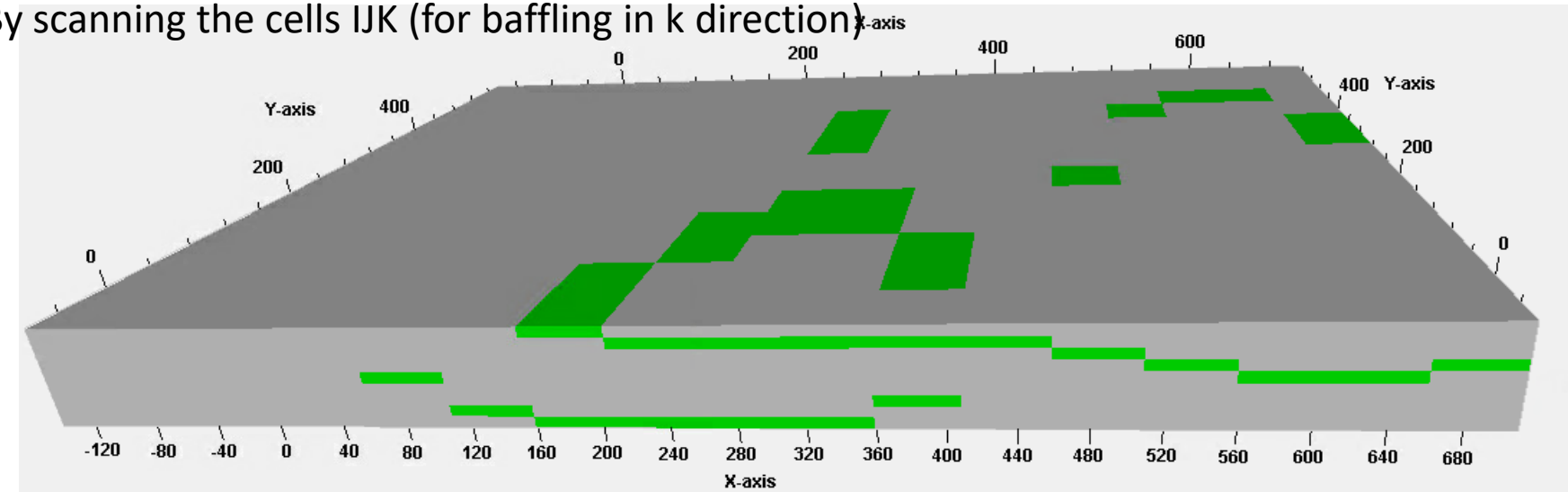
Directional Perm



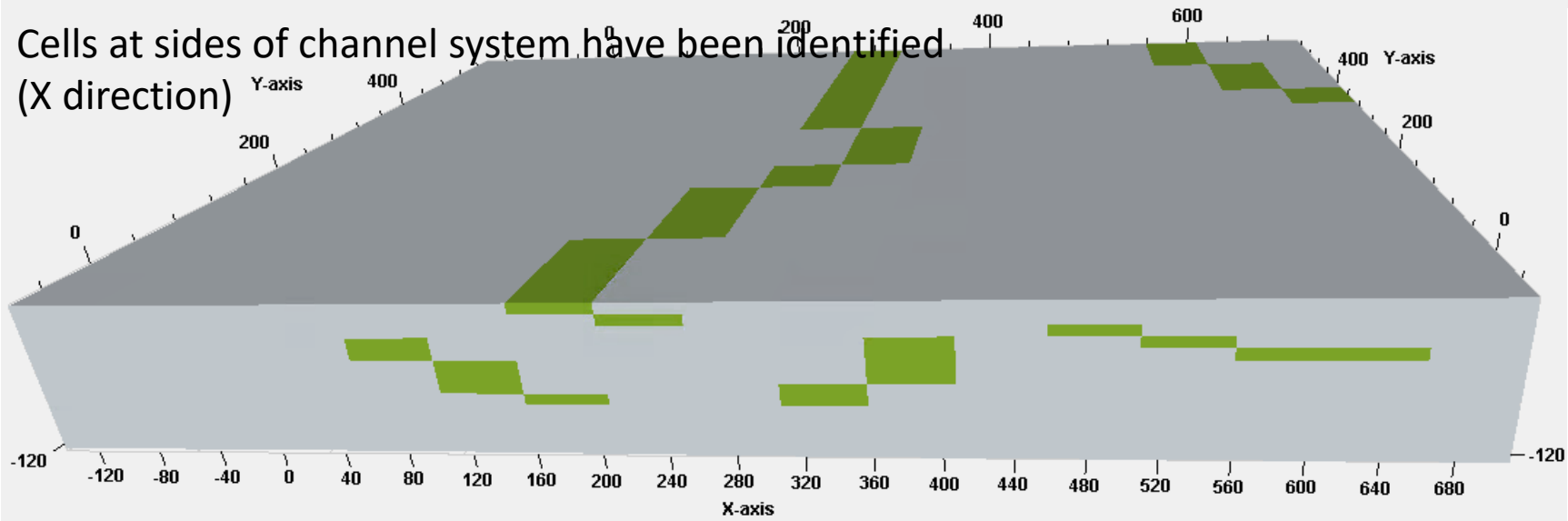


Add Permeability Baffles

Cells at base of channel system or channel objects can be identified
By scanning the cells IJK (for baffling in k direction)



Cells at sides of channel system have been identified (X direction)



Core Plugs

Outcrops

Facies bed-scale

Full-Field Model

Model Baffles

Directional Perm

Directional Permeability Trend Model

Core Plugs

Outcrops

Facies bed-scale

Full-Field Model

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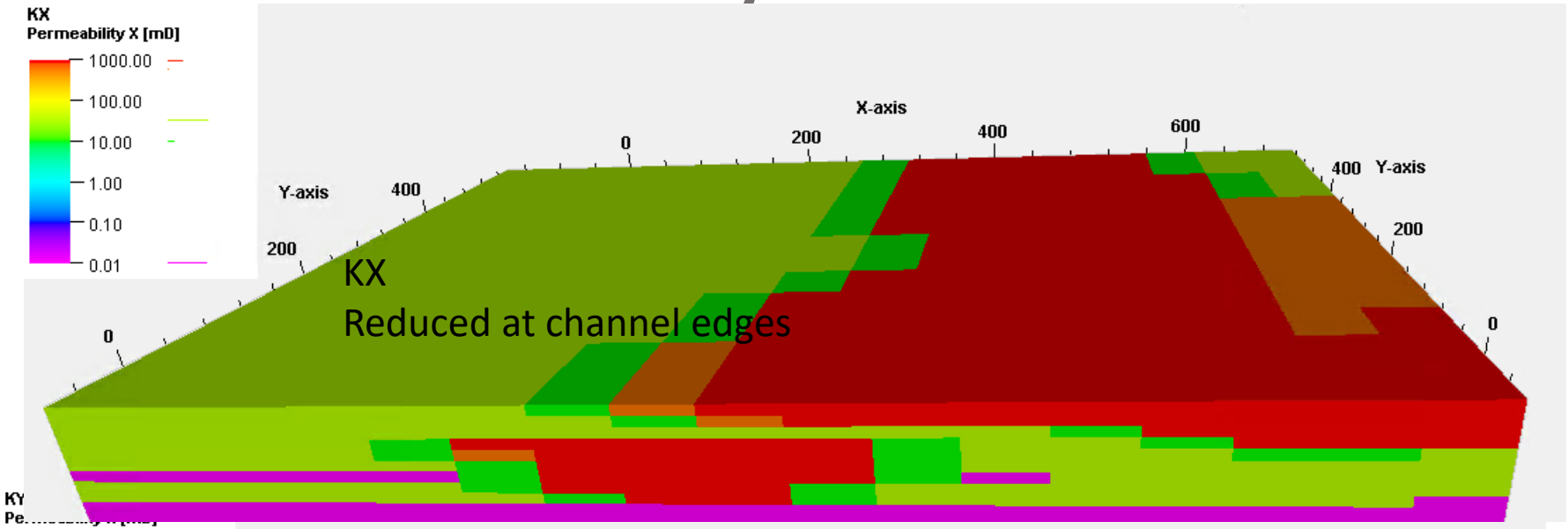
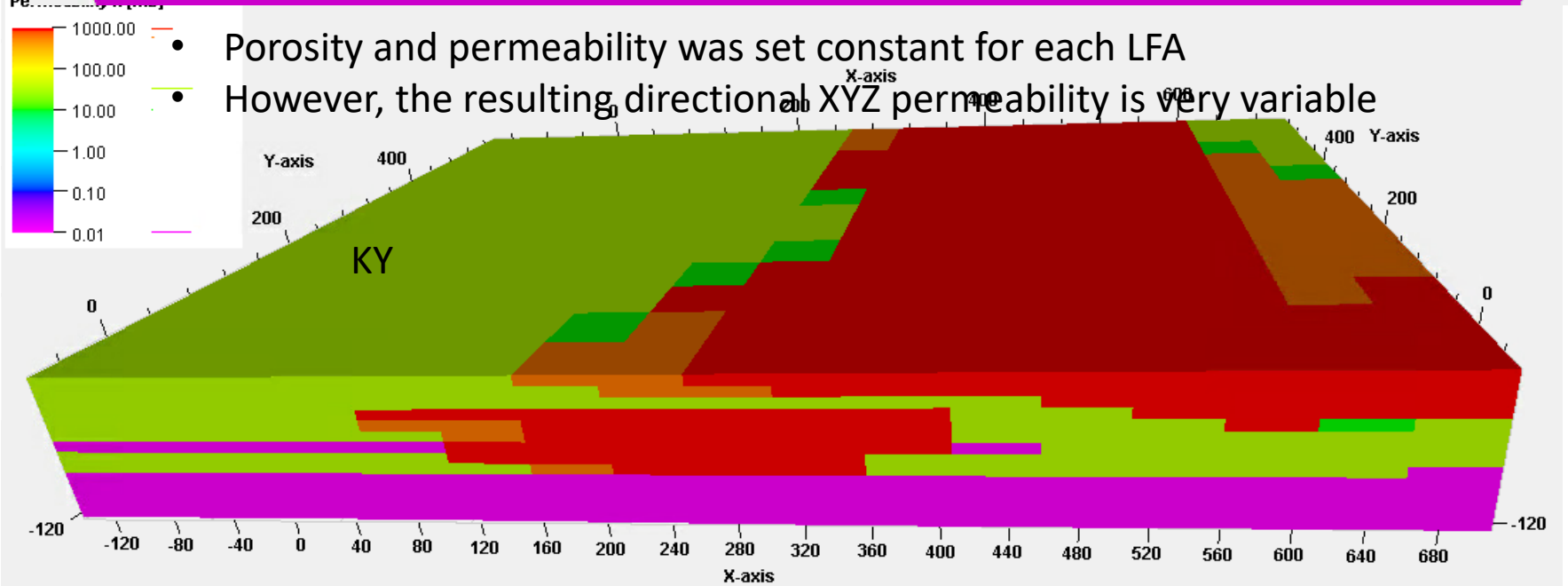
Directional Perm



- Porosity and permeability was set constant for each LFA
- However, the resulting directional XYZ permeability is very variable



Vertical Permeability Trend Model

- The Kv is calculated from:
  - The LFA cells
  - The relative position of the cells
    - e.g. reduced at base of channel

Core Plugs

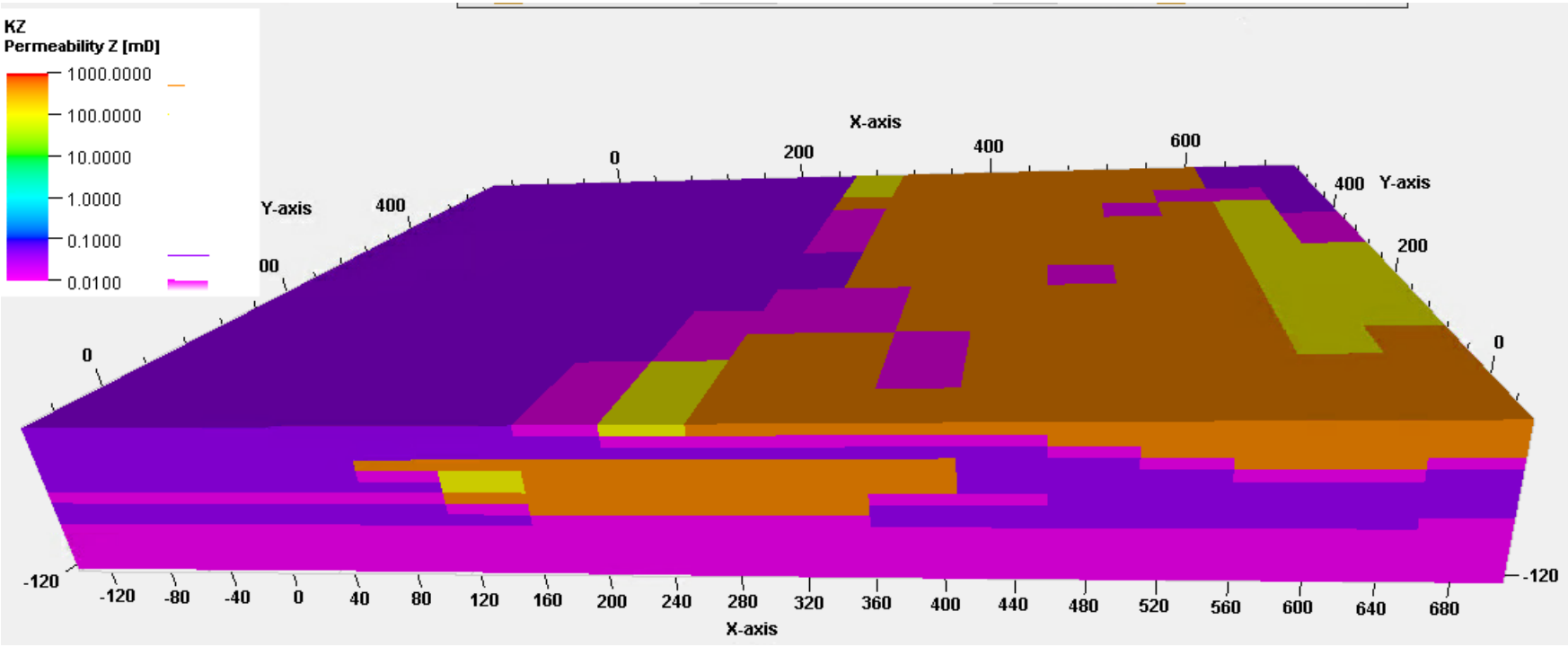
Outcrops

Facies bed-scale

Full-Field Model

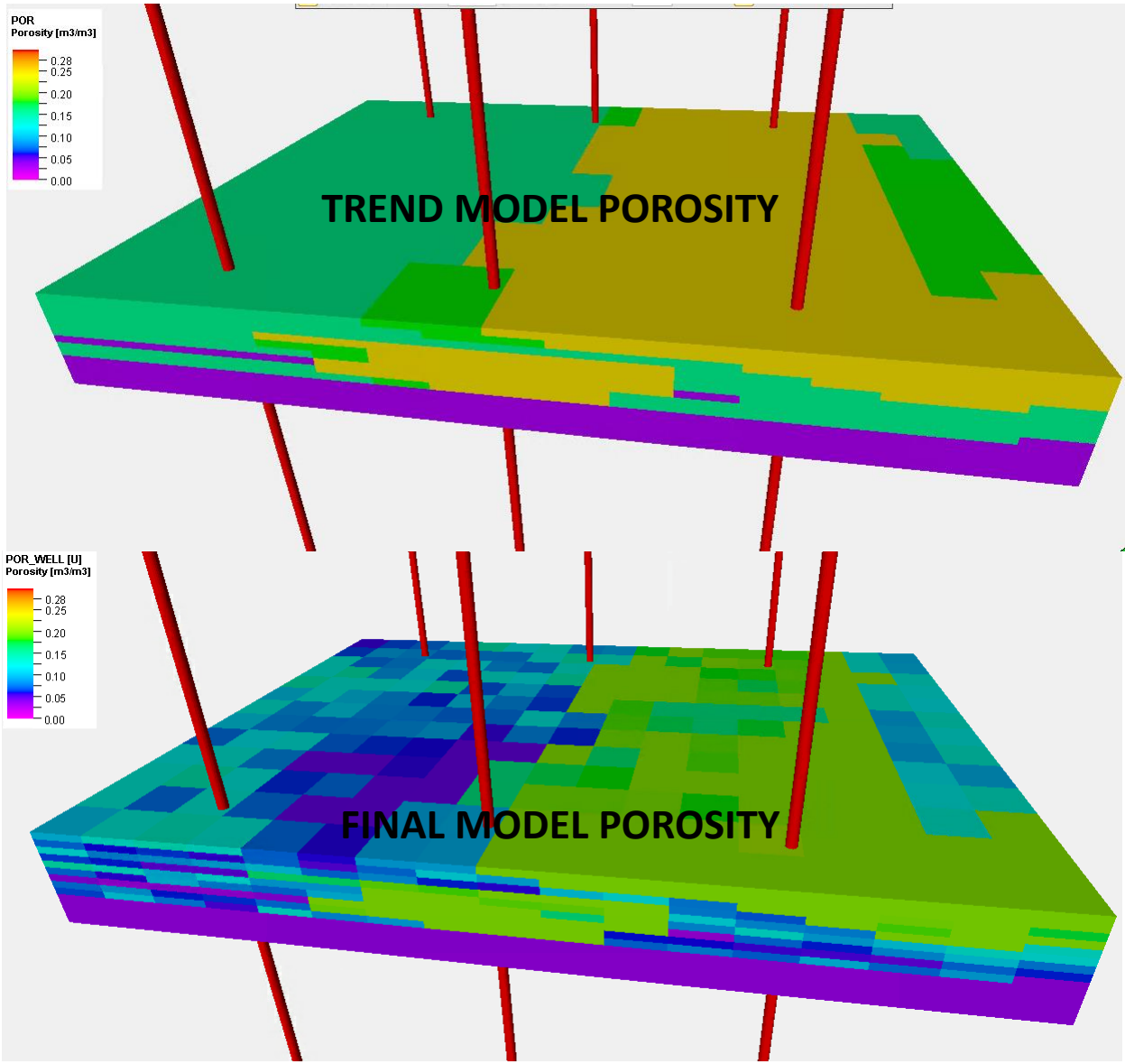
Model Baffles

Direction Perm



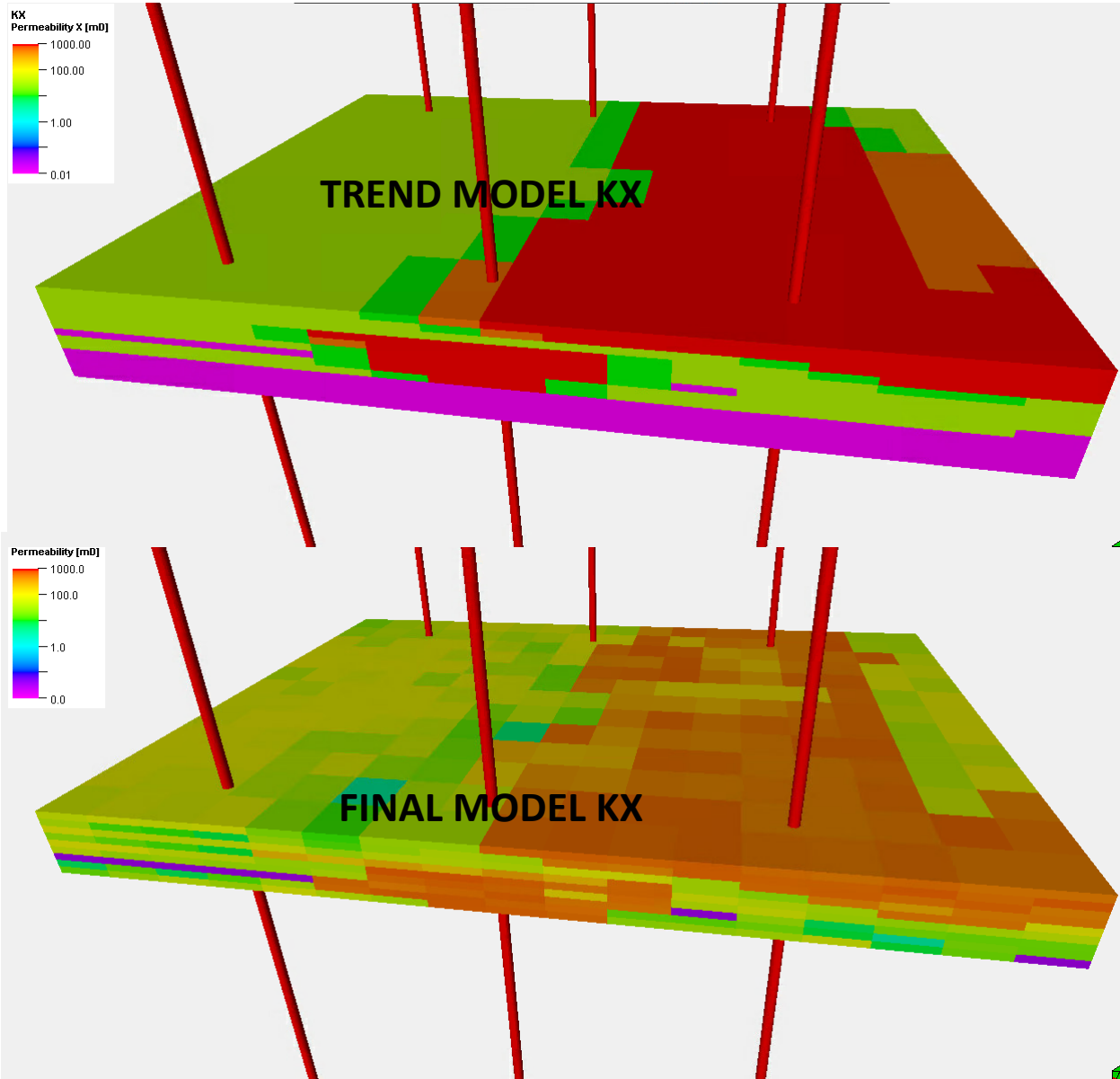
Input the Well Logs – Final Porosity Model

- A suitable petrophysical workflow needs to be applied to the wells
- The well log porosity is co-kriged with the trend model porosity
- For each LFA



Final Permeability Model

- The well log Kh is co-kriged with the trend model Kh permeability
  - Don’t need to have Kh in all wells
- KV directly from trend model

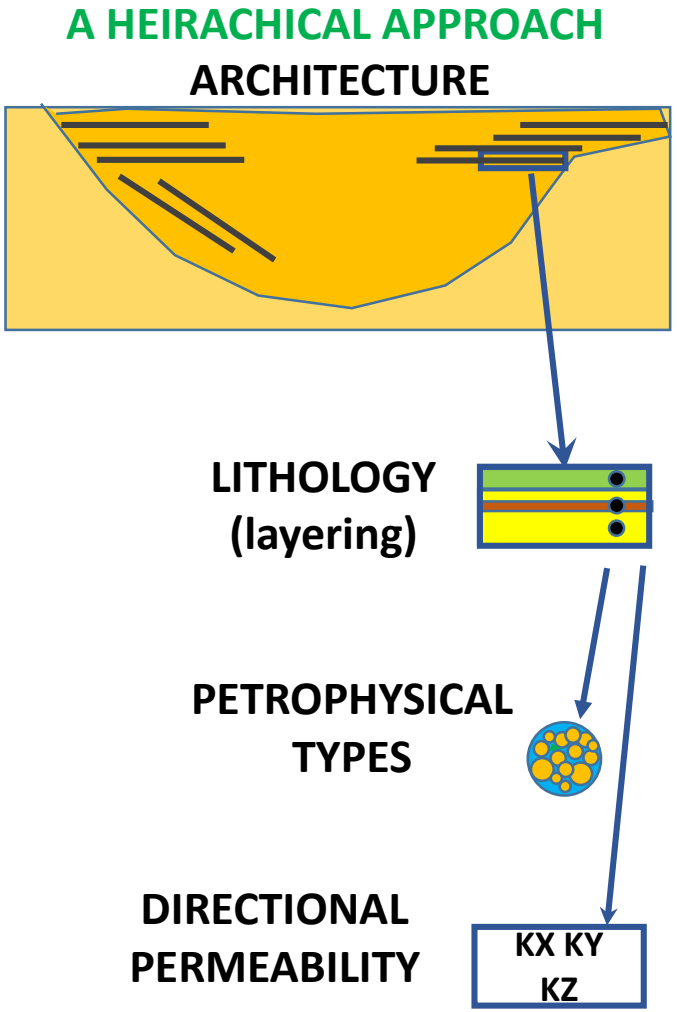


Advantages

- Use of core data can be maximised
- Easily to adjust model parameters
  - Build several scenarios
  - Not attempting to define every thin bed in the whole model, but the effect is captured geologically
- Degree of baffling between geo-bodies can be adjusted
  - The relative positions of cells can be identified
- Static and Simulation grid is the same
  - For the simulator, a permeability exists in all cells
- Using commercially available software
  - standard modules

Conclusions

- We need to think about WHAT geology needs to be represented at simulation scale
  - Not just make a finer cellular model
- Detailed examination of core plugs can assist in estimating permeability in the poor facies
- The core sedimentology can be used to build typical LFA cells that can be upscaled to estimate vertical and horizontal permeability separately
- Both the core-scale permeability and the large scale architecture are known to be especially important in thin bedded turbidites
- An additional geo-cellular method has been outlined that enables directional permeability to be estimated according to the position of each cell in 3D
  - Not just generating scattered low K cells
- A sensible range of vertical permeability can be estimated for the reservoir engineer

Summary Workflow

- Aim to build 3D model at dynamic simulation scale
- Large-scale architecture from outcrop information
- From core and logs, define Lithofacies Associations
- Intelligent use of core plugs from the poorer facies
- Single cell models are built to generate properties for each LFA
- In the full-field model baffles can be applied at the body interfaces
- Resulting directional permeability model supplied to reservoir engineer