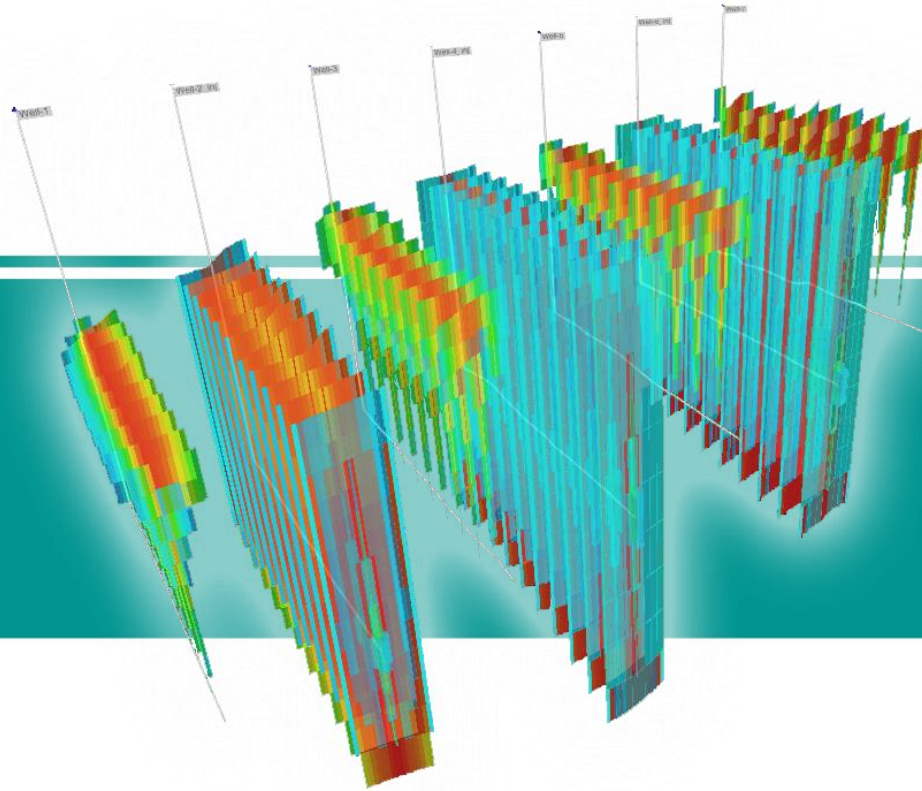
多保真度方法模拟非常规储层水力压裂

Modelling Hydraulically Fractured Wells: A Multi Fidelity Approach to Unconventional Reservoirs



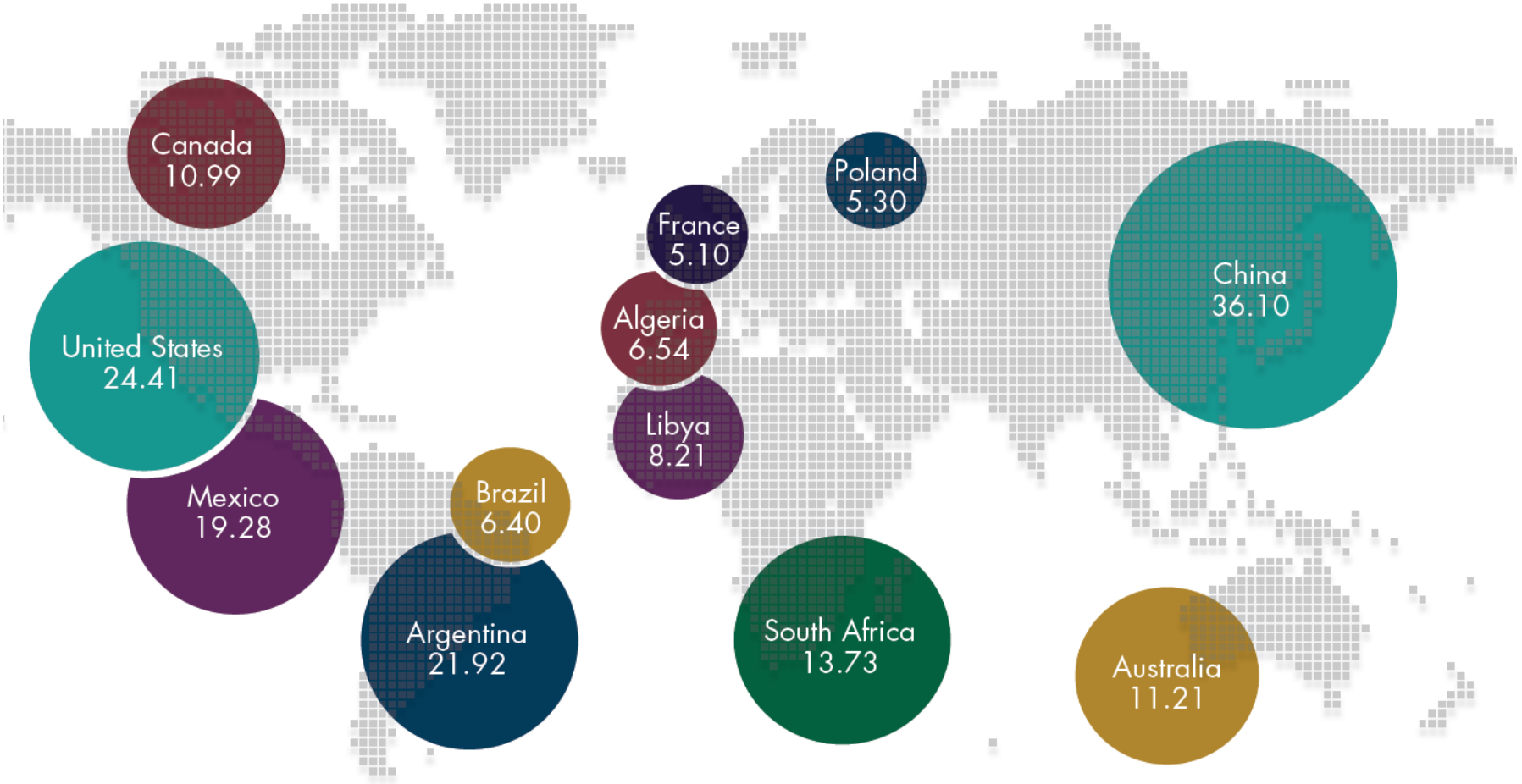
Kevin Joslin
Reservoir Simulation Engineer

Anjani Kumar
Vice President
Engineering Solutions & Marketing

Agenda

- Introduction/Workflows Overview
- Hydraulic Fracture Production Modelling Methods
- Hydraulic Fracture Initiation/Propagation Modelling

Worldwide Distribution of Shale gas



Source: US Energy Information Administration (EIA)

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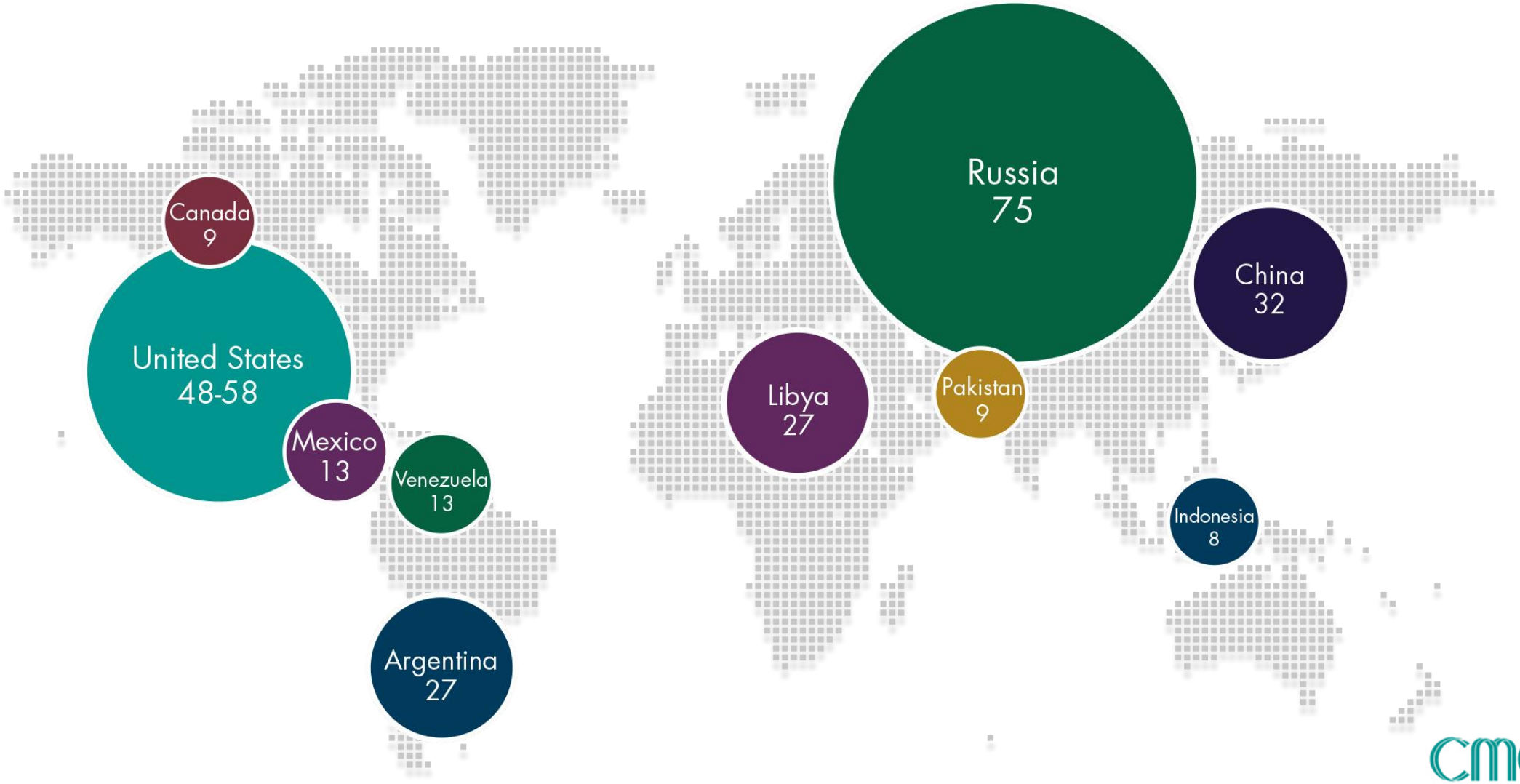
Worldwide Distribution of Tight Oil



Source: US Energy Information Administration (EIA)

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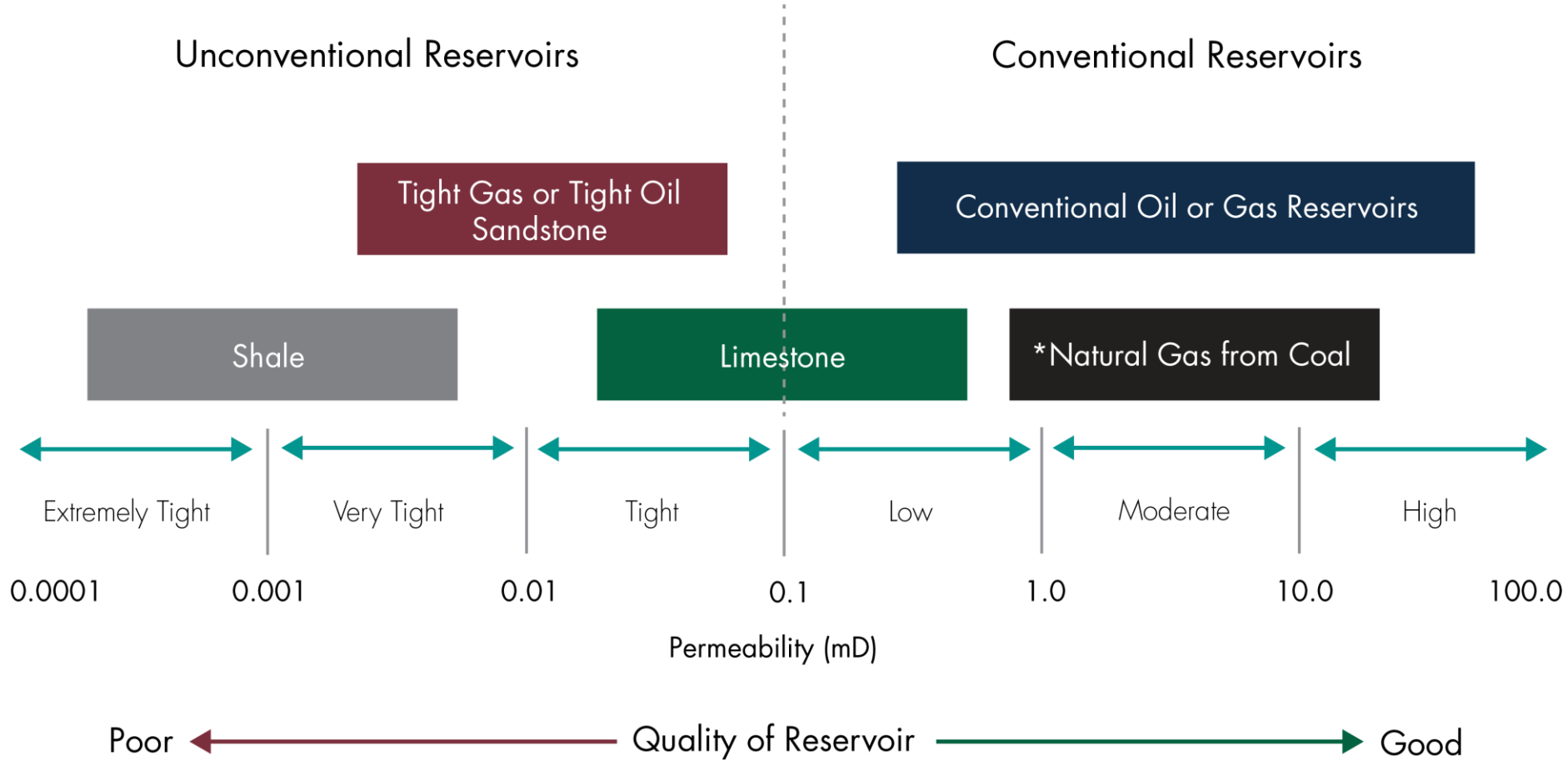
Characterization of Tight Formations



Source: ***Canadian Society for Unconventional Resources****:*
http://www.csur.com/sites/default/files/Understanding_TightOil_FINAL.pdf

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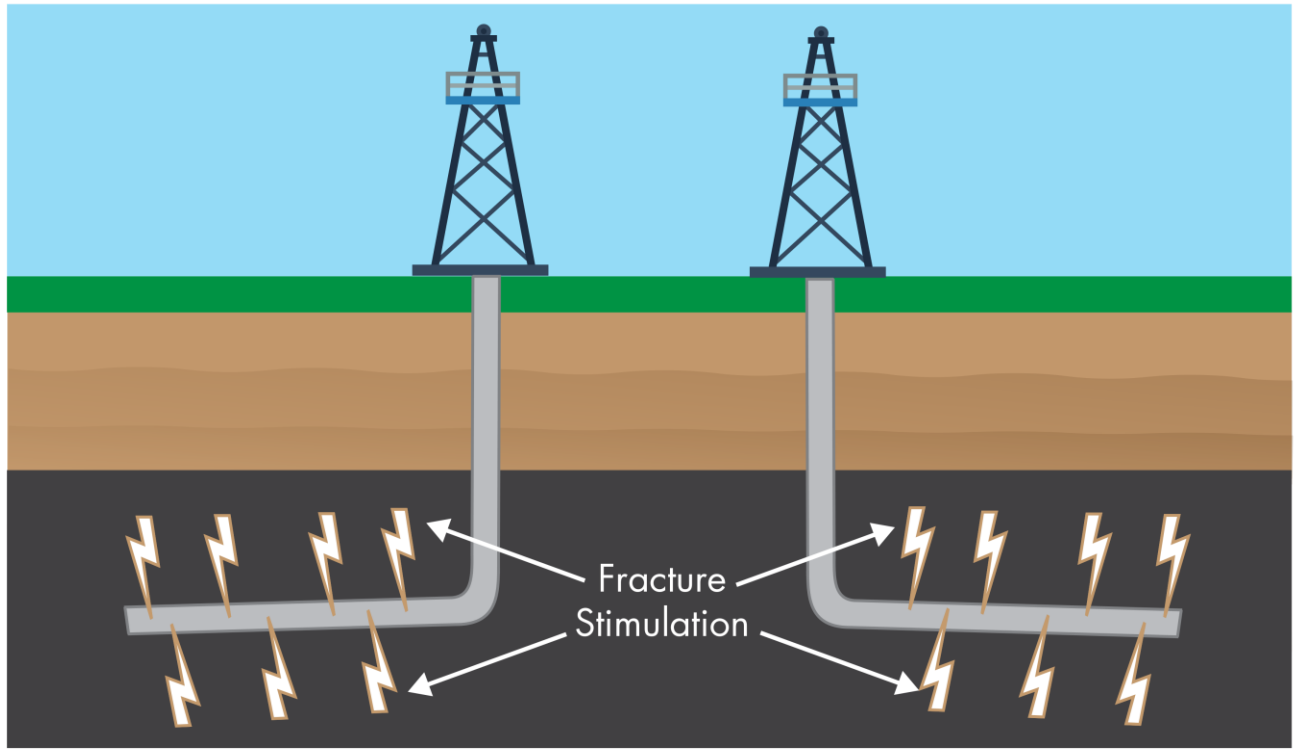
Developing Unconventional Assets

- Horizontal Multi-Stage Fractures



Source: thebreakthrough.org

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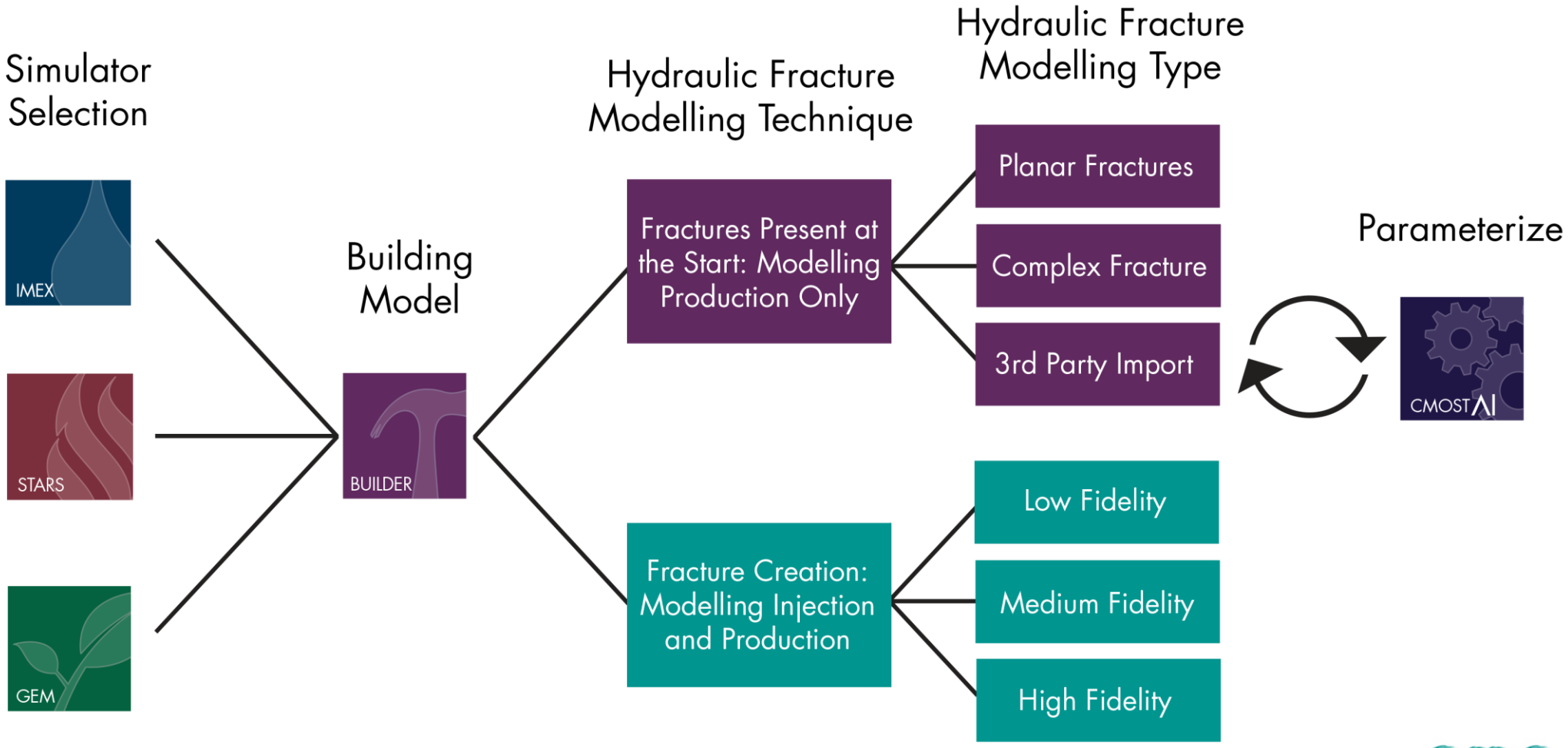
Workflows



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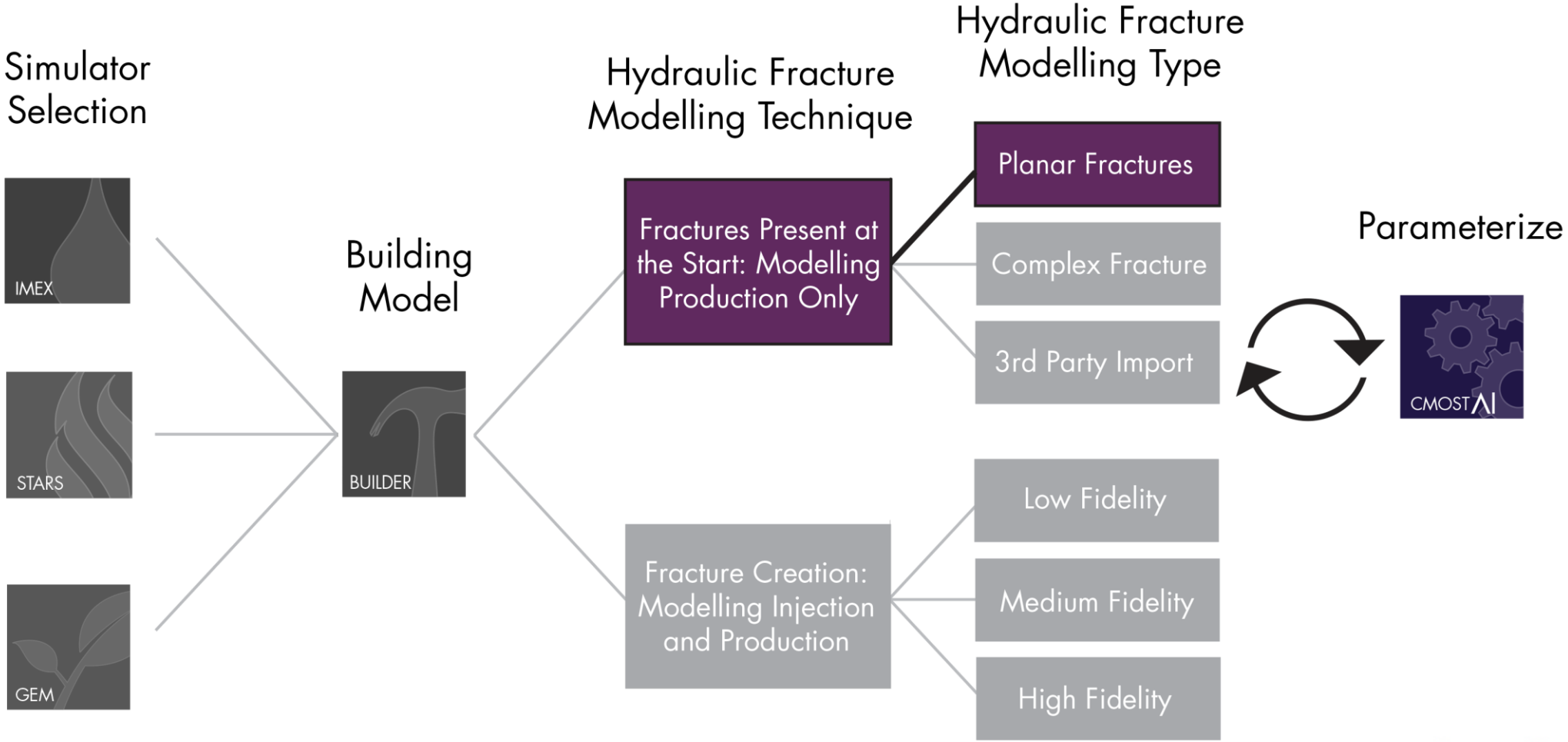
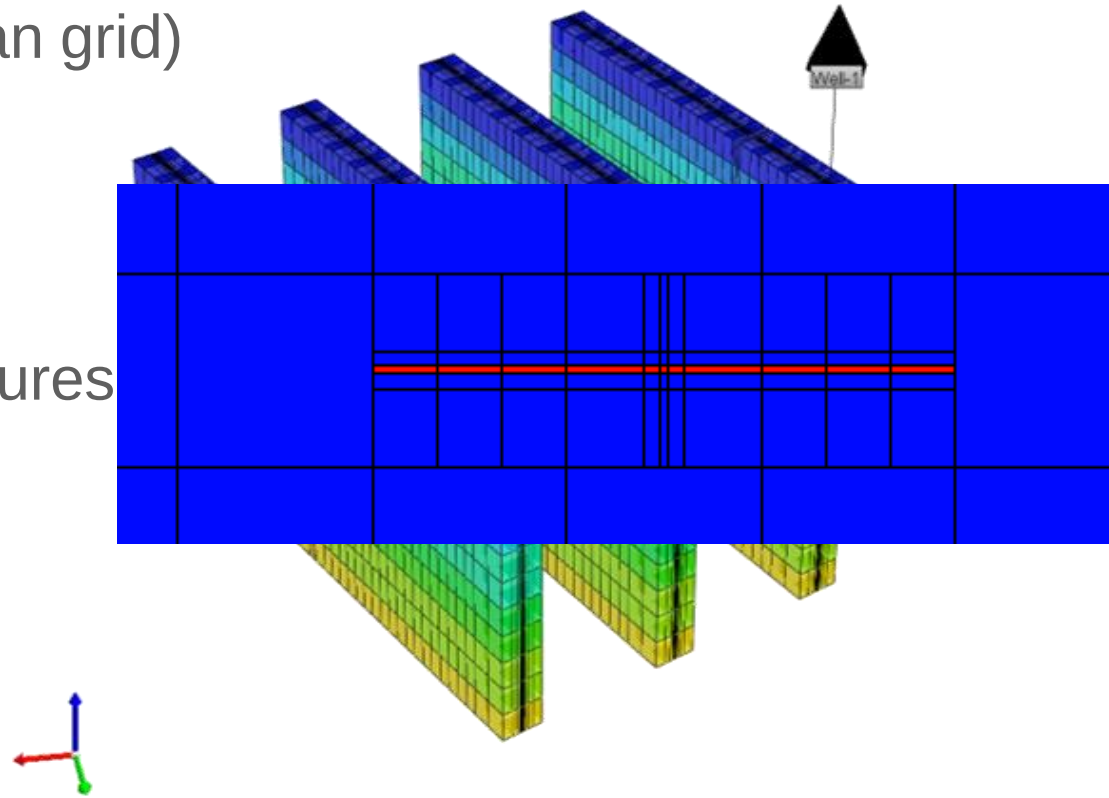
Planar Fractures



Planar Fractures

- Specify Half-length, height, conductivity of each fracture
- Modelled through LS-LR-DK model (tartan grid)
    - Logarithmic spacing
    - Local Refinement
    - Dual Permeability
- Fast and accurate way of modelling fractures
- Properties easily parameterized
- Multi-well Simulations



Planar Fractures

```
*PLNRFRAC_TEMPLATE 'Planar Template'
  *PLNR_REFINE *INTO  7 7 1
    *BWHLEN 350
    *JDIR
    *INNERWIDTH 2
    *LAYERSUP 4
    *LAYERSDOWN 5
  *PERMI MATRIX *FZ 25 2.5
  *PERMJ MATRIX *FZ 25 2.5
  *PERMK MATRIX *FZ 25 2.5
*END_TEMPLATE
```

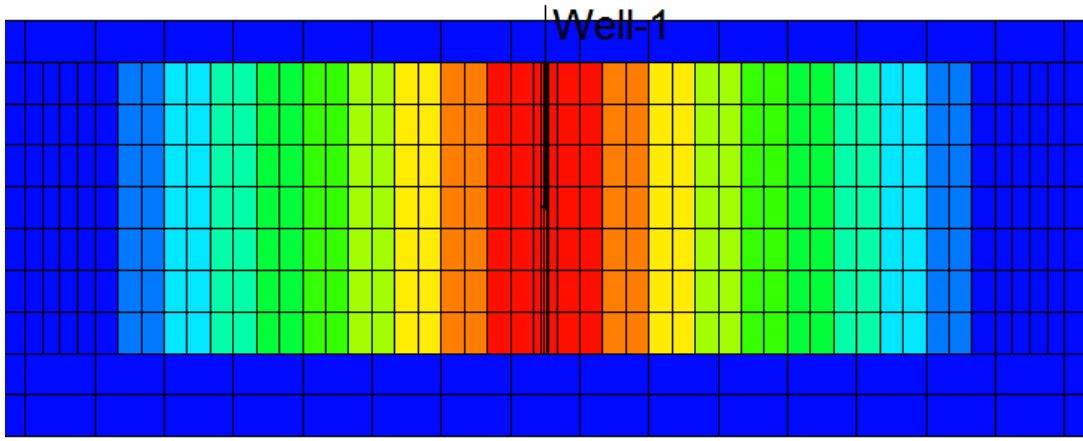
refinement level

half-length

effective width

frac height

effective permeability
linear gradient



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Planar Fractures

perf location

*PLNRFRAC 'Planar Template' 22,28,5 *BG_NAME 'Well-1 - Frac_1'

Template name

Creating a block group with a specific name

Property

Fracture Zone

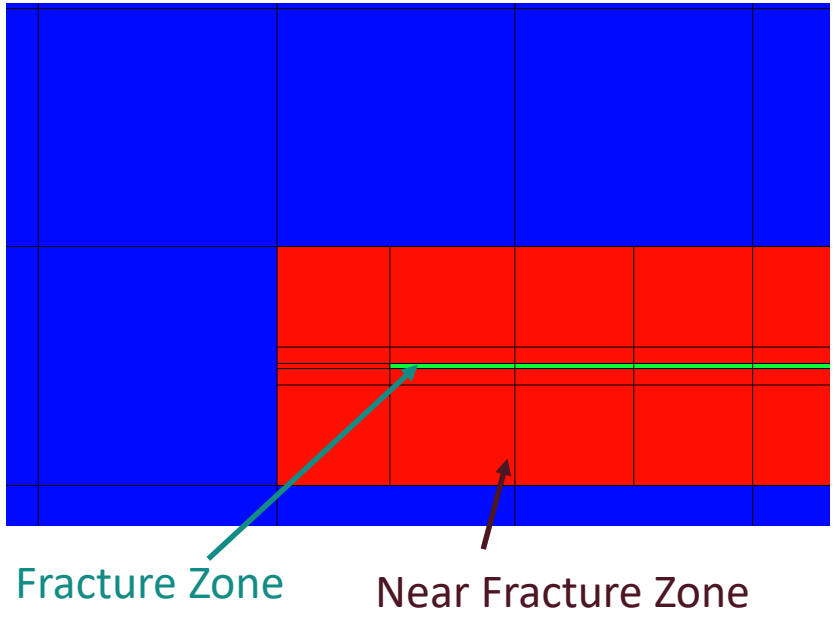
*RTYPE MATRIX BG 'Well-1 - Frac_1' *FZ 2

Referencing a specific block group

Property Value

*RTYPE MATRIX BG 'Well-1 - Frac_1' *NFZ 3

Near Fracture Zone



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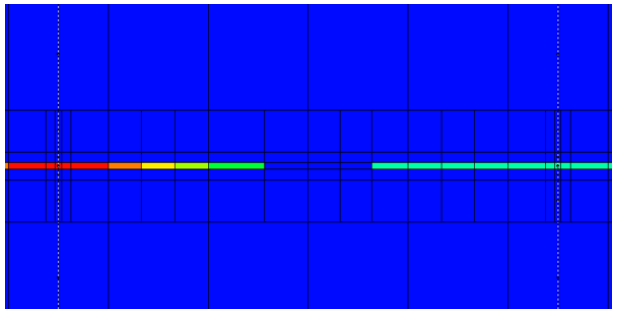
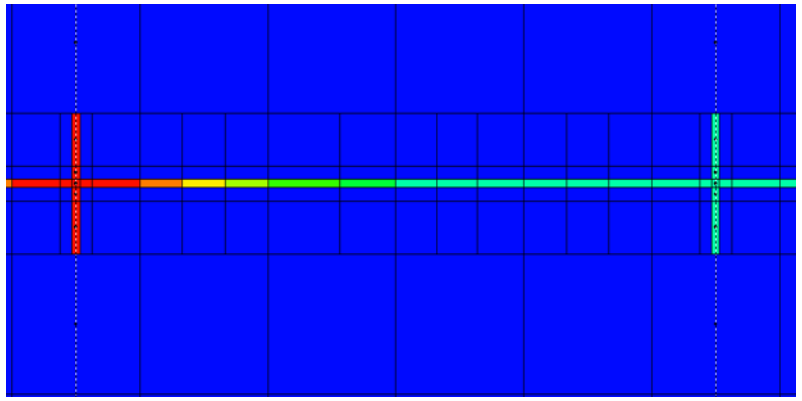
Planar Fractures

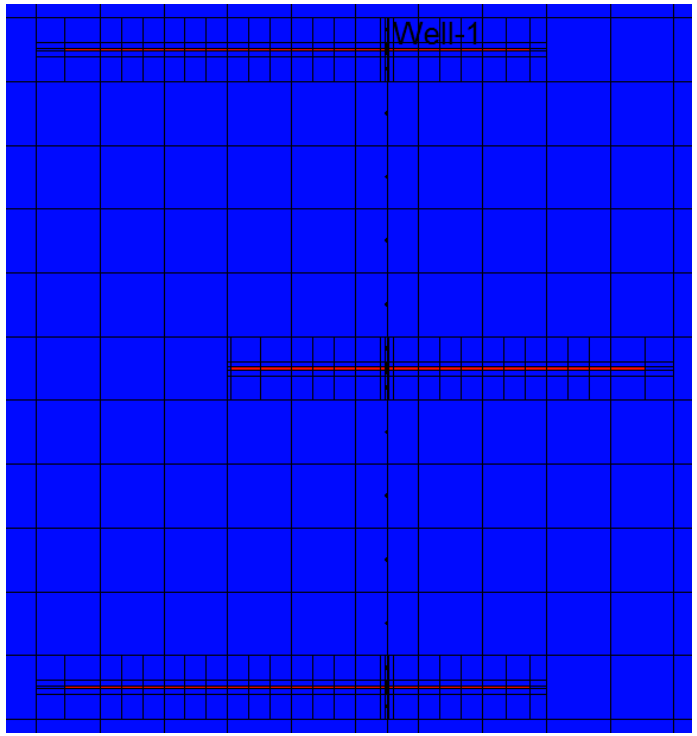
- Connecting Fractures and uneven Half-lengths



Two fractures from neighbouring wells unconnected



Fractures Connected at Tip and Longitudinal Fractures

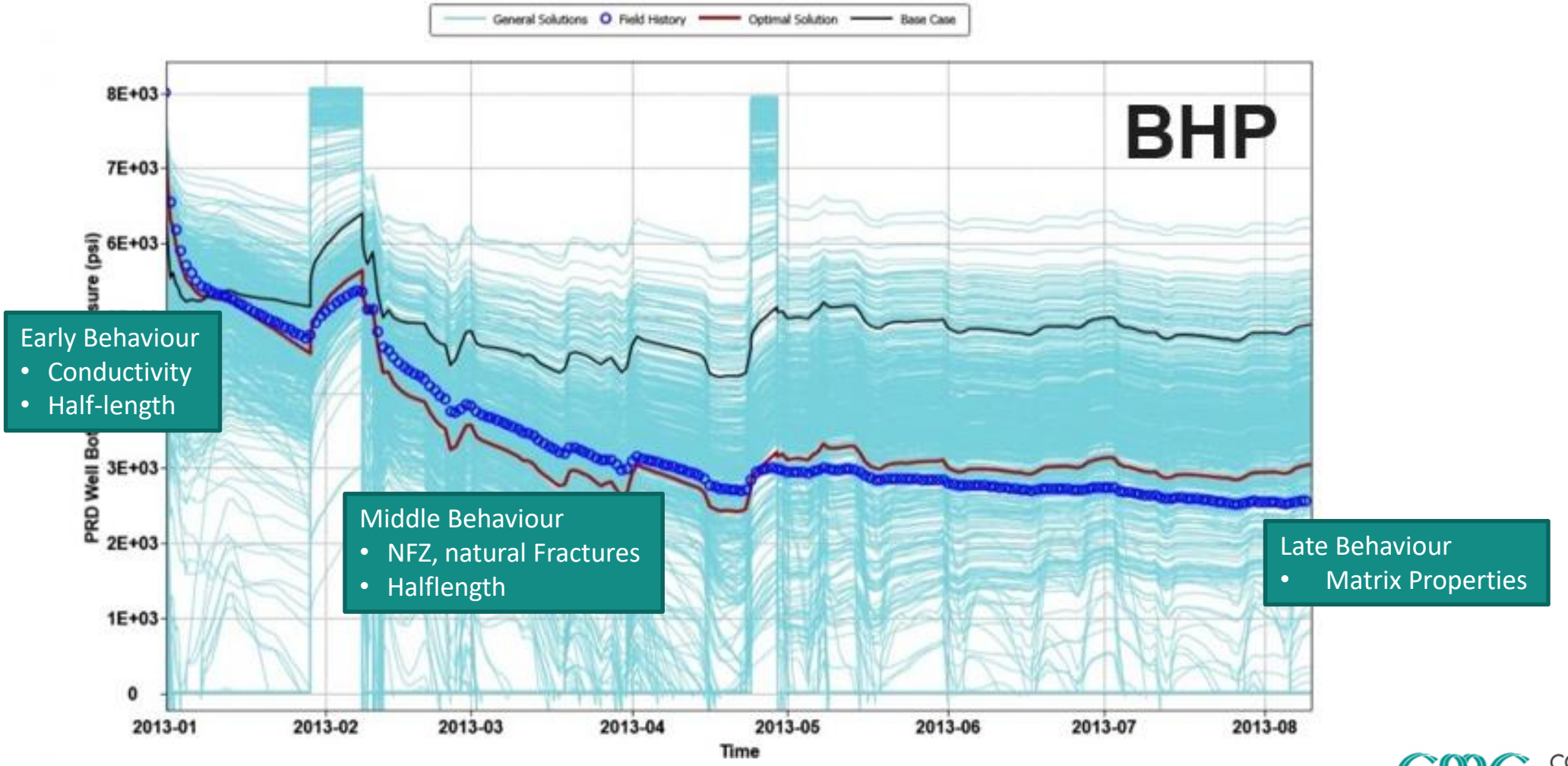


Uneven Half-lengths

Planar Fractures: Linking to CMOST

- CMOST-AI
  - Fully linked to hydraulic fracture keywords
  - Can parameterize:
    - Half-length
    - Fracture spacing
    - Fracture conductivity
    - Initial fracture water saturation
    - FZ/NFZ properties

Planar Fractures: History Matching



Early Behaviour
- Conductivity
- Half-length

Middle Behaviour
- NFZ, natural Fractures
- Halflength

Late Behaviour
- Matrix Properties

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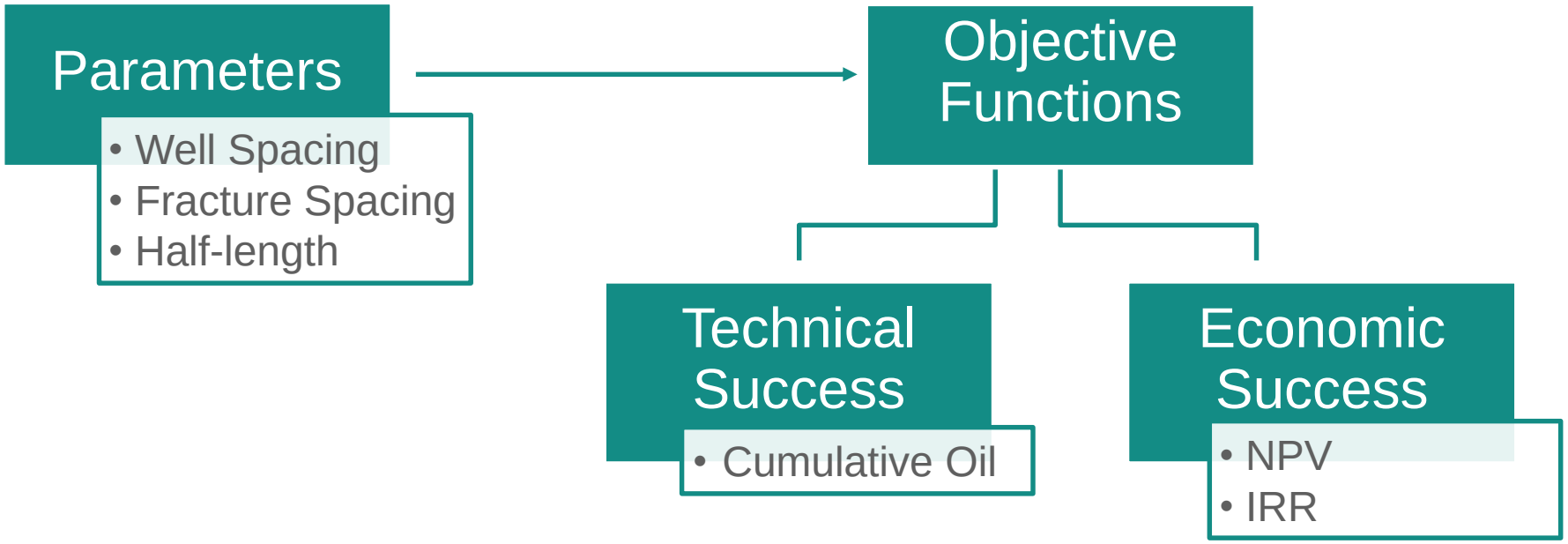
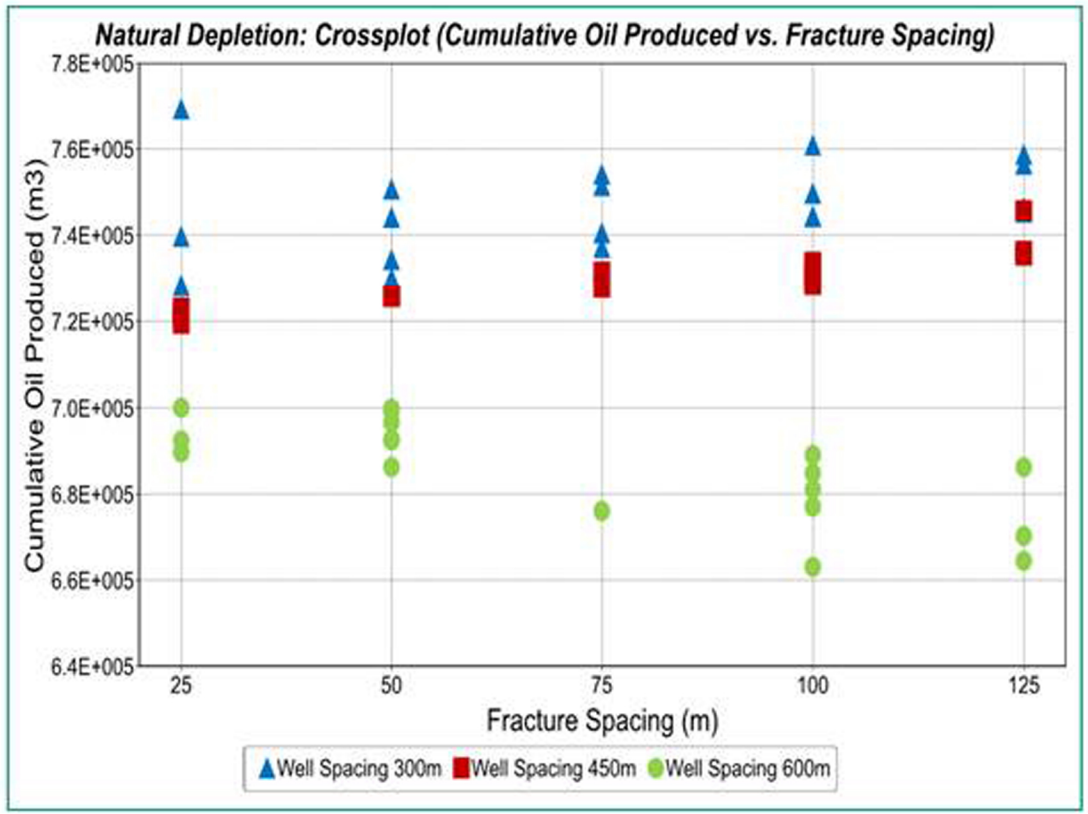
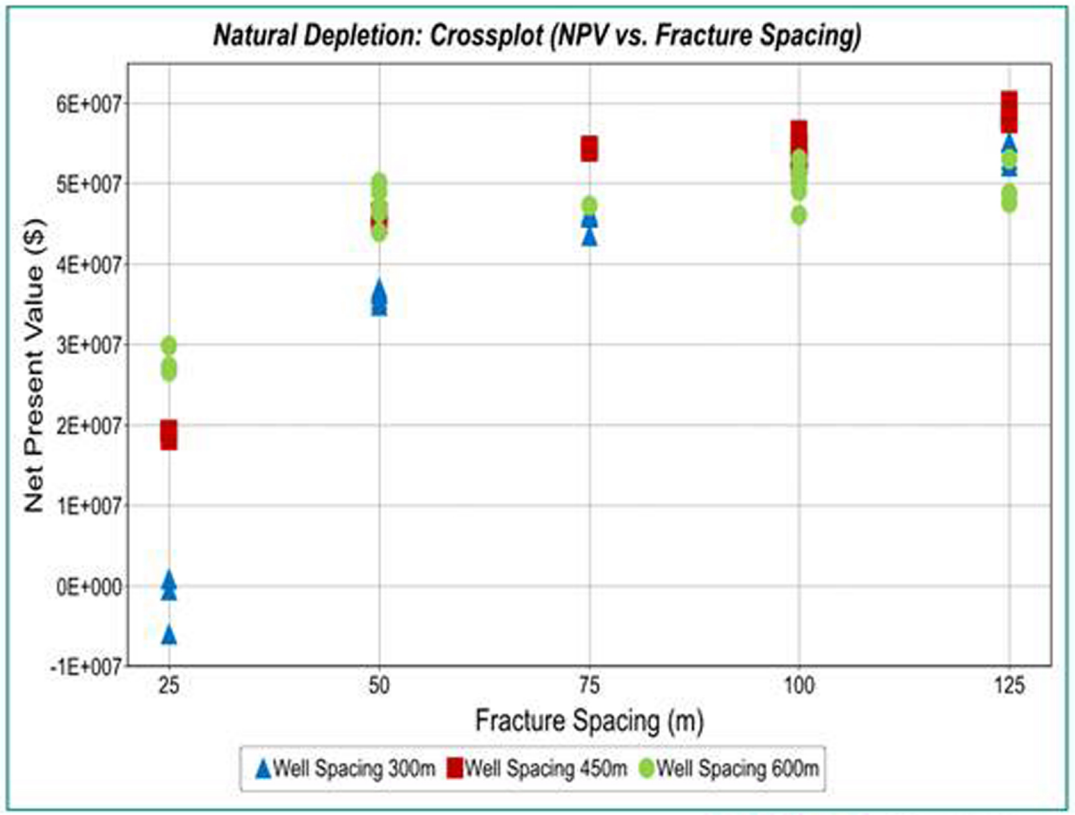
Planar Fractures: Optimization



Planar Fractures: Optimization





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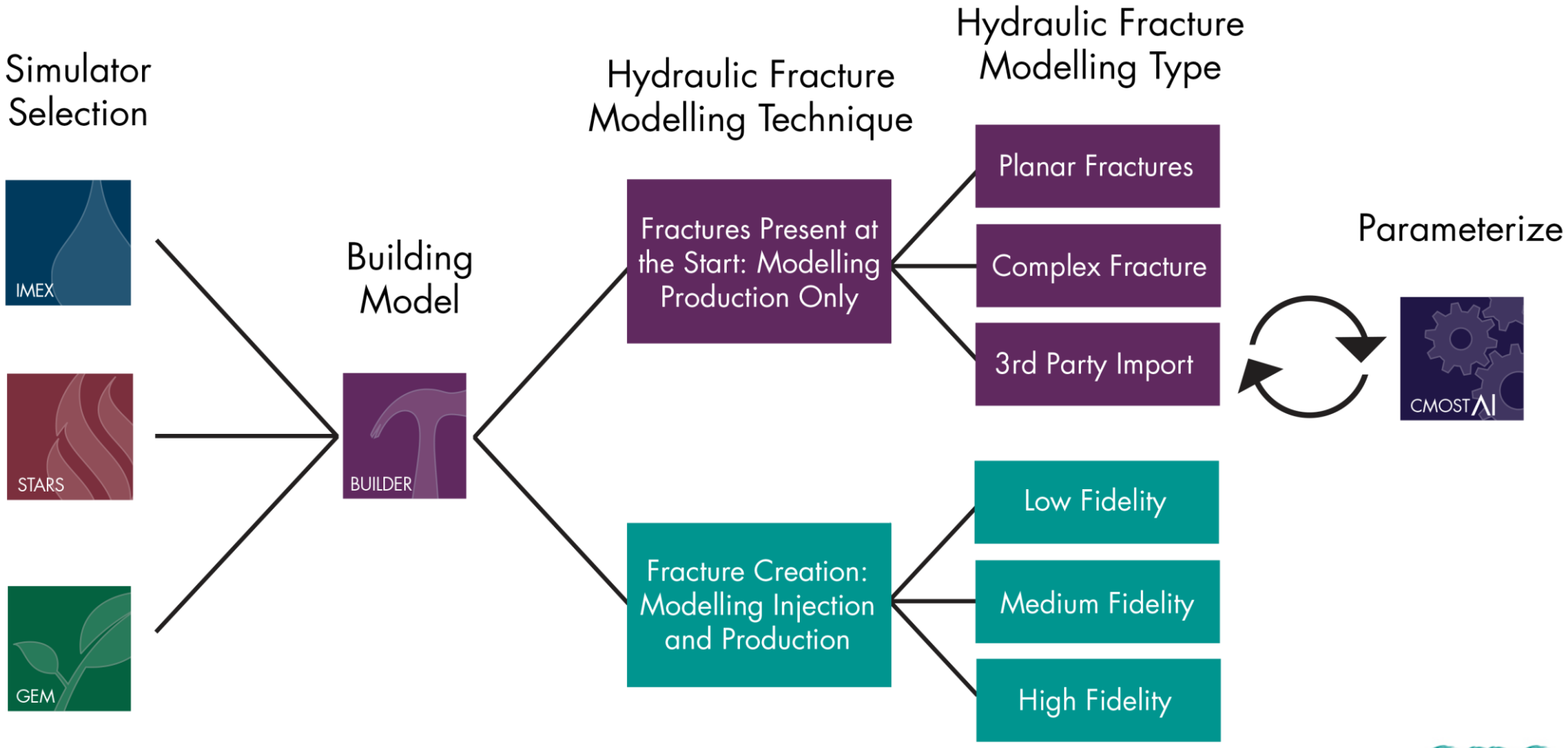
Workflows



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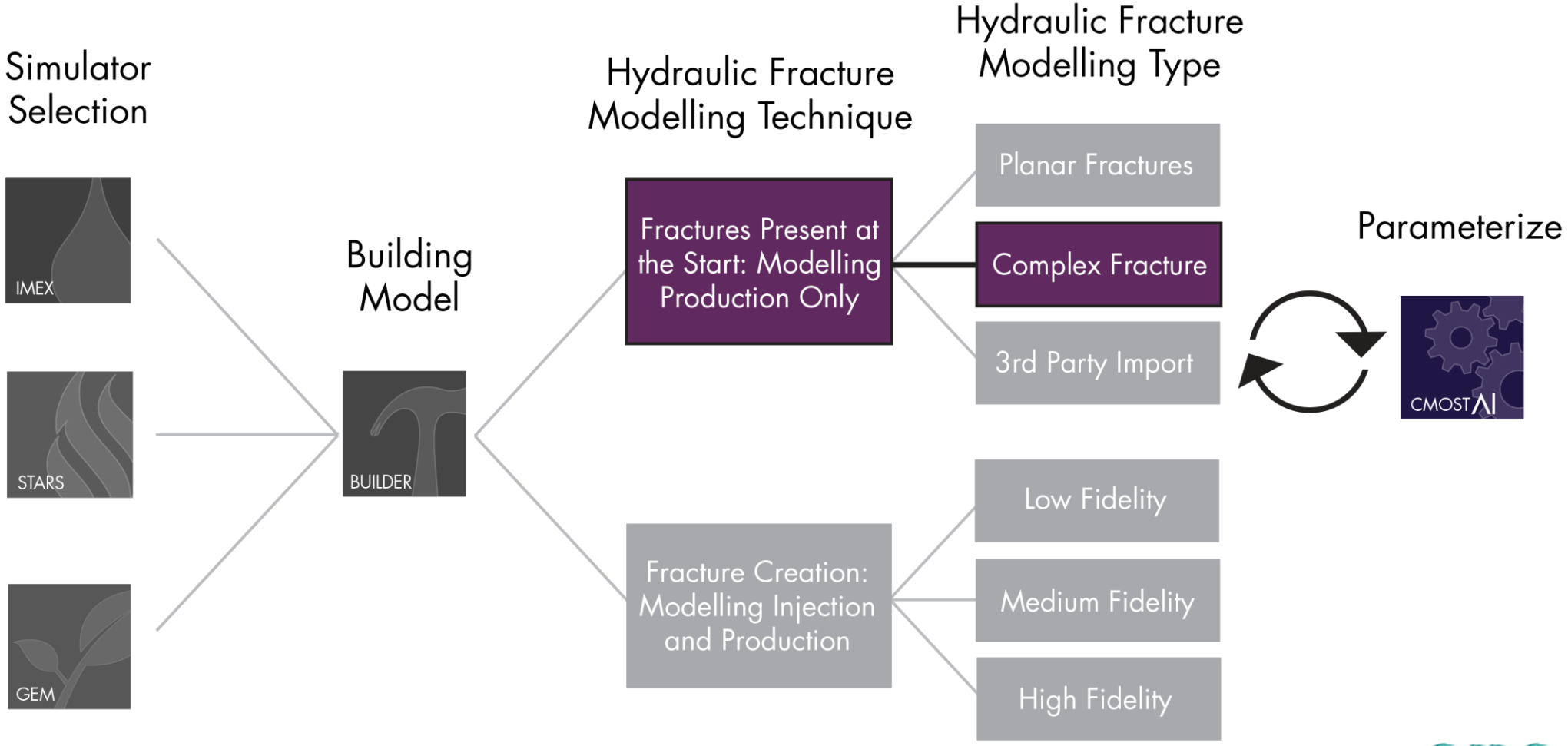
Complex Fractures



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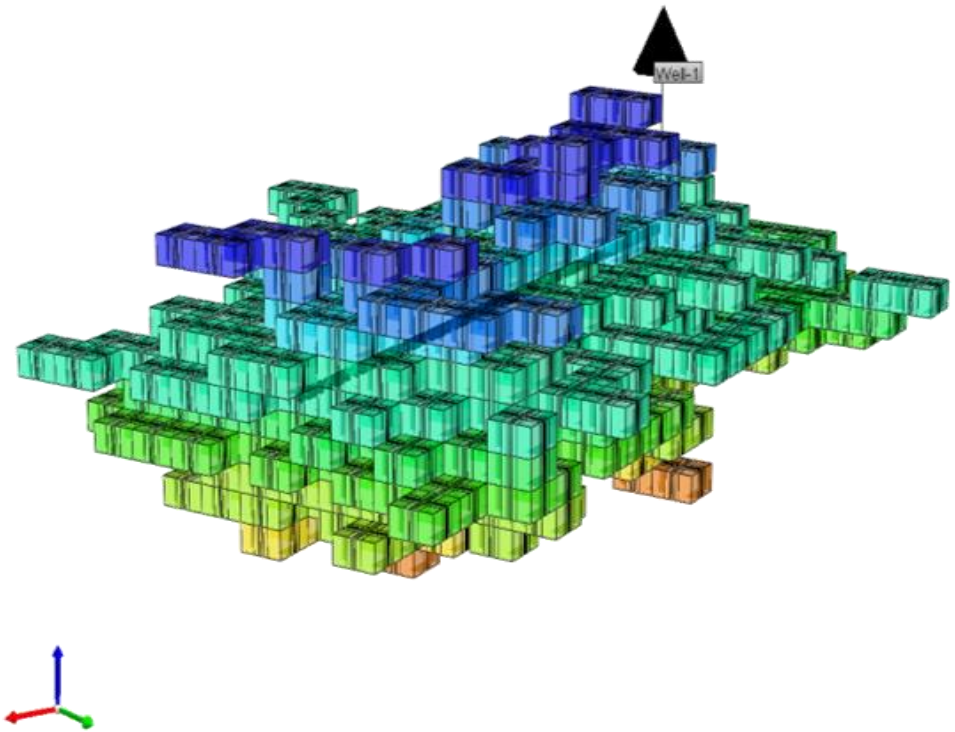
Complex Fractures

- Model complex fracture networks
- Based on micro-seismic data or user defined areas
- Uses tartan gridding
- Captures the complexity of a fracture network
- Useful for when fractures are close together or when fracture systems become connected



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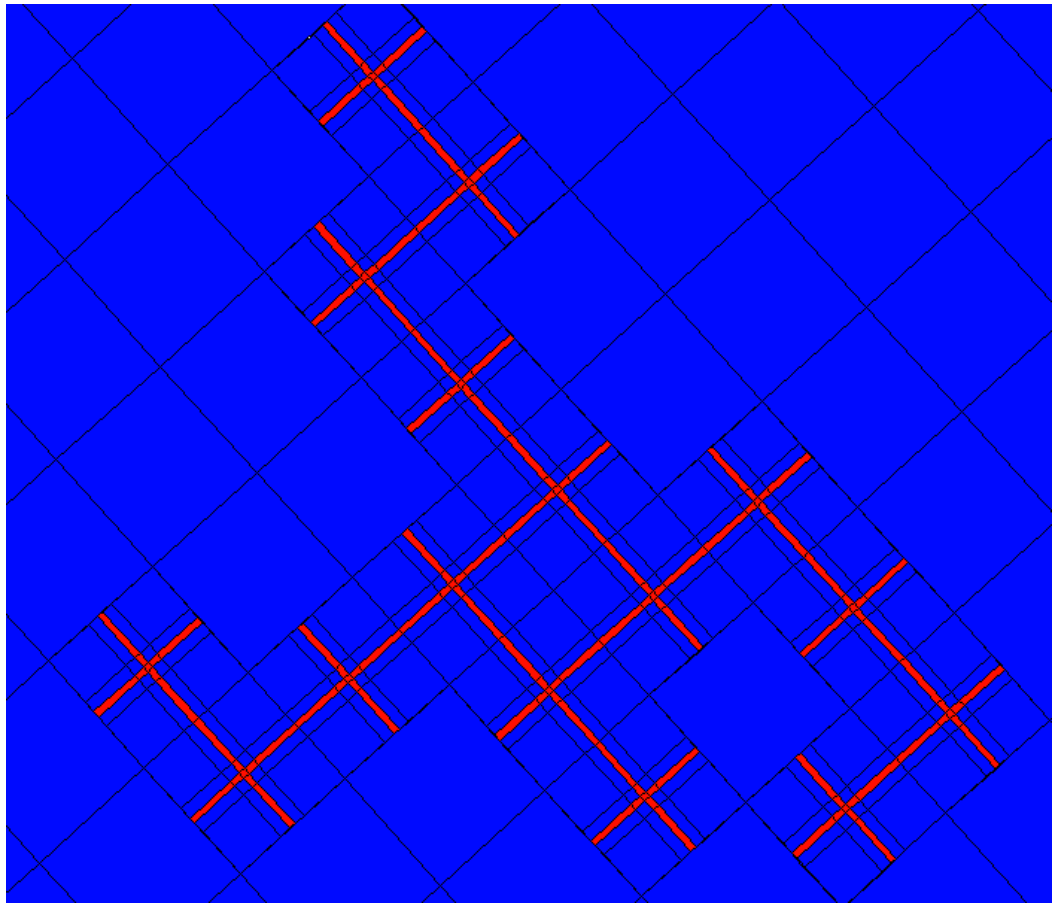
Complex Fractures

```
*BLOCKGROUP 'Complex Fracture 1'
*IJK 22:40 23:33 1:10 1
*REFINE *INNERWIDTH 2
    *BG 'Complex Fracture 1' INTO 5 5 1


*PERMI MATRIX BG 'Complex Fracture 1' *FZ 5
*PERMJ MATRIX BG 'Complex Fracture 1' *FZ 5
*PERMK MATRIX BG 'Complex Fracture 1' *FZ 5
```



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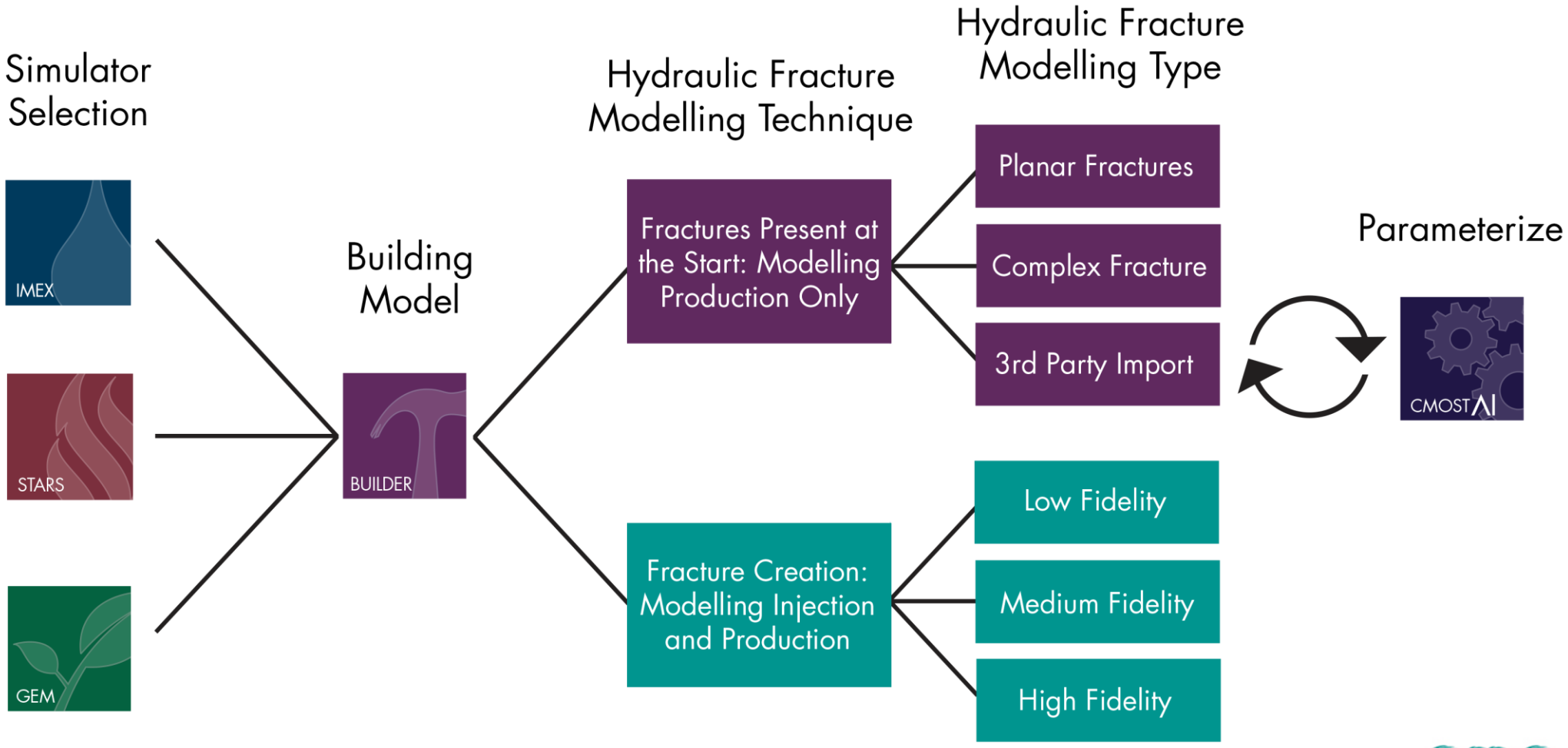
Workflows



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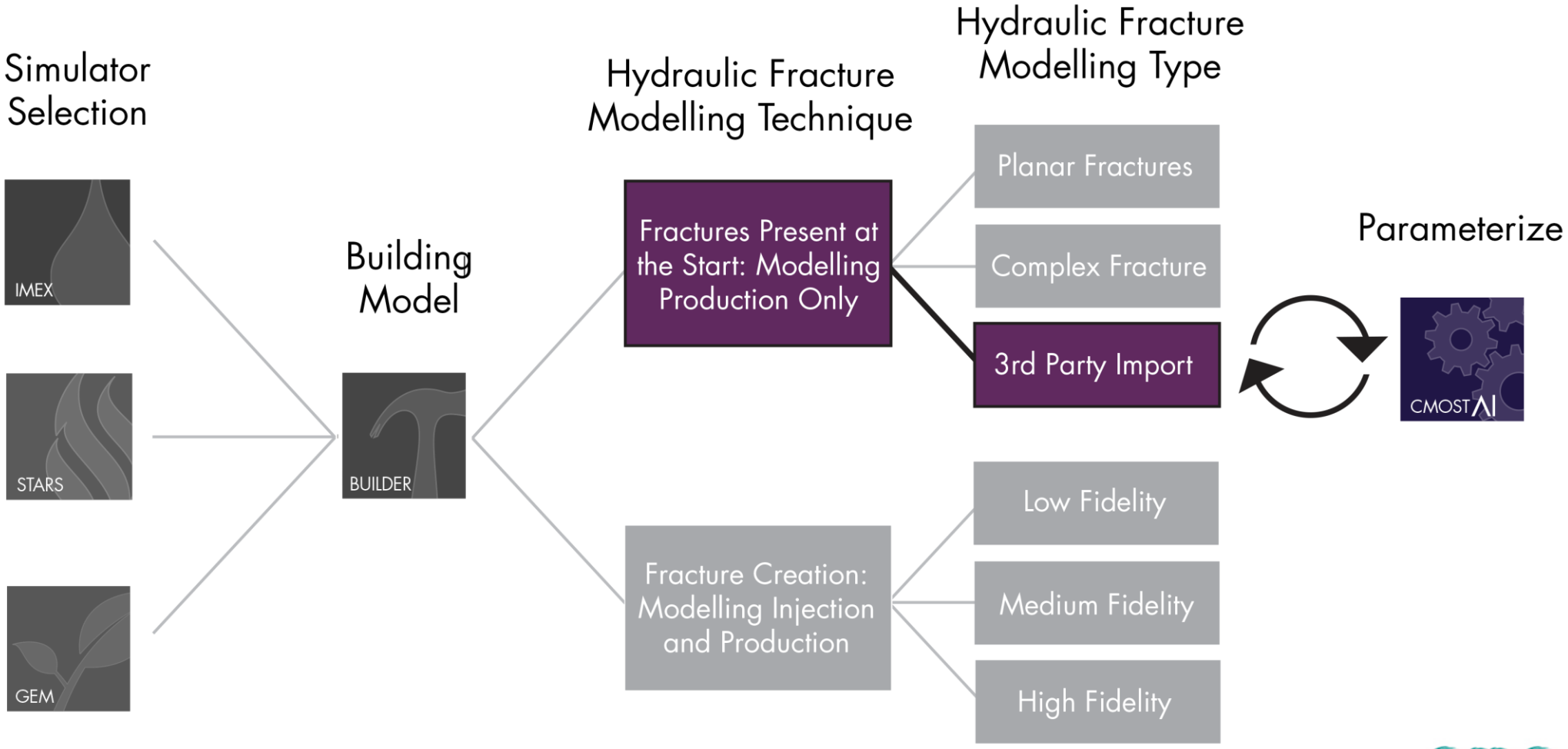
Fracture Importing



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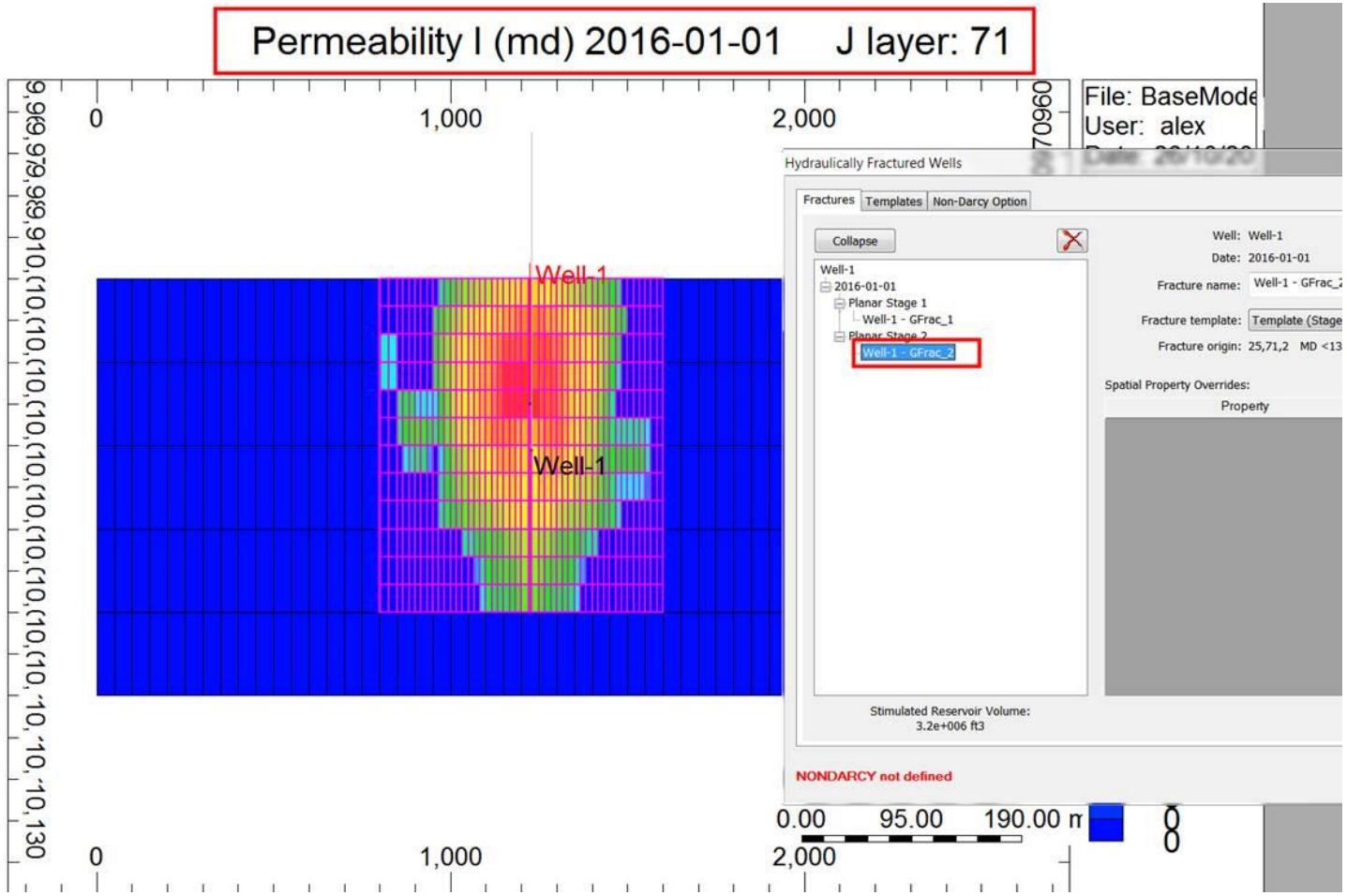
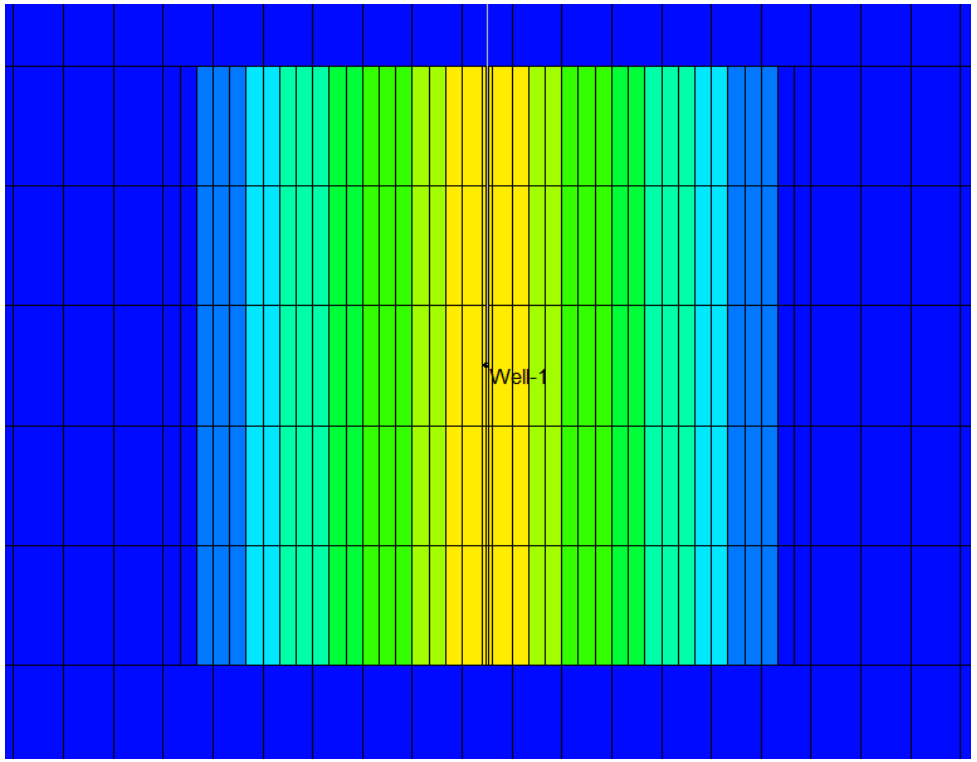
Fracture Importing

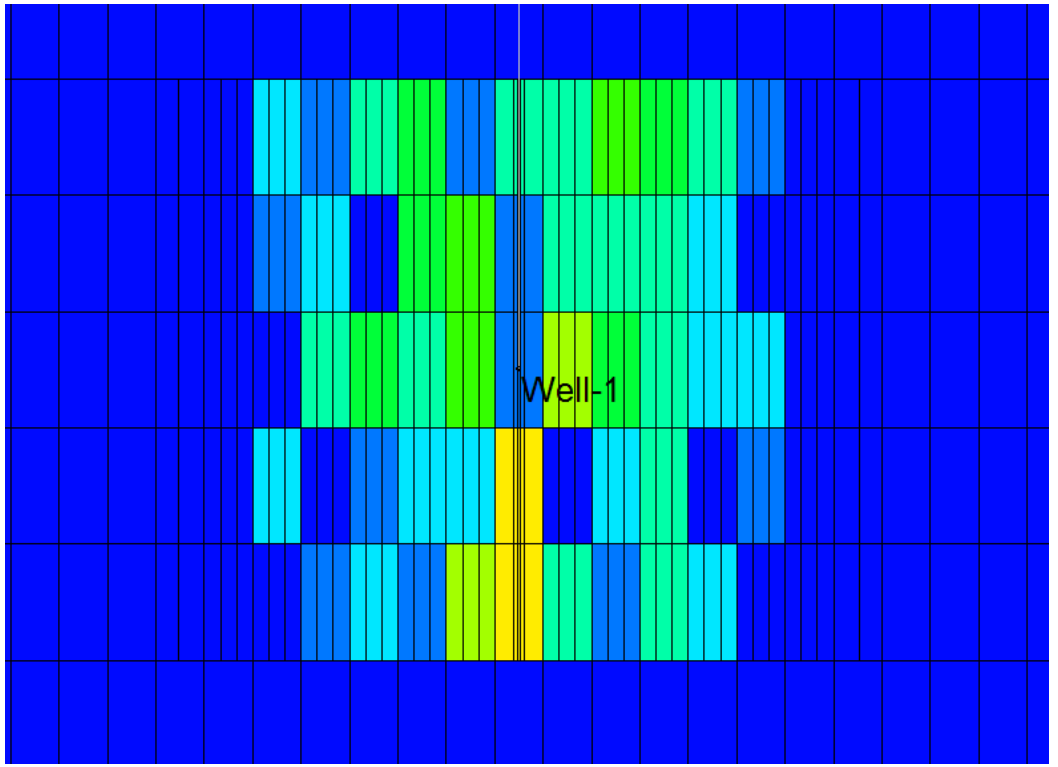
- Import hydraulic fractures from third party software
- Modelled as planar fractures in CMG but preserves permeability distribution



Fracture Importing



Hydraulic fracture created with block groups-constant permeability



Hydraulic fracture created with structured block group-variable permeability

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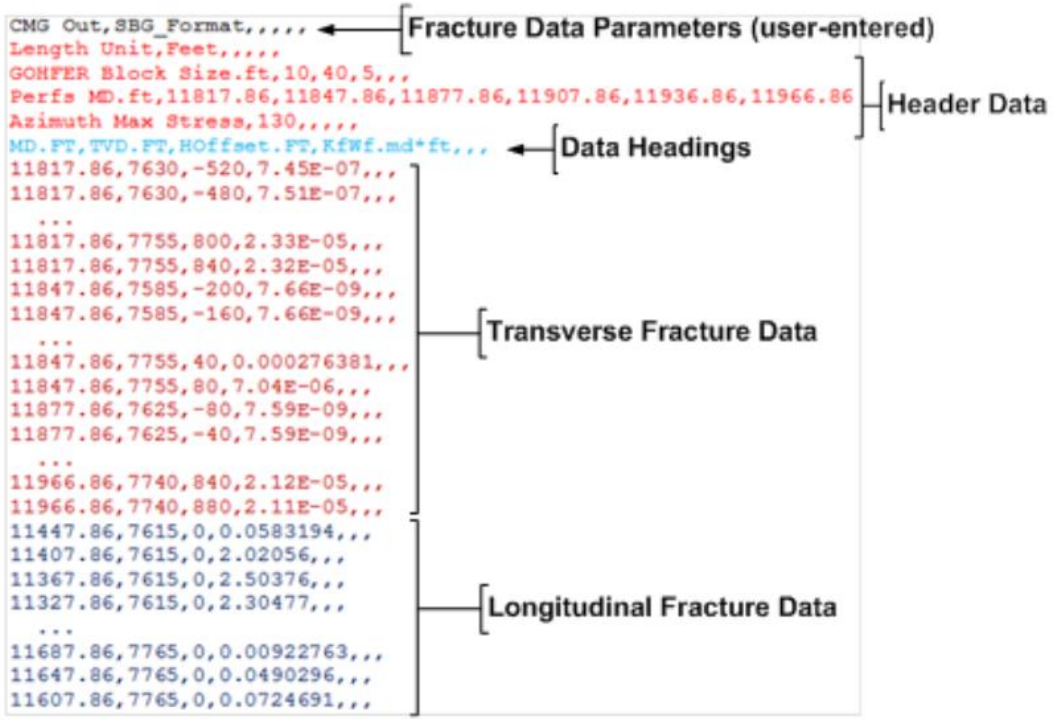
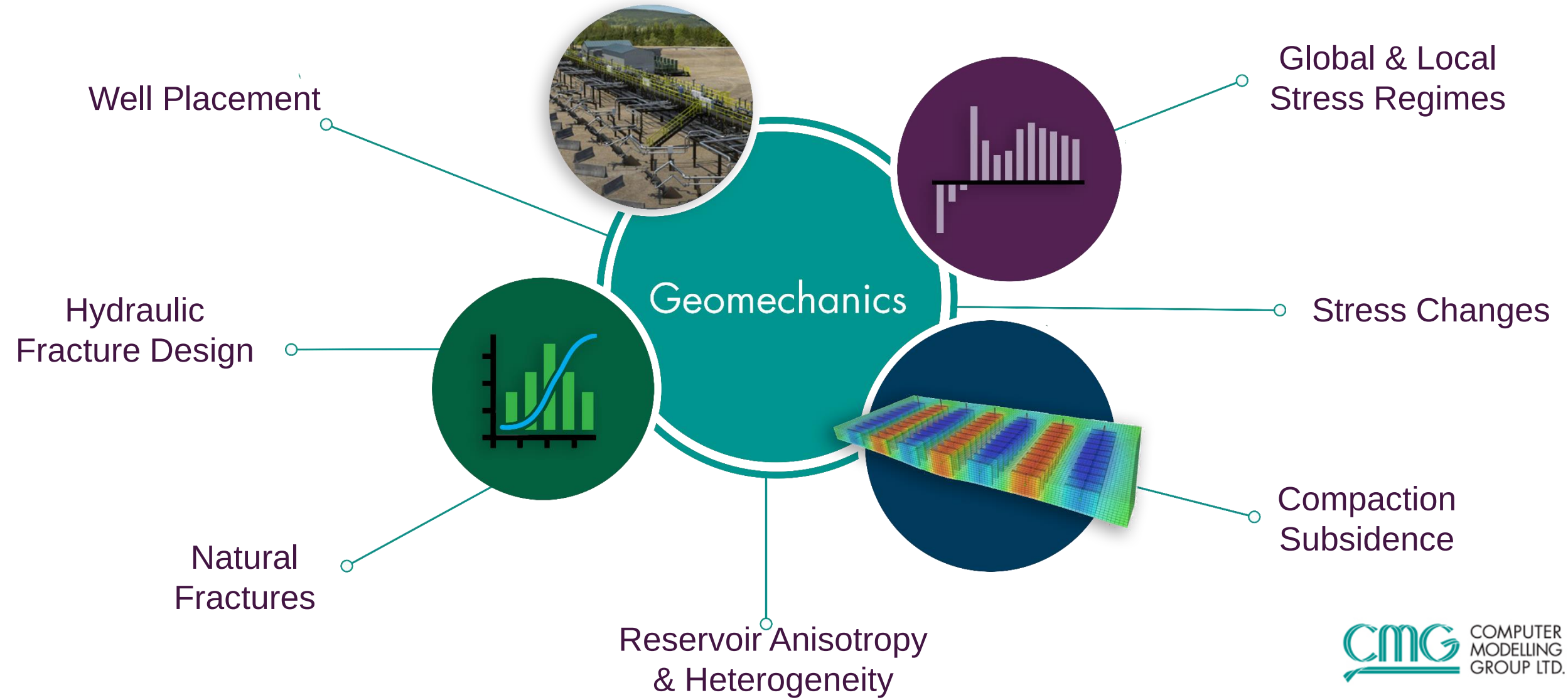
Fracture Importing

- File format needs to have *.cmg.csv* extension
- Programs that can export this format
  - GOHFER
  - FracproPT
  - Stimpro
  - StimPlan
  - FracPredictor
  - Mfrac*

*Not available in a released version



Geomechanics for Unconventional Reservoirs



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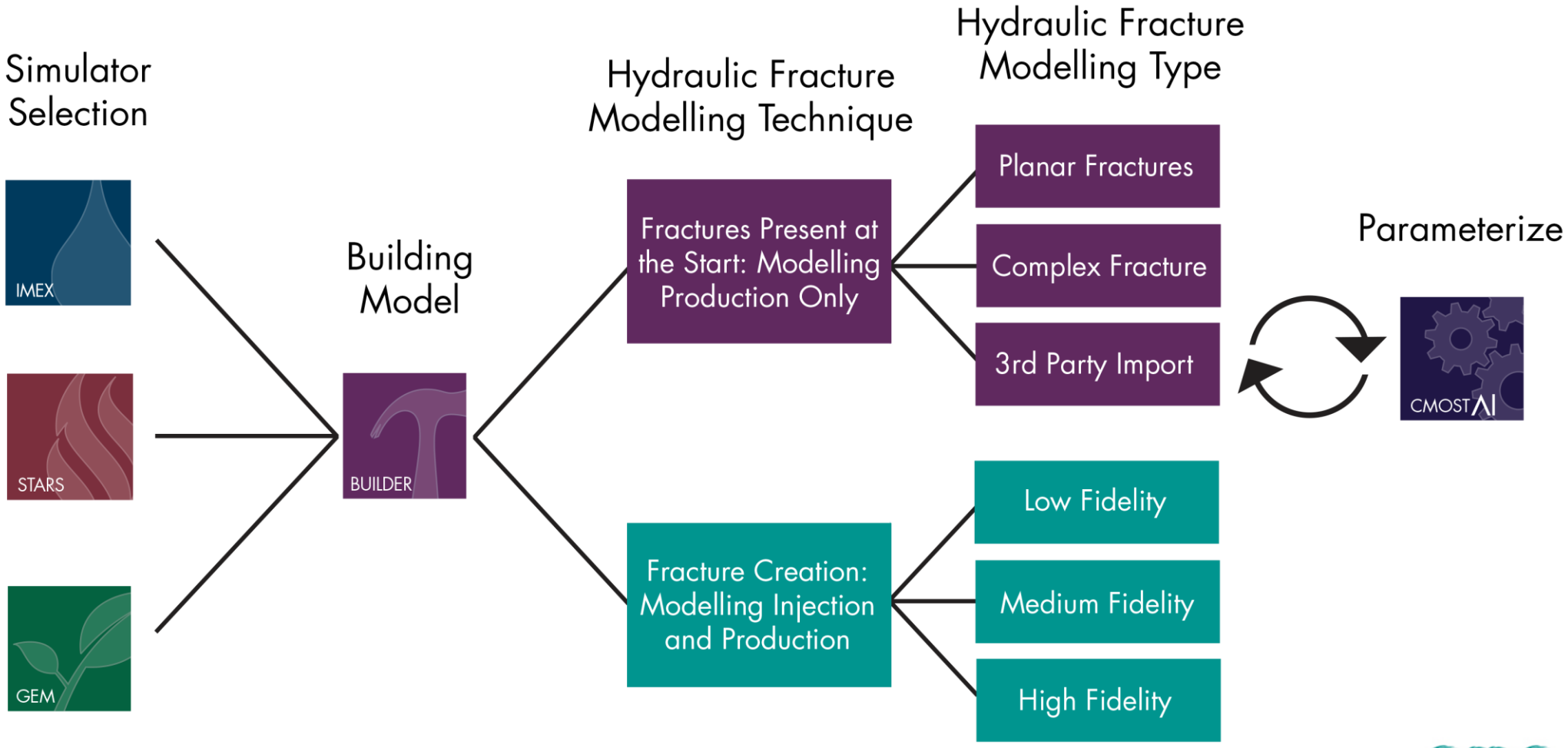
Workflows



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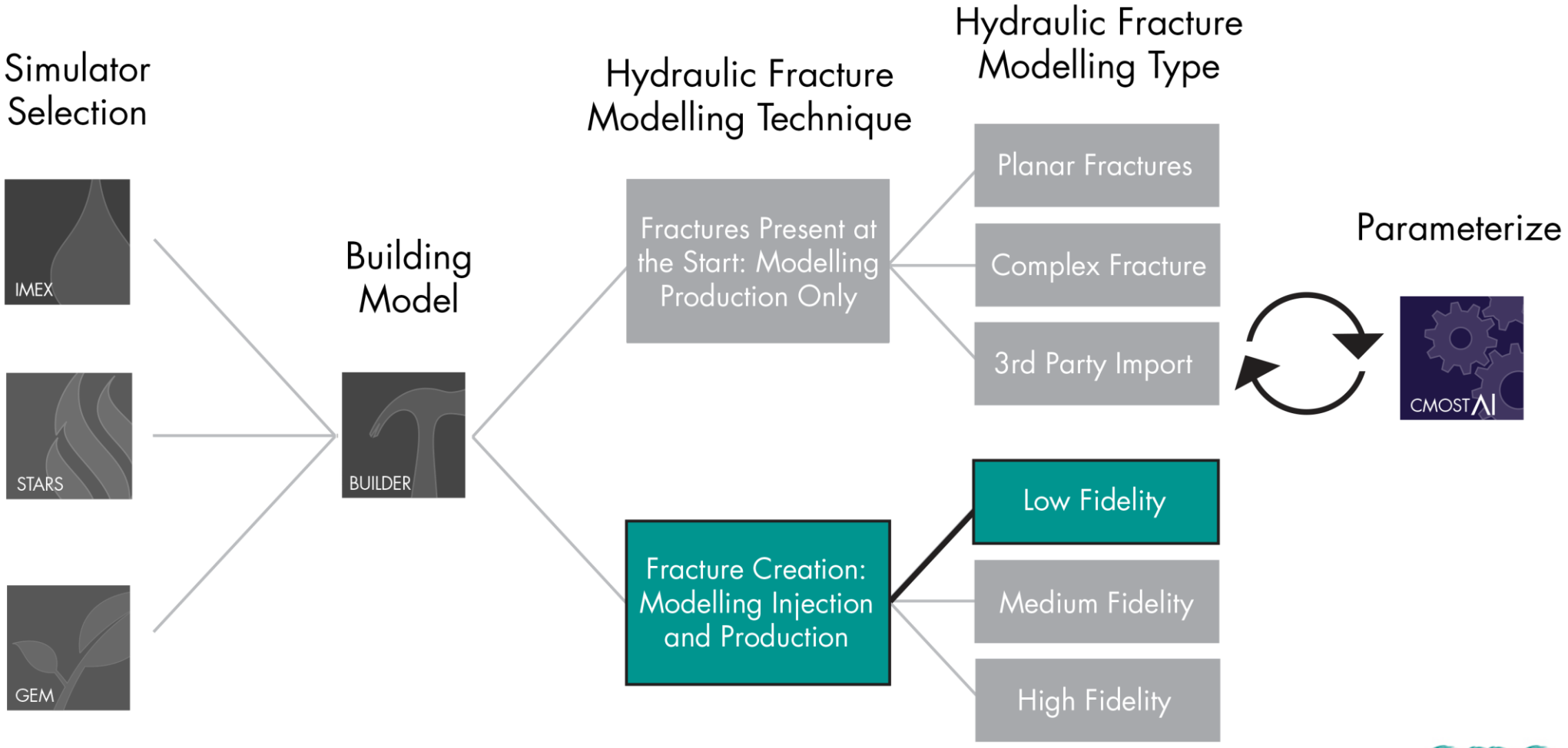
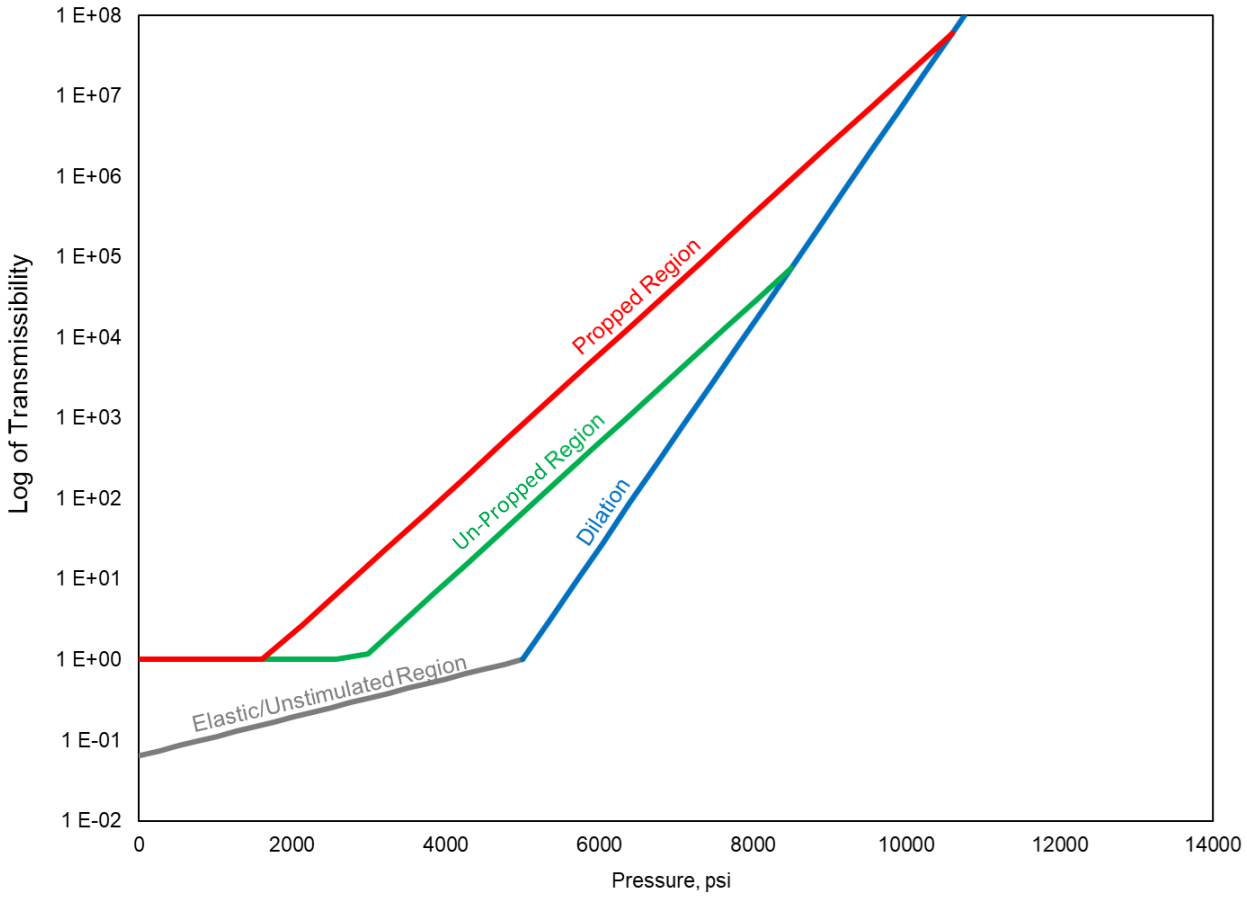
Low Fidelity Fracture Creation

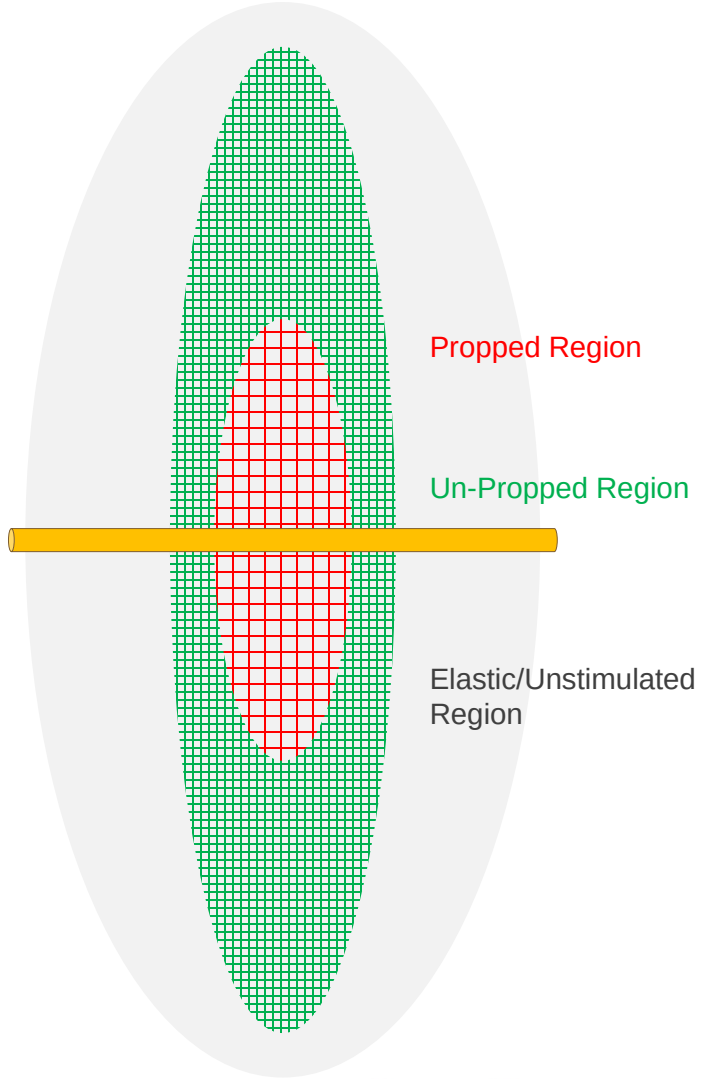


Low Fidelity: Compaction/Dilation Curves

- Simple model that relates permeability/transmissibility to pressure
  - Geomechanics module not used
- Models the creation of an SRV
- Can model injection/production separately or together in the same model
- Can be single porosity or dual porosity

Low Fidelity: Compaction/Dilation Curves





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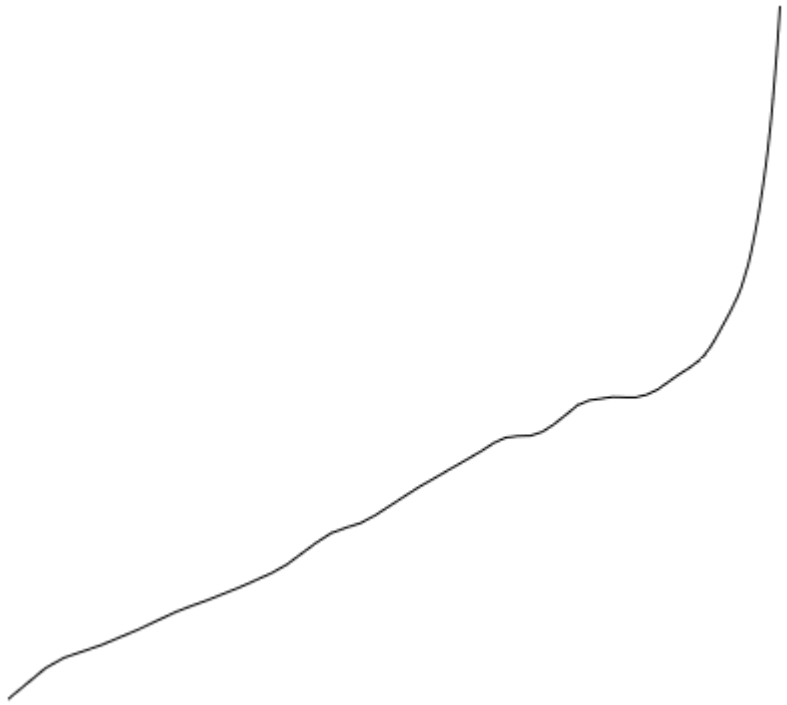
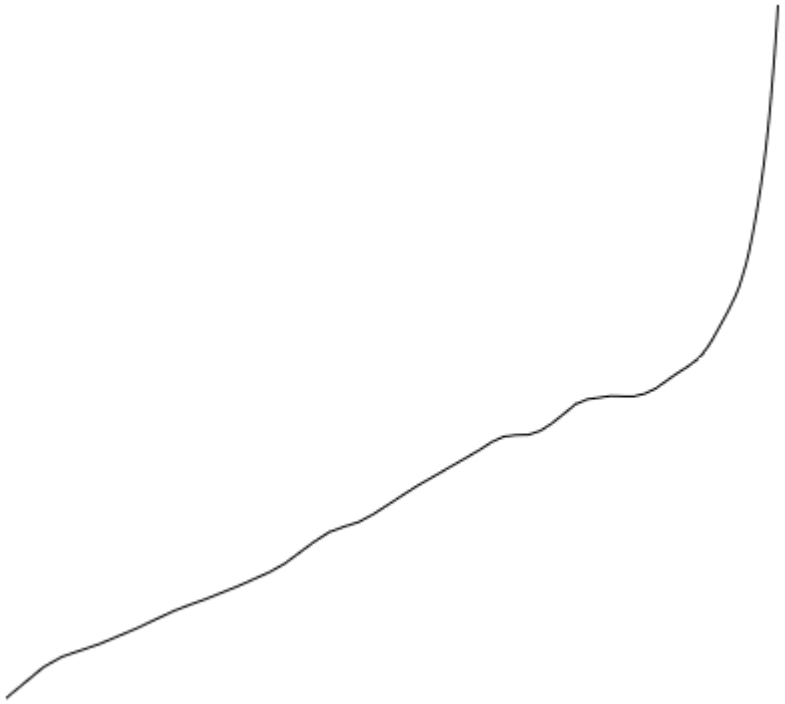
Low Fidelity: Example

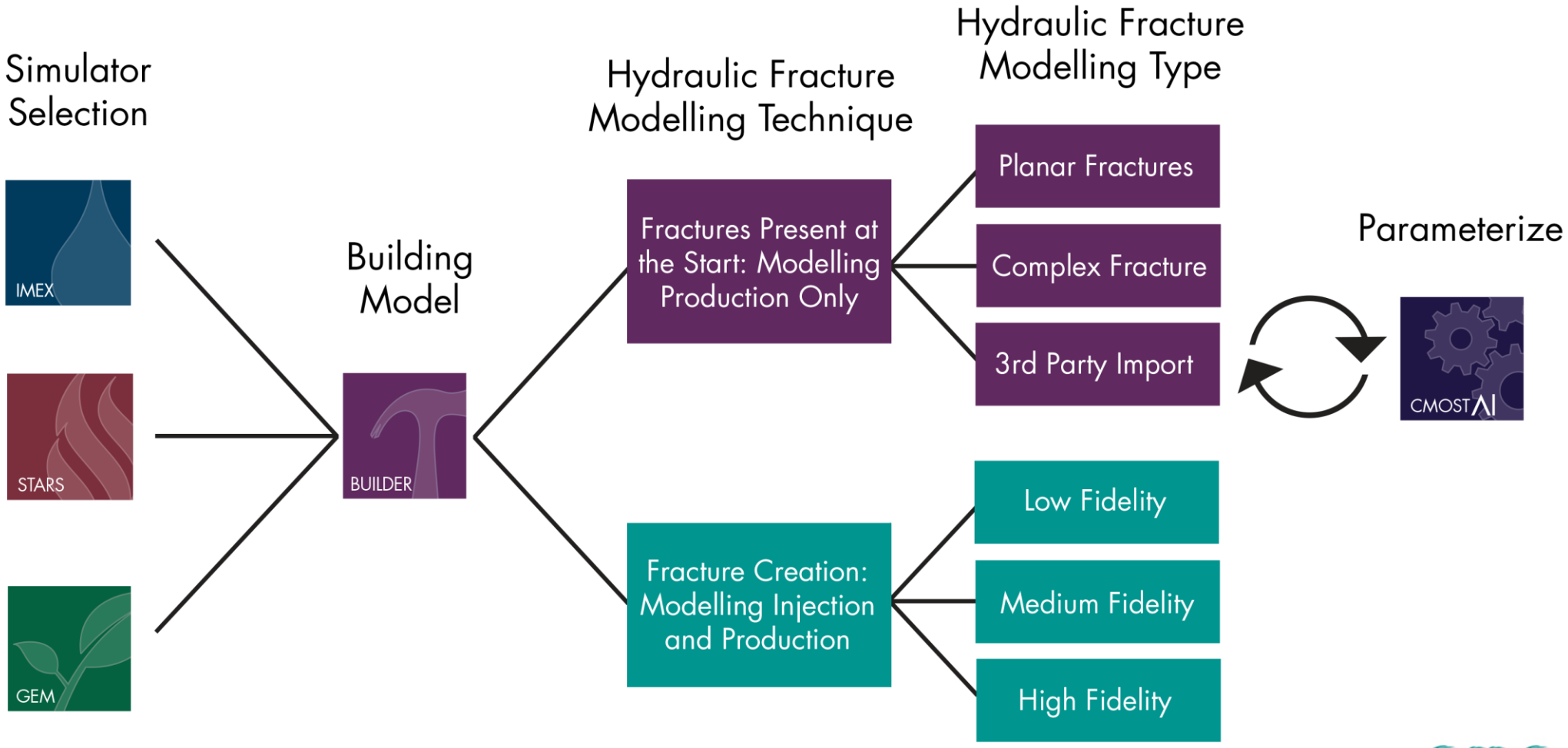
Water Saturation



Transmissibility



Workflows



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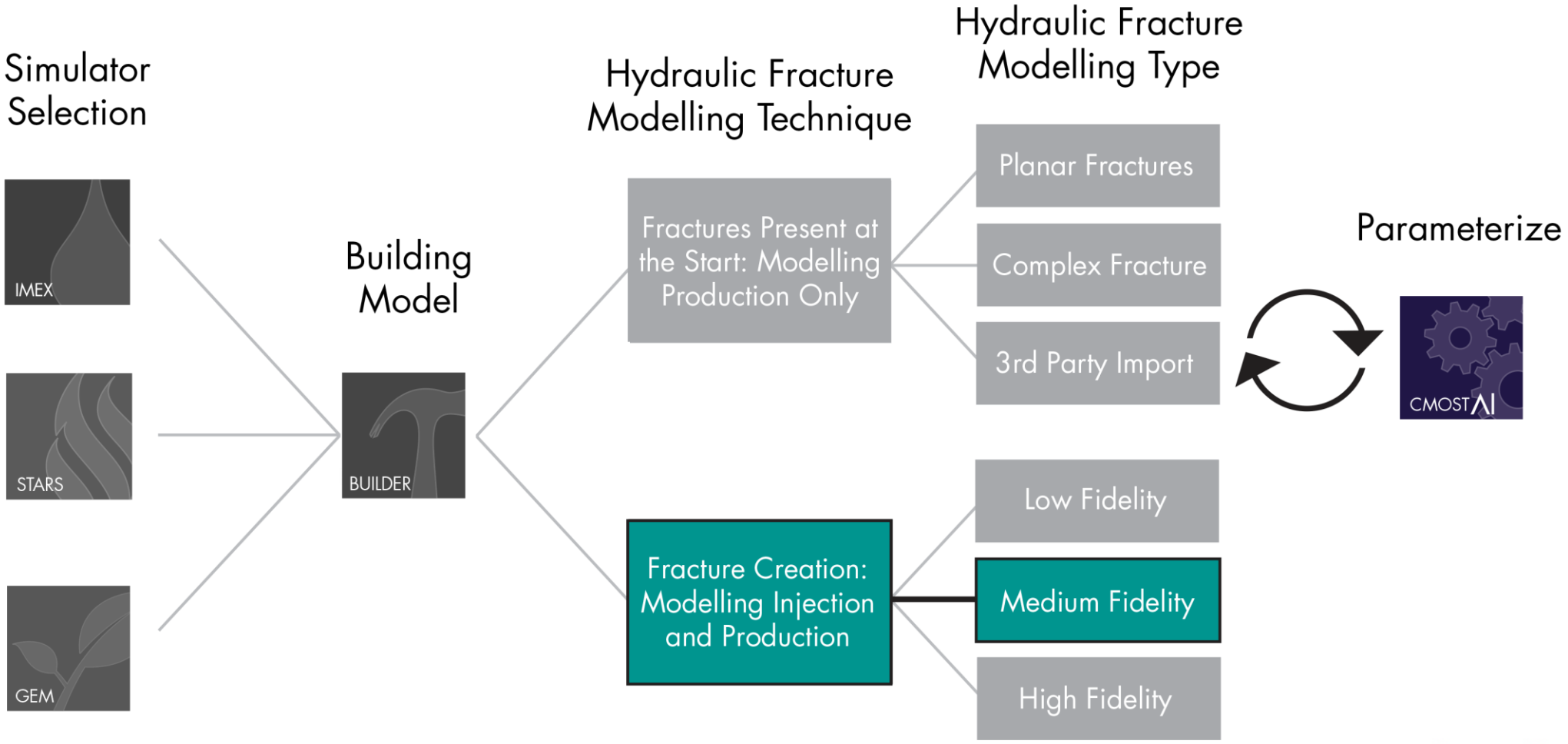
Medium Fidelity Fracture Creation



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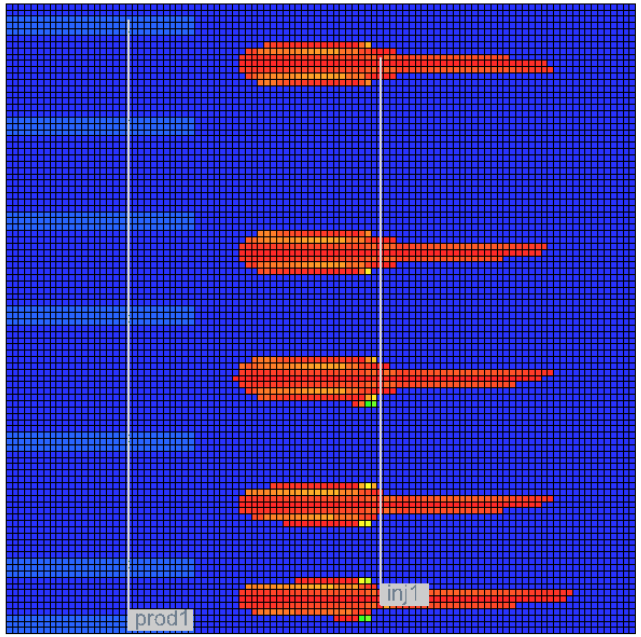
Medium Fidelity: Geomech With Barton Bandis

- Geomechanics module fully integrated to calculate stresses in the rock
    - Used to determine tensile and shear failure
- Failed rock represented by permeability enhancement
    - Natural fractures used to represent hydraulic fracture
- Models the creation of an SRV
- Injection/Production can be done through the same model



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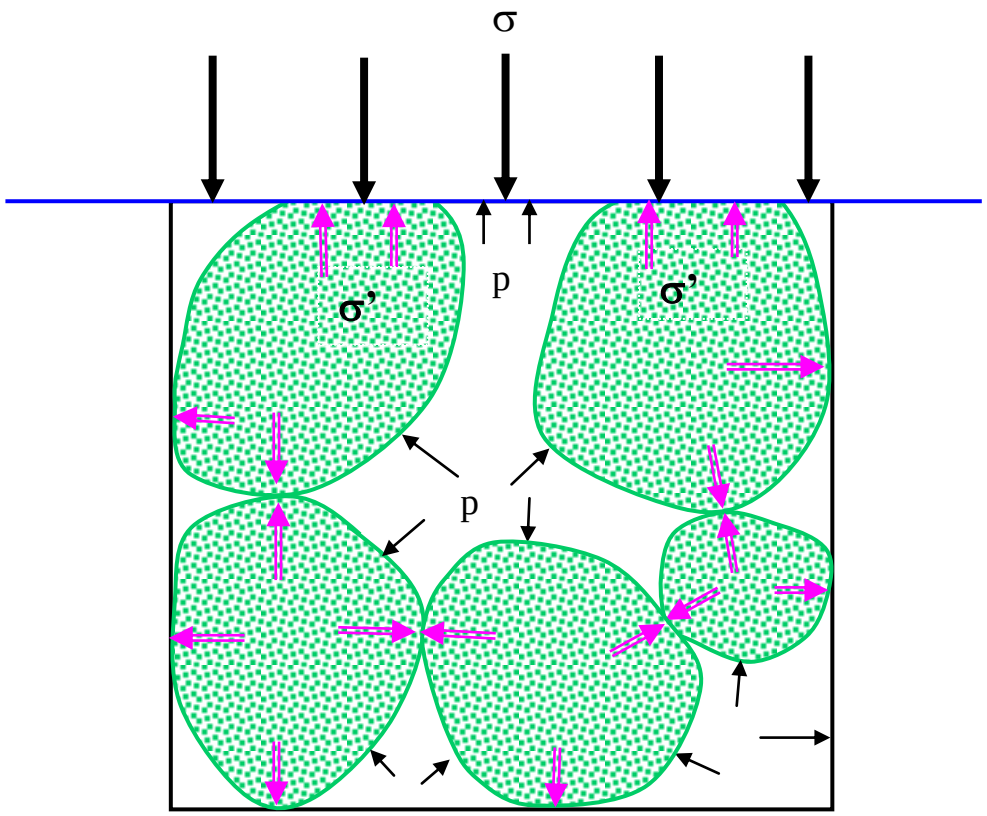
Geomechanics Review



Total stress = pore pressure + effective stress

$$\sigma = \alpha p + \sigma'$$

- α : Biot's coefficient
- p : pore pressure
- σ : Total stress
- σ' : Effective stress

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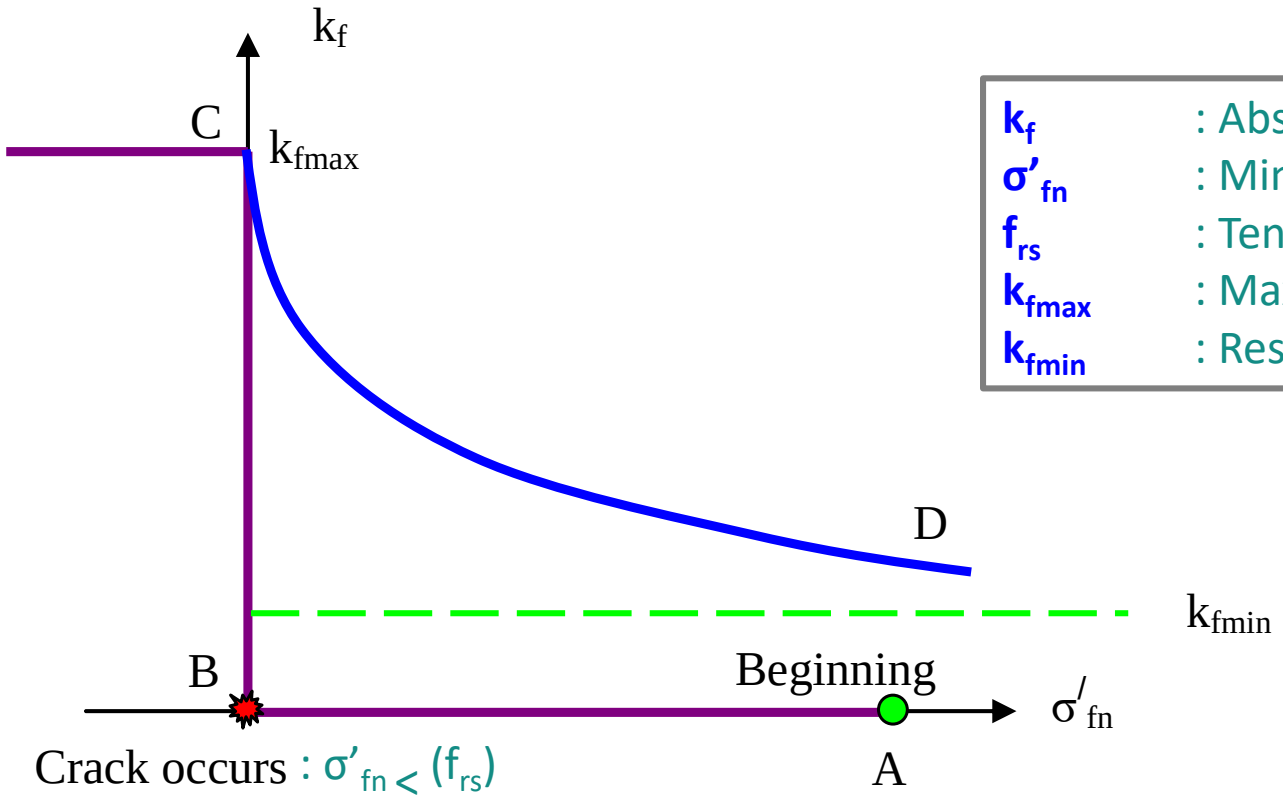
Tensile Failure - Barton Bandis



k_f	: Absolute fracture permeability coord.
σ'_{fn}	: Minimum principal effective stress
f_{rs}	: Tensile fracture criterion
k_{fmax}	: Maximum fracture permeability
k_{fmin}	: Residual fracture permeability

$$\sigma = \sigma' + \alpha P$$

Tran et al. SPE 125167-PP

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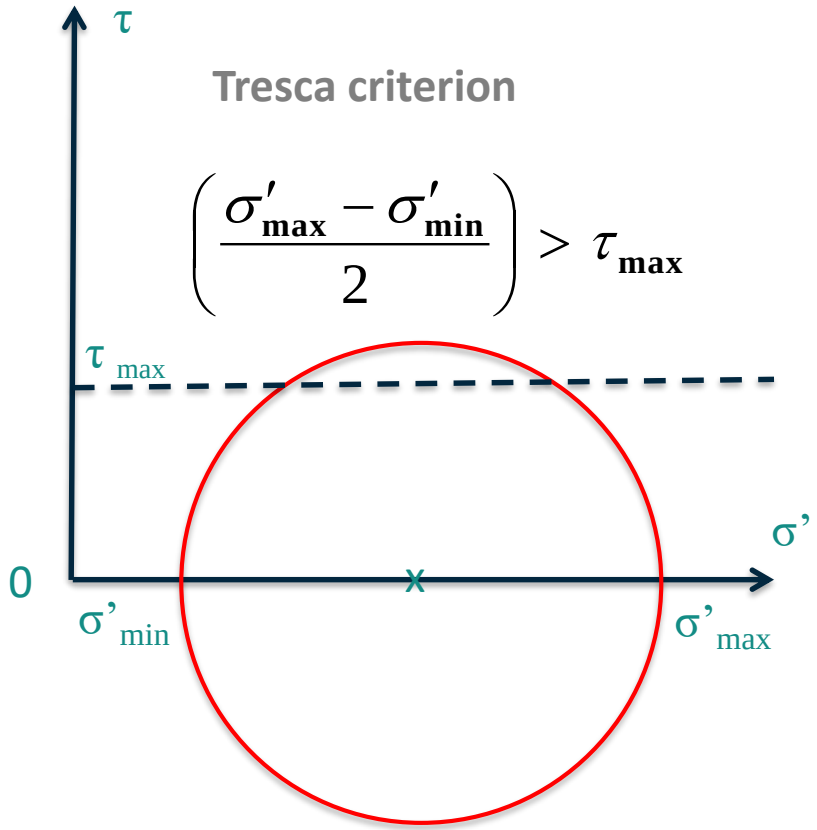
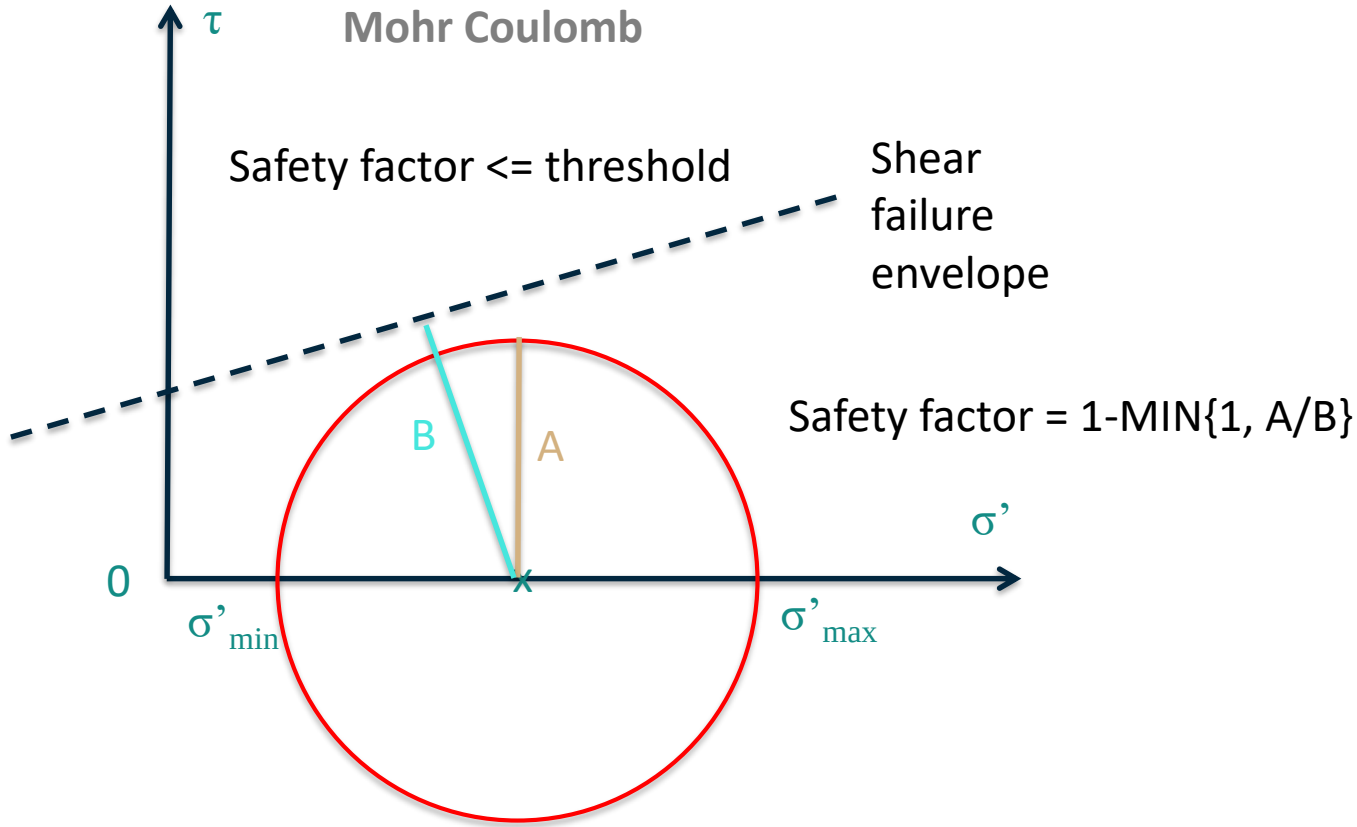
Shear Failure



Compressive stress is positive



Compressive stress is positive

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Application: Well to Well Interactions

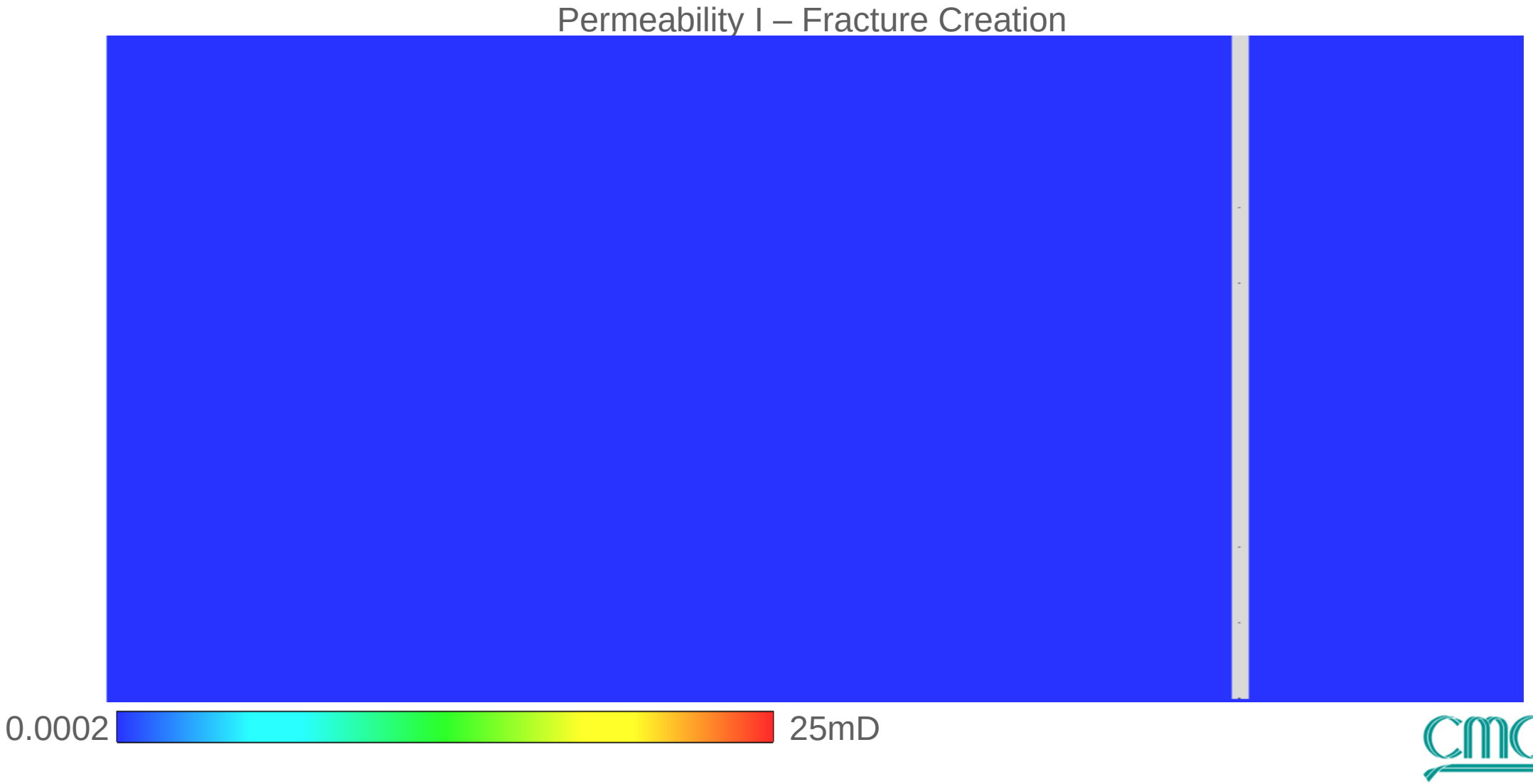
- If a new horizontal well (child well) is drilled too close to an existing horizontal well (parent well), the wells can interact potentially hurting the performance of both wells
- If a new well is drilled too far away there will be areas of the reservoir left uncontacted, leaving behind oil
- Need to place well such that production profiles and NPV is optimized

What Are Frac Hits?

- Fracture hits are defined as hydraulic fractures generated by a child well (new well) that grow towards and hit a parent well (existing well).

- If fracture hits occur, the production profile from the child well is often worse than that of a parent well

Medium Fidelity Geomech Example



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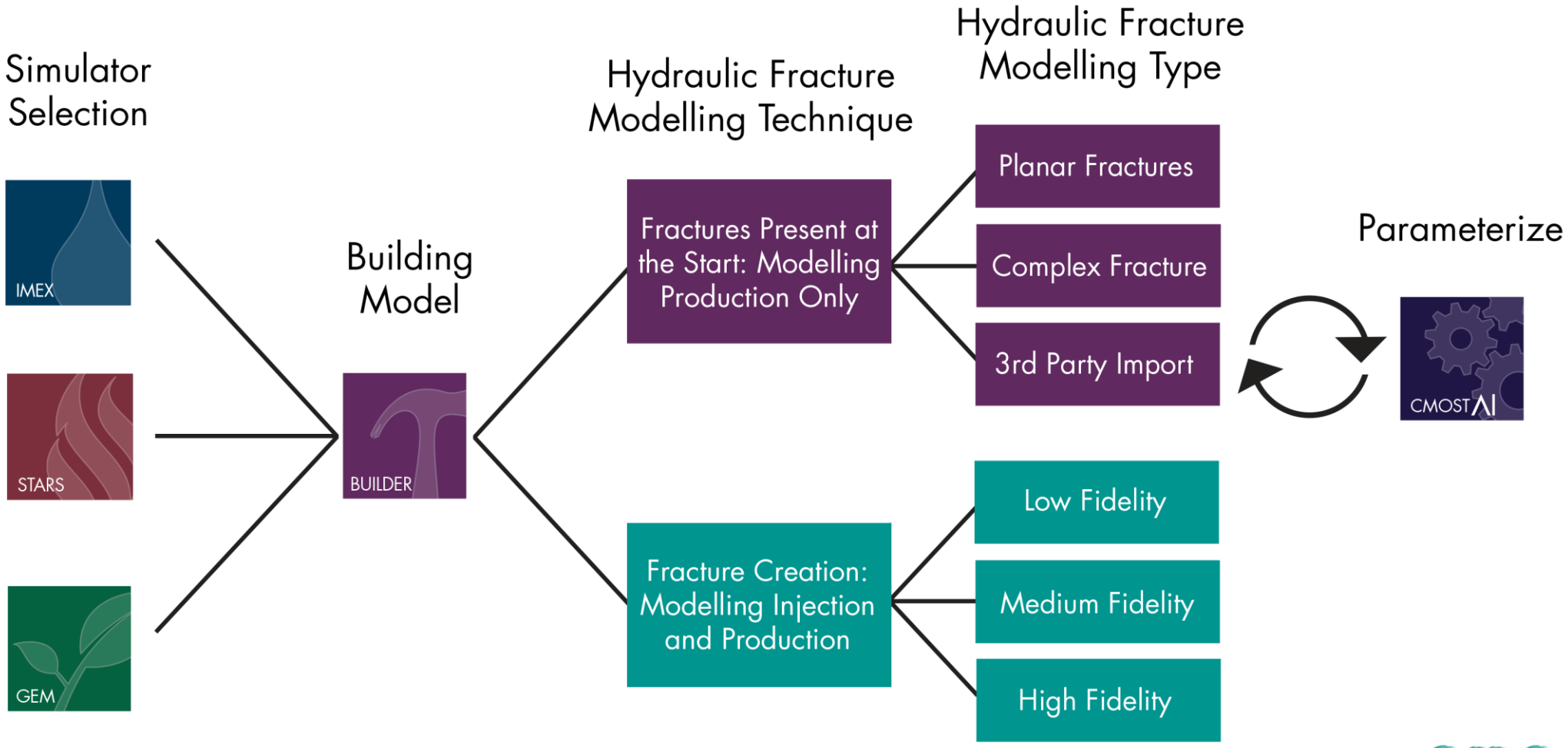
Child Fractures

- Child well fractures are influenced by
  - Fracture spacing
  - Length of production
  - Initial stress regime
  - Geomechanical properties

- In addition to causing fracture hits, parent well production may also result in reorientation of the fractures.

Workflows



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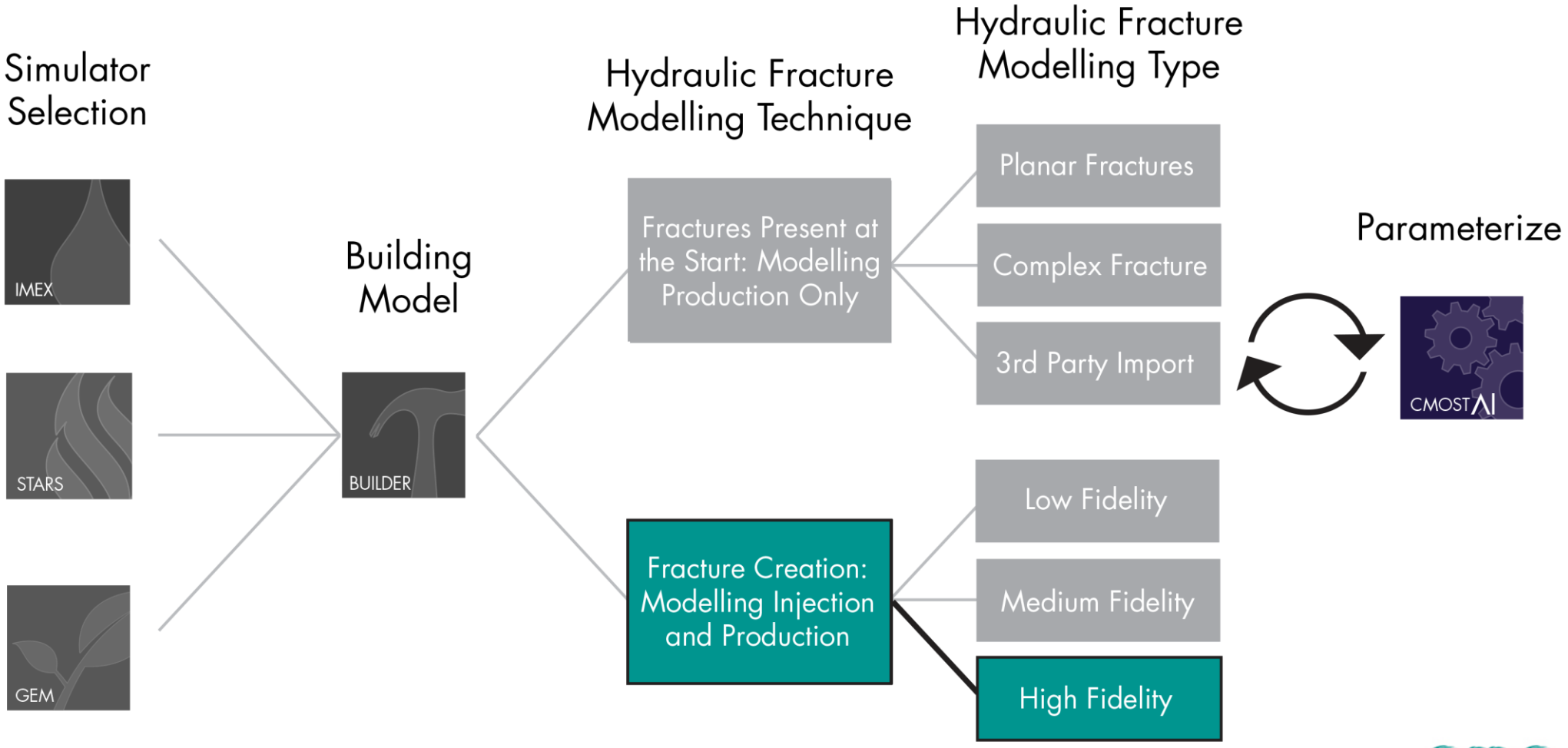
High Fidelity Fracture Creation



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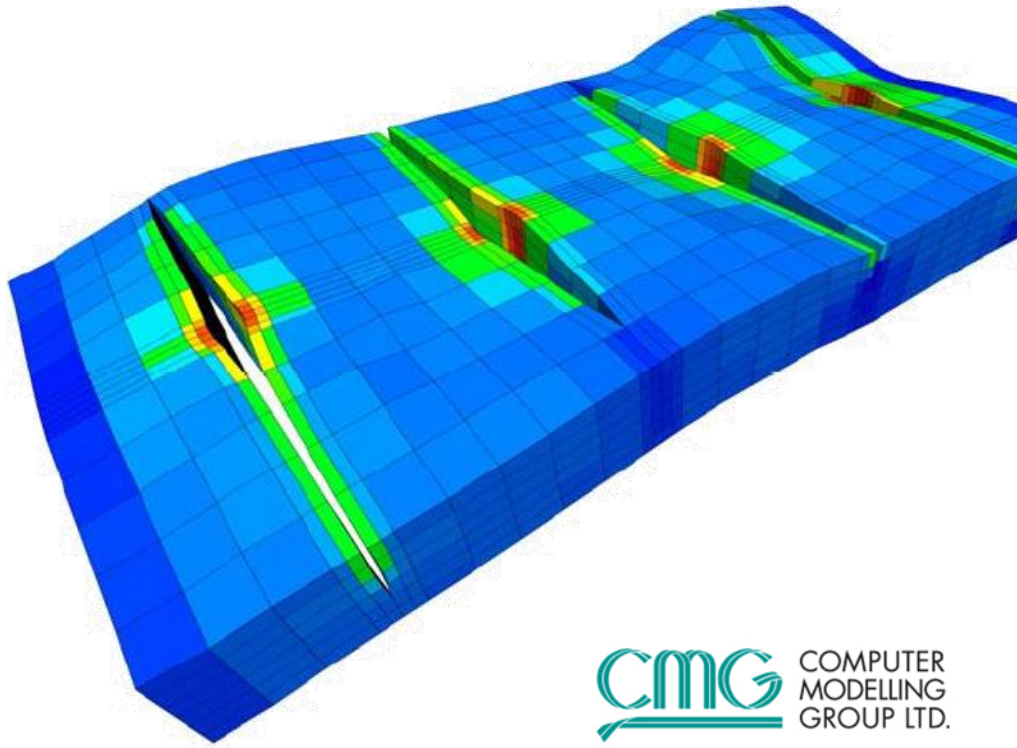
High Fidelity: Node Splitting

- Model that integrates geomechanics to predict the creation of hydraulic fractures
- Determine hydraulic fracture half-length, aperture and height for Planar Fractures
- Visualize and analyze the fracture growth



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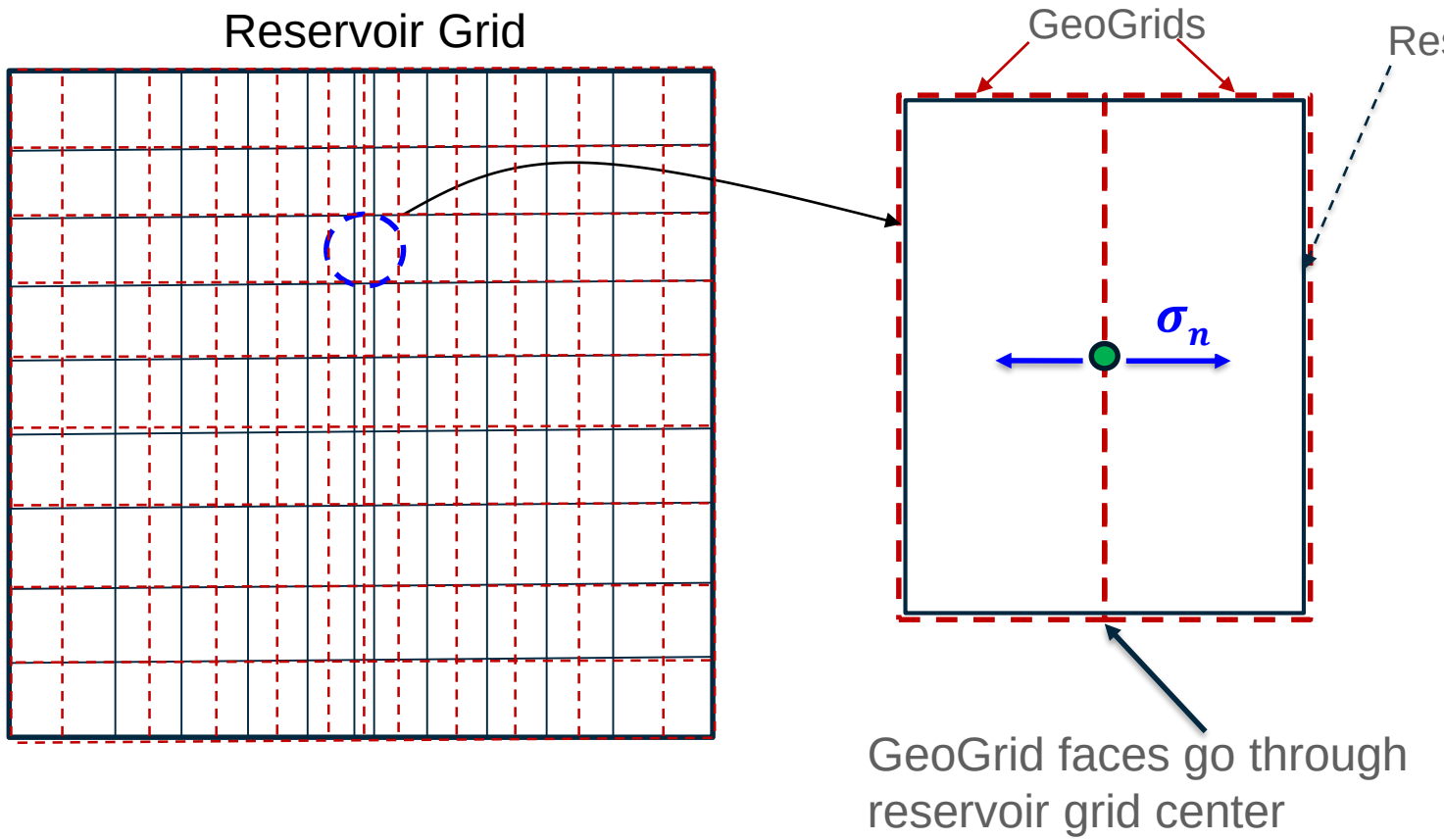
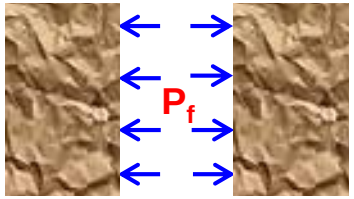
High Fidelity: Node Splitting

- A separate geomechanical grid is used to compute the fracture creation

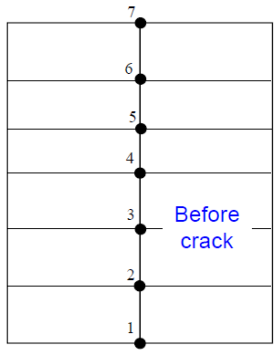


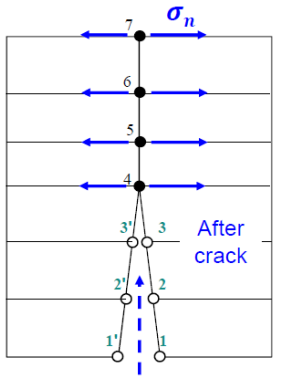
High Fidelity: Node Splitting

- The fracture is modelled through the node splitting of the geomechanical grid



Pressurization

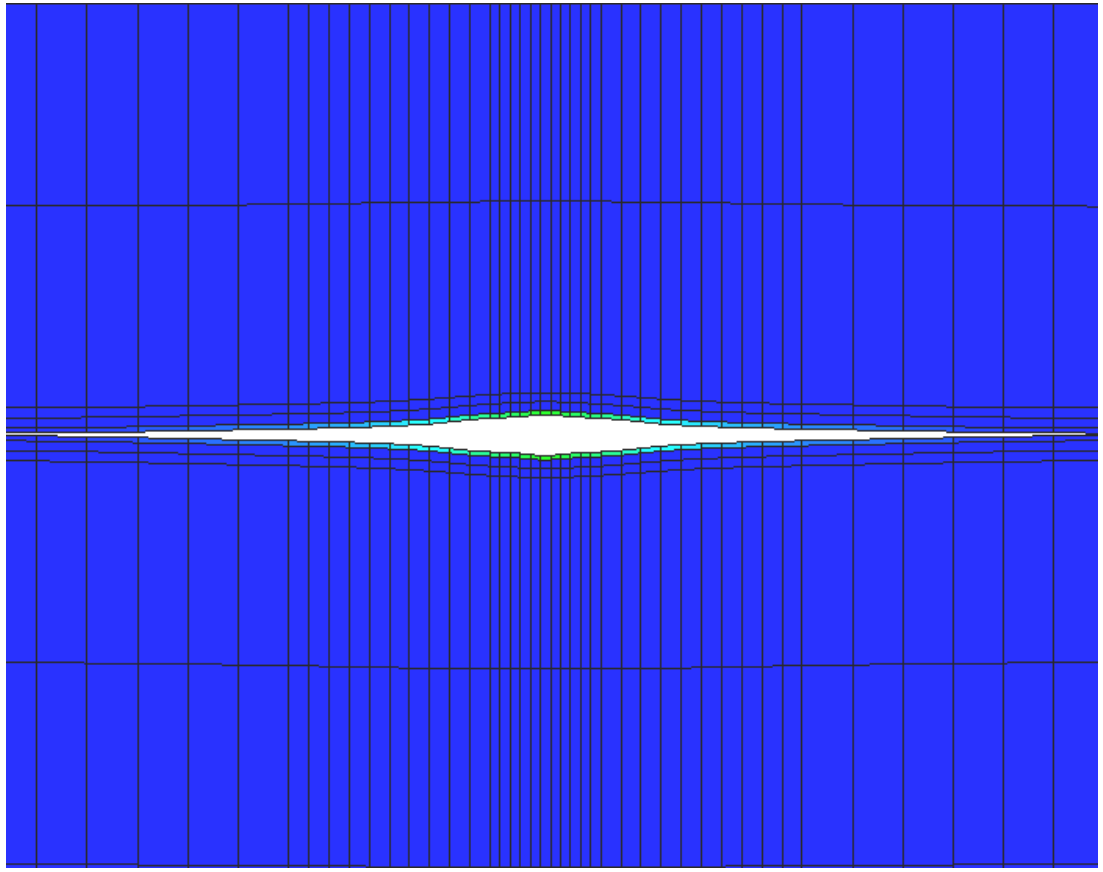




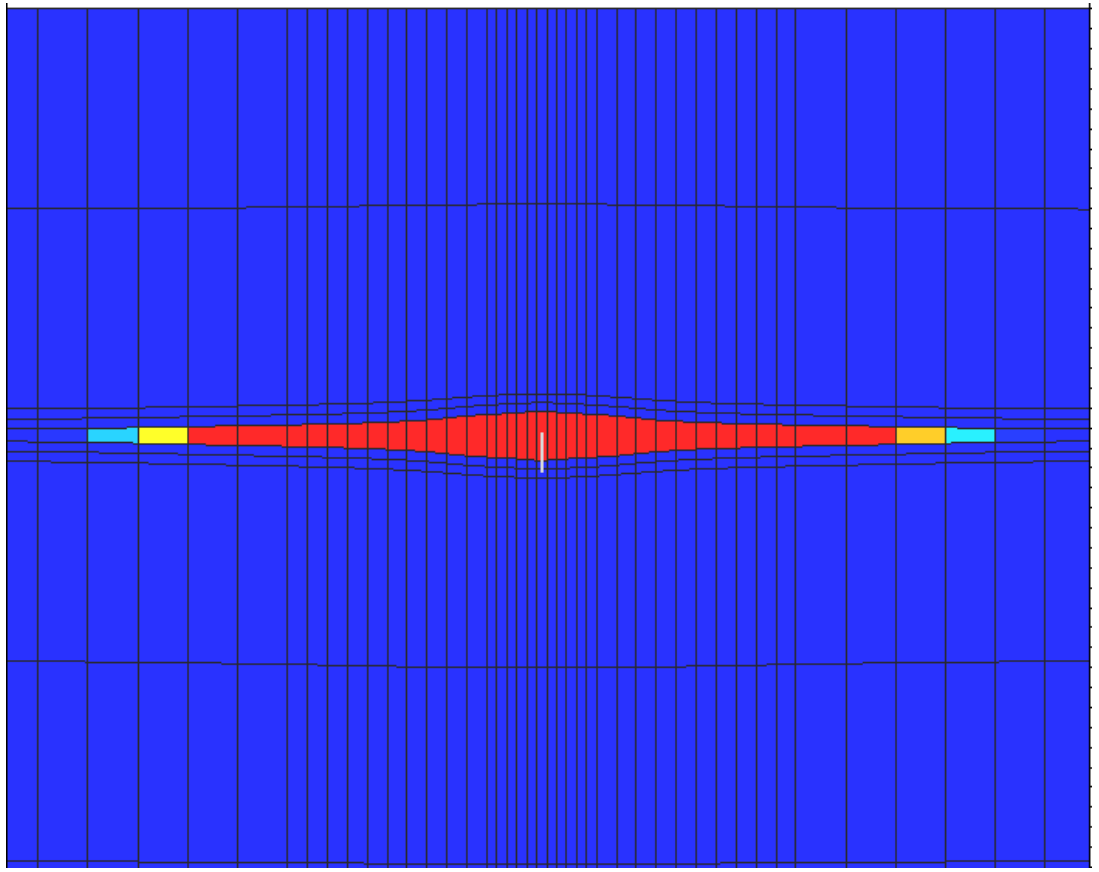
- Nodes split based on failure criteria
  - Effective Stress < tensile failure

High Fidelity: Node Splitting

GeoGrid Fracture Width (ft)



Flow Grid Fracture Permeability (mD)



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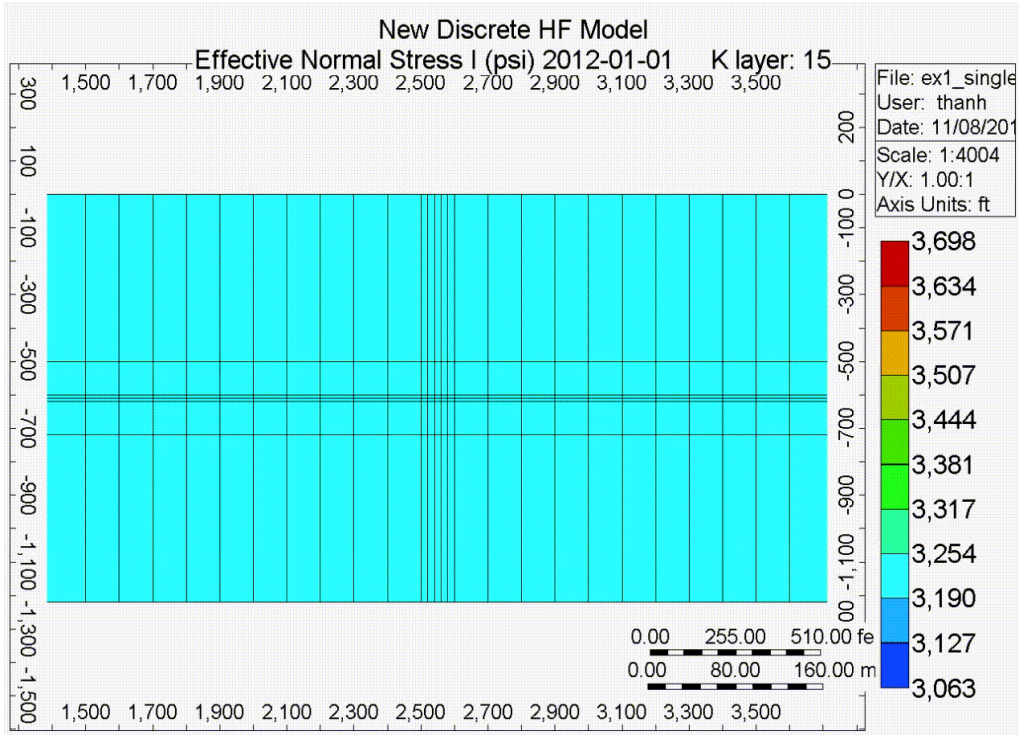
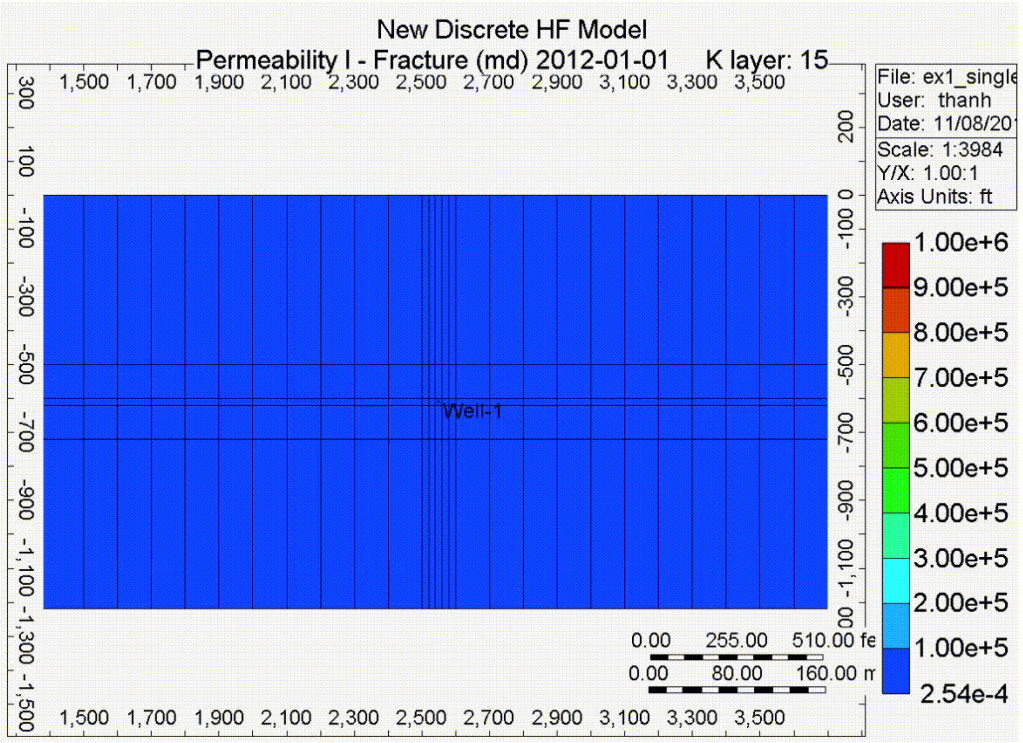
High Fidelity Example

Effective Normal Stress I (psi) vs Perm I Fracture – Layer 15



GEOGRID



RESERVOIR GRID

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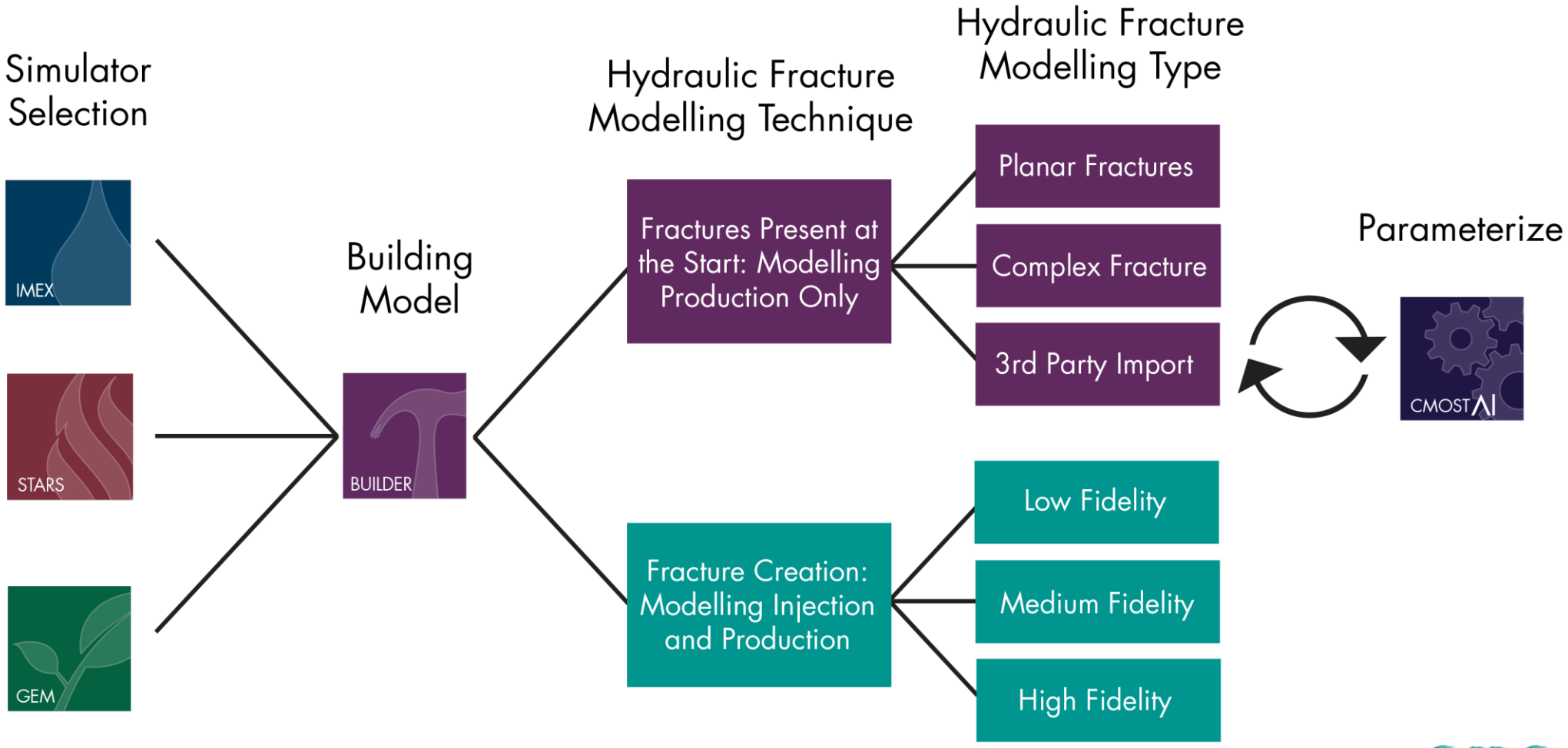
Workflows



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Combining Workflows

- Planar Fractures with Geomech
  - Incorporate geomechanics into model with planar fractures to see how stresses change with production
- Create planar fractures from Compaction/Dilation Curves
- Node Splitting with Barton Bandis
  - Model not a perfectly planar fracture

Summary

Methodology	When to Use
Planar Fractures	• Production only studies • Multi-well studies
Complex Fractures	• When reliable microseismic data is available
Fracture Import	• Third party software for fracture creation modelling
Low Fidelity Geomech: Compaction/Dilation	• Modelling full well lifecycle • Fast running models
Medium Fidelity Geomech: Barton Bandis	• Increased physics for fracture creation modelling • Fracture growth for interacting wells
High Fidelity Geomech: Node Splitting	• Comprehensive planar fracture initiation modelling • Simulate DFIT tests

CMG's Unconventional Reservoir Workflow

- Six physics-based workflows that can be utilized depending on the requirements/situation
- CMG has provided the tools the user can use to replicate the field and desired behavior
- Model entire unconventional reservoir life cycle
- Capture well-well fracture interactions affects

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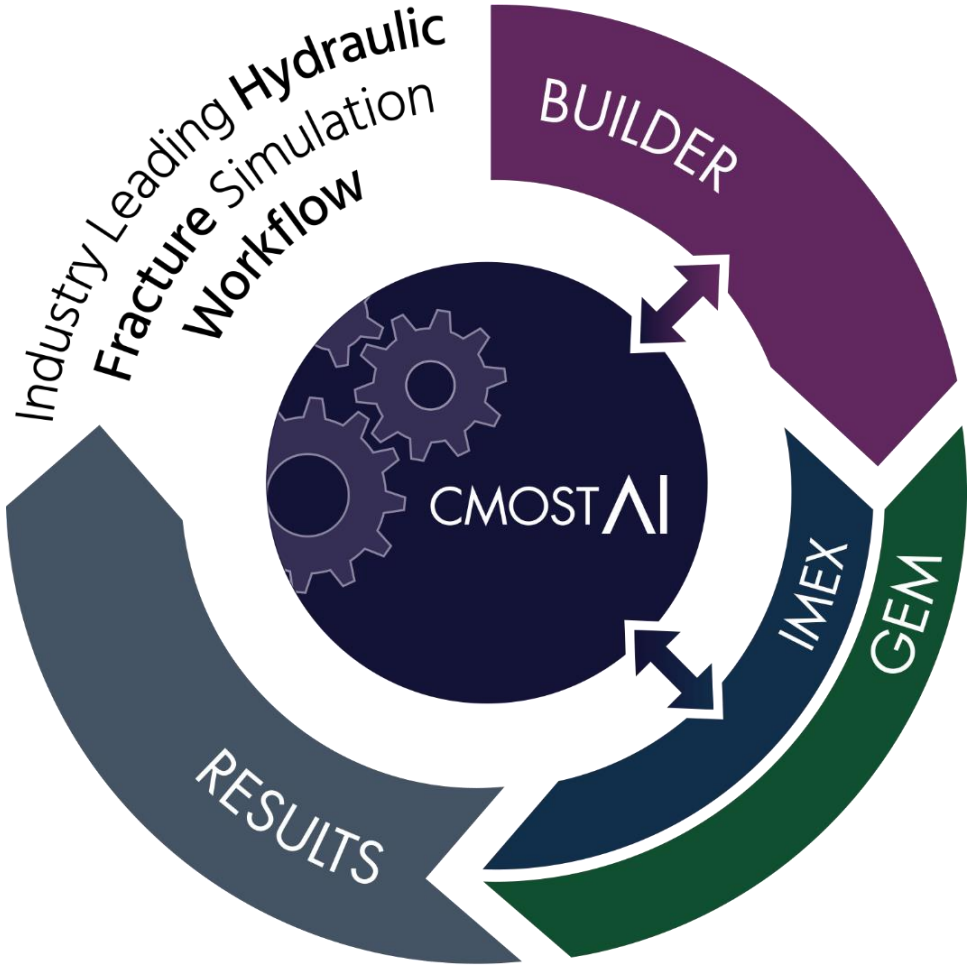
CMG's Unconventional Reservoir Workflow



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For more information:

Please contact cmgchina@qq.com

Vision: To be the leading developer and supplier of dynamic reservoir technologies in the **WORLD**