Uncertainty Workflows for a Naturally Fractured Granite, getting to multiple models with 2000 variations.

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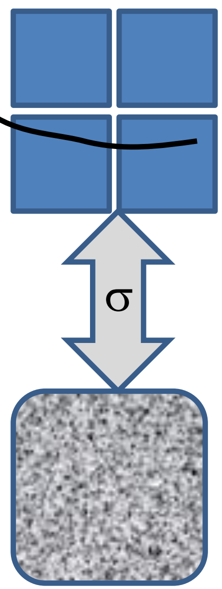
- Complex field: Fracture Basement
  - Some wells work (10kbopd/well), some don't
  - Some fractures matter, some don't

- Challenge: build a reliable forecast model for infills and waterflood.
  - History matched model including DSTs using DFN / geomechanics to predict Kx,Ky away from well control, for infill wells.
  - Dual porosity model to calibrate K/phi, for water flood expectations.
  - Knowing the Simulation time of 24 core-hours /case
  - Knowing each model is wrong in some detail, use Uncertainty Analysis to capture range of outcomes
    - 1500 cases to get history matches.
    - 1200 cases to do variations
- And do it in 3 months.

Dual Porosity, Dual Permeability model

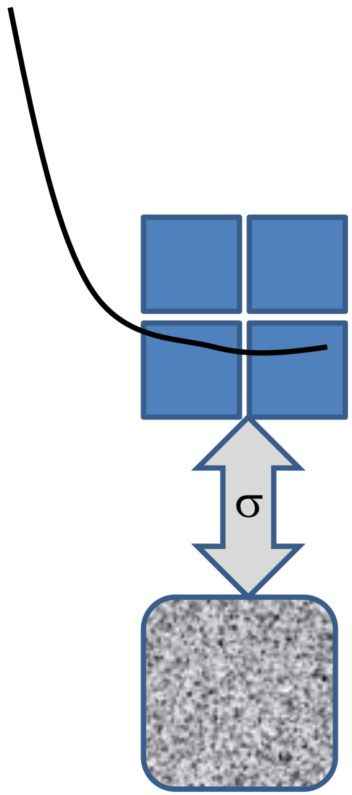


Dominates permeability
Can be very low porosity
High K/phi dominates water flood.

Diffusivity, linked to fracture density

Dominates porosity,
but fractured granite might be only 0.5% to 1.5%

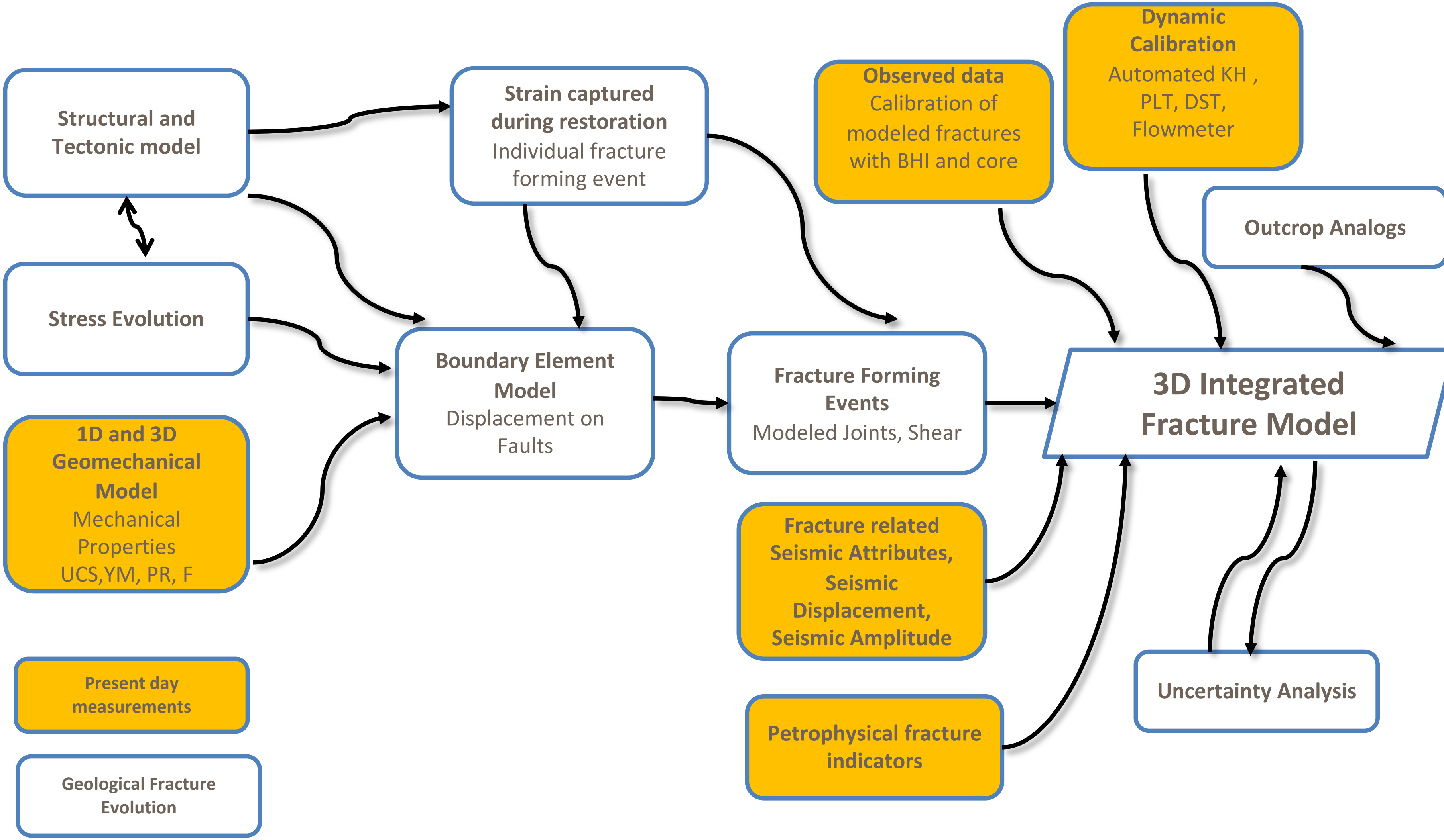
“Facies” for Dual Porosity, Dual Permeability model



Faults, or subseismic lineaments?
Size of throw? Orientation?
Critically stressed?
Particular uplift/tectonic event?

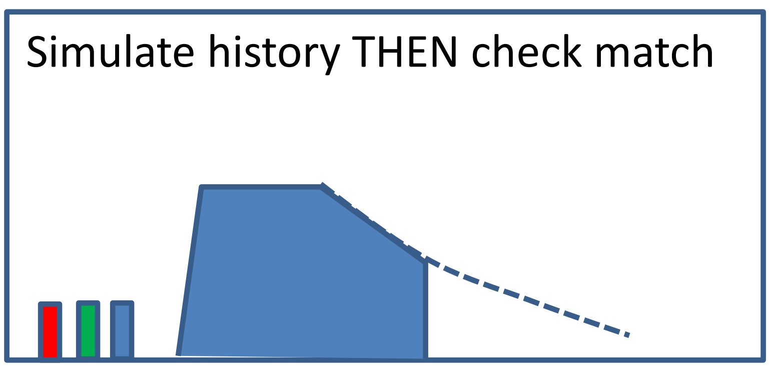
Particular uplift event?
Fresh or weathered?
Hydrothermally altered?
Shallow or deep?

Integrated Fracture Model Workflow
Time step DFN geological evolution



Lots of models, so limit simulation time : Event based history matching

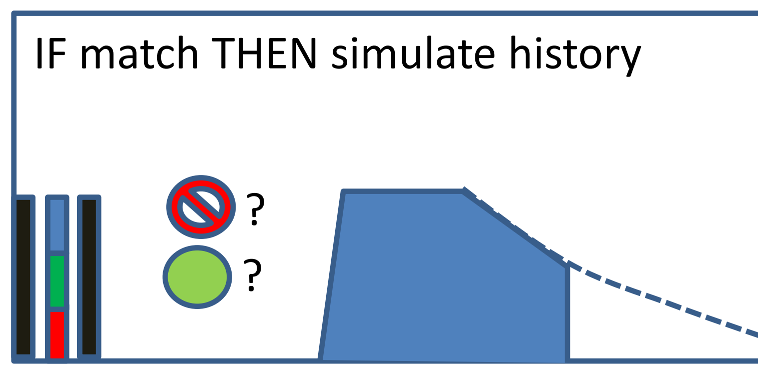
- Conventional
  - Simulate history
  - Compare to history
  - If it matches history, assume it matches key issues.



24 core hours

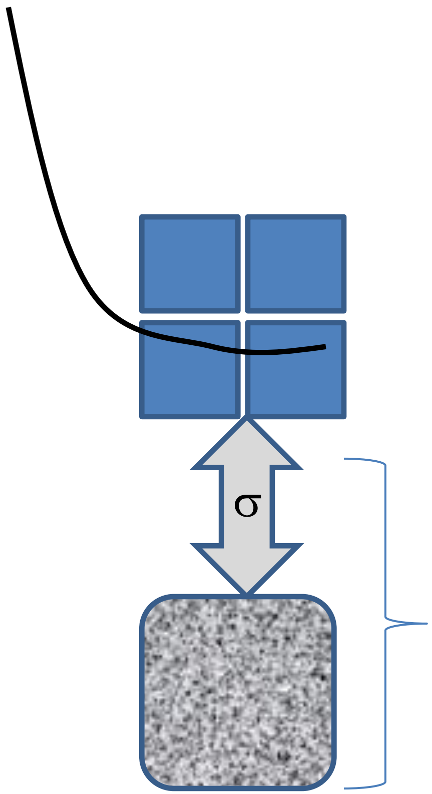
DSTs Production

- Strategic
  - Material balance
  - DST for primary permeability, porosity
  - Deconvolve production history for interference tests



10 minutes:
Material Balance
DSTs
Interference

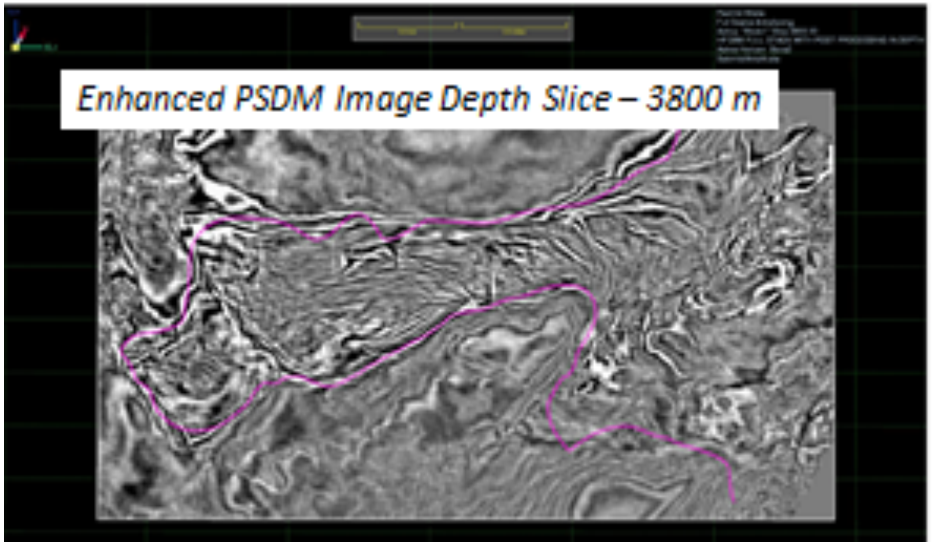
Dual Porosity, Dual Permeability model

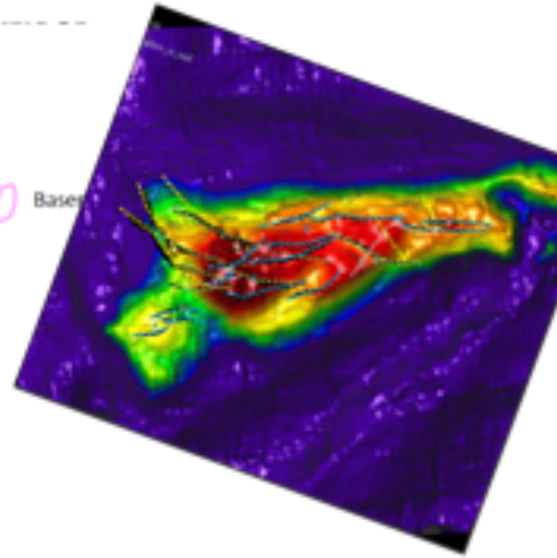


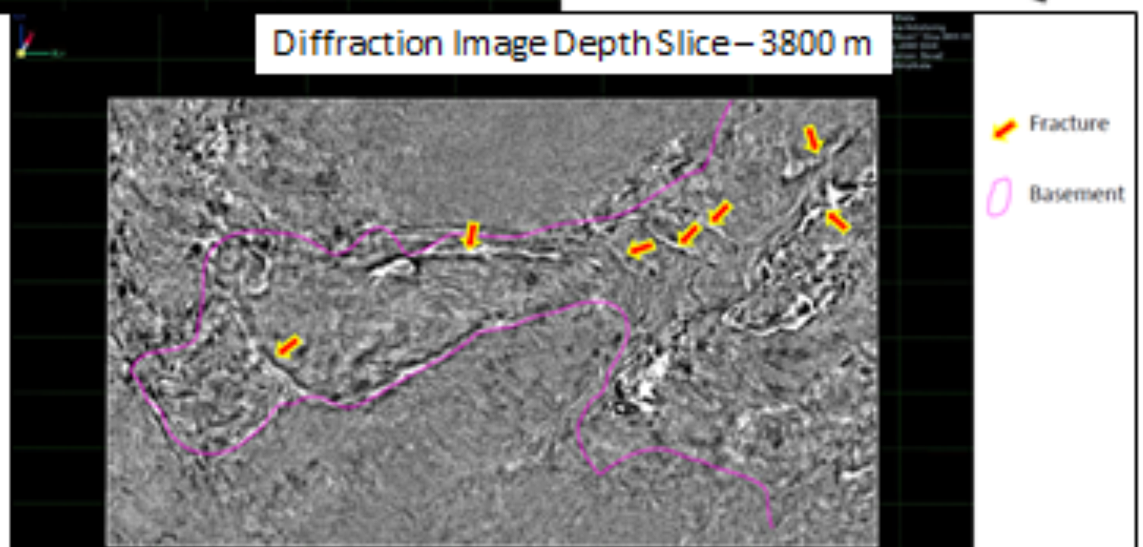
DST for productive fracture permeability, porosity
Deconvolve production history for interference tests

Material balance

Fault vs lineament







Stress Evolution and modeling of fracture forming events

Fracture Halos and Hydrothermal Influences

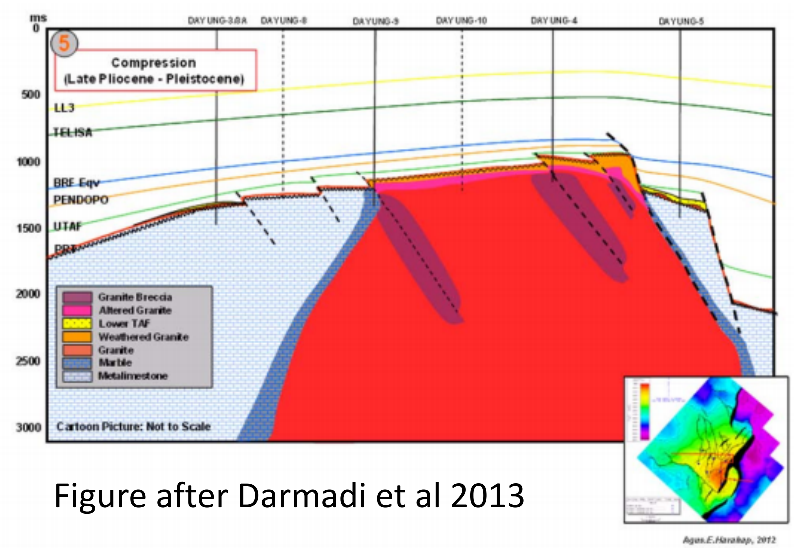
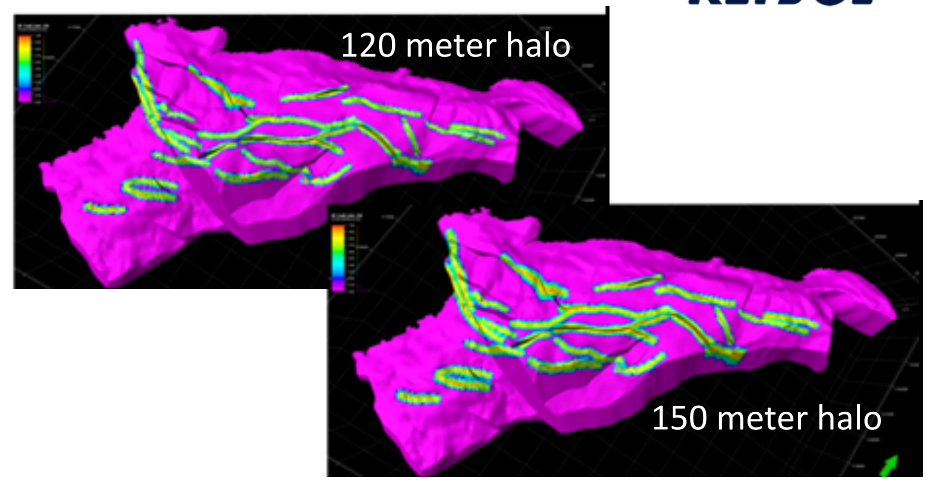
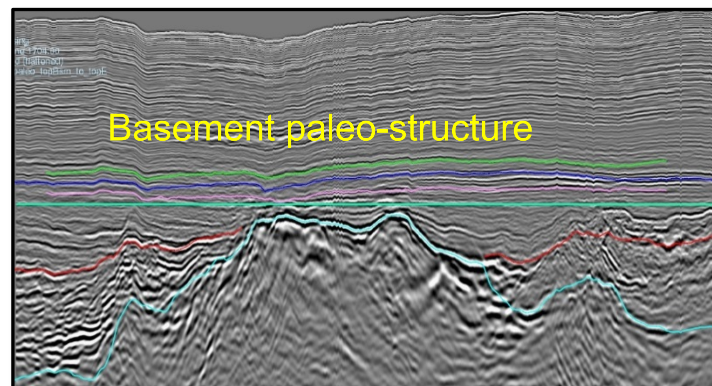
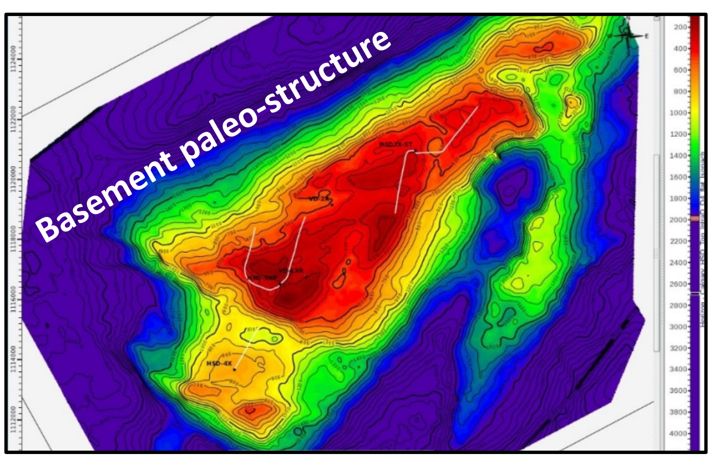
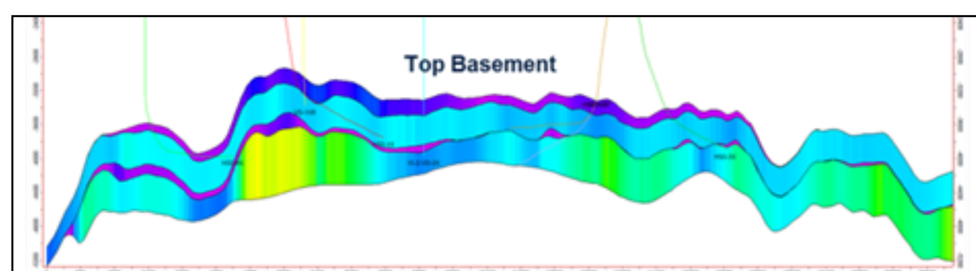


Figure after Darmadi et al 2013







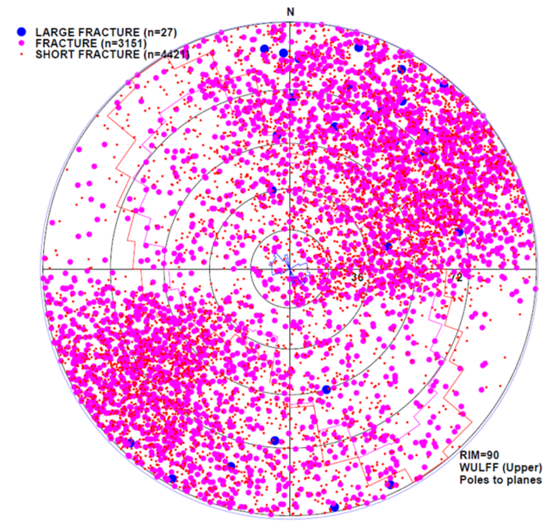


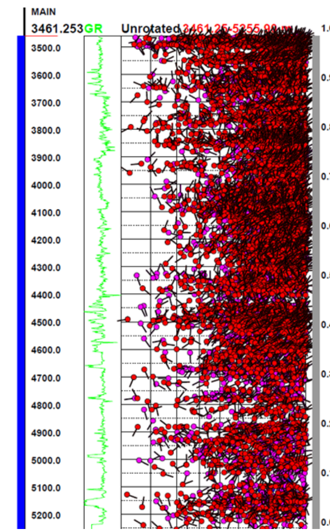
Hydrothermal- Diagenesis Overprint

Fracture Intensity As A False Positive For Productivity

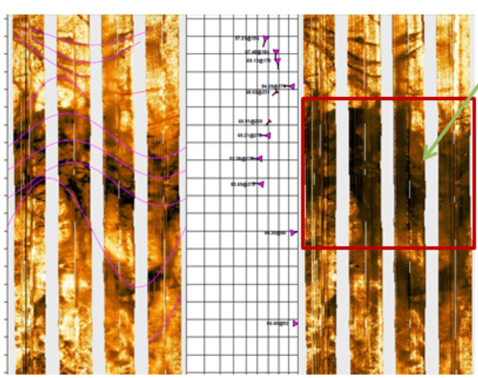
Not all primary fractures matter but the ones that are

- critically stressed
- have sustained communication with the background fractures
- Are not occluded by hydrothermal diagenesis and likely have been reactivated by multiple tectonic events.



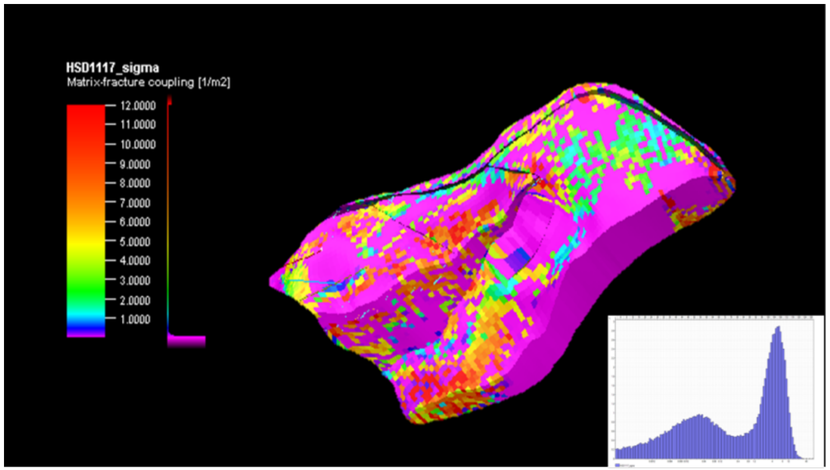


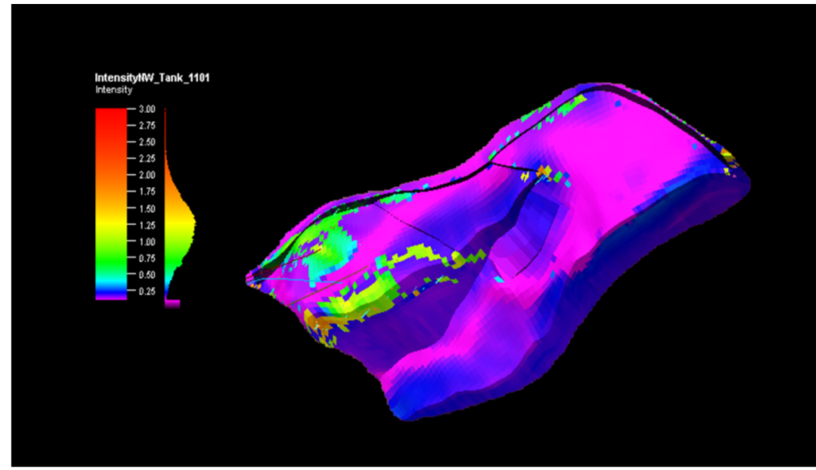
Sigma or shape factor represents the fluid flow between the matrix and the macro fractures which are both considered to be in pseudo steady state.

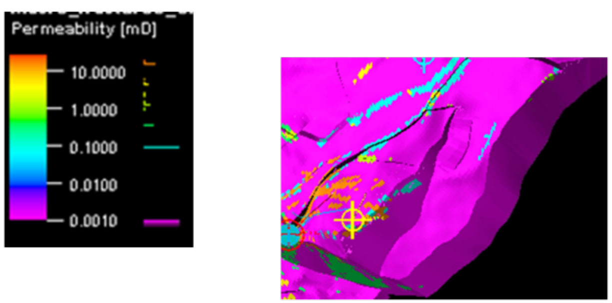


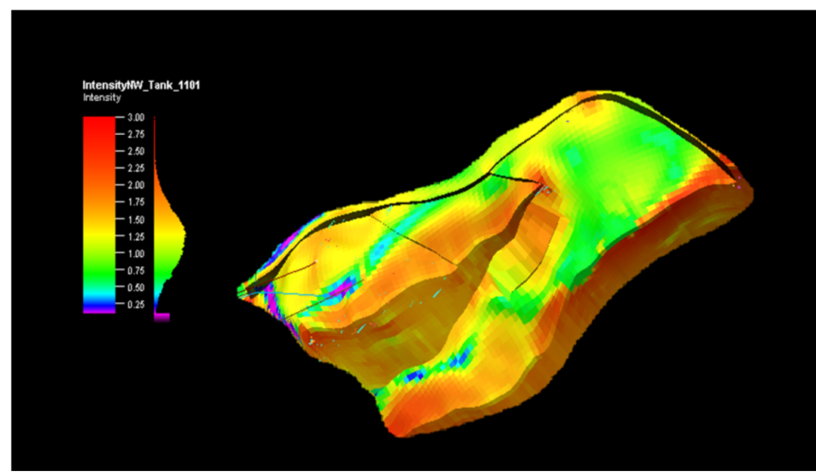
Enhancement

Comparison of Sigma Values and History Matched Permeabilities

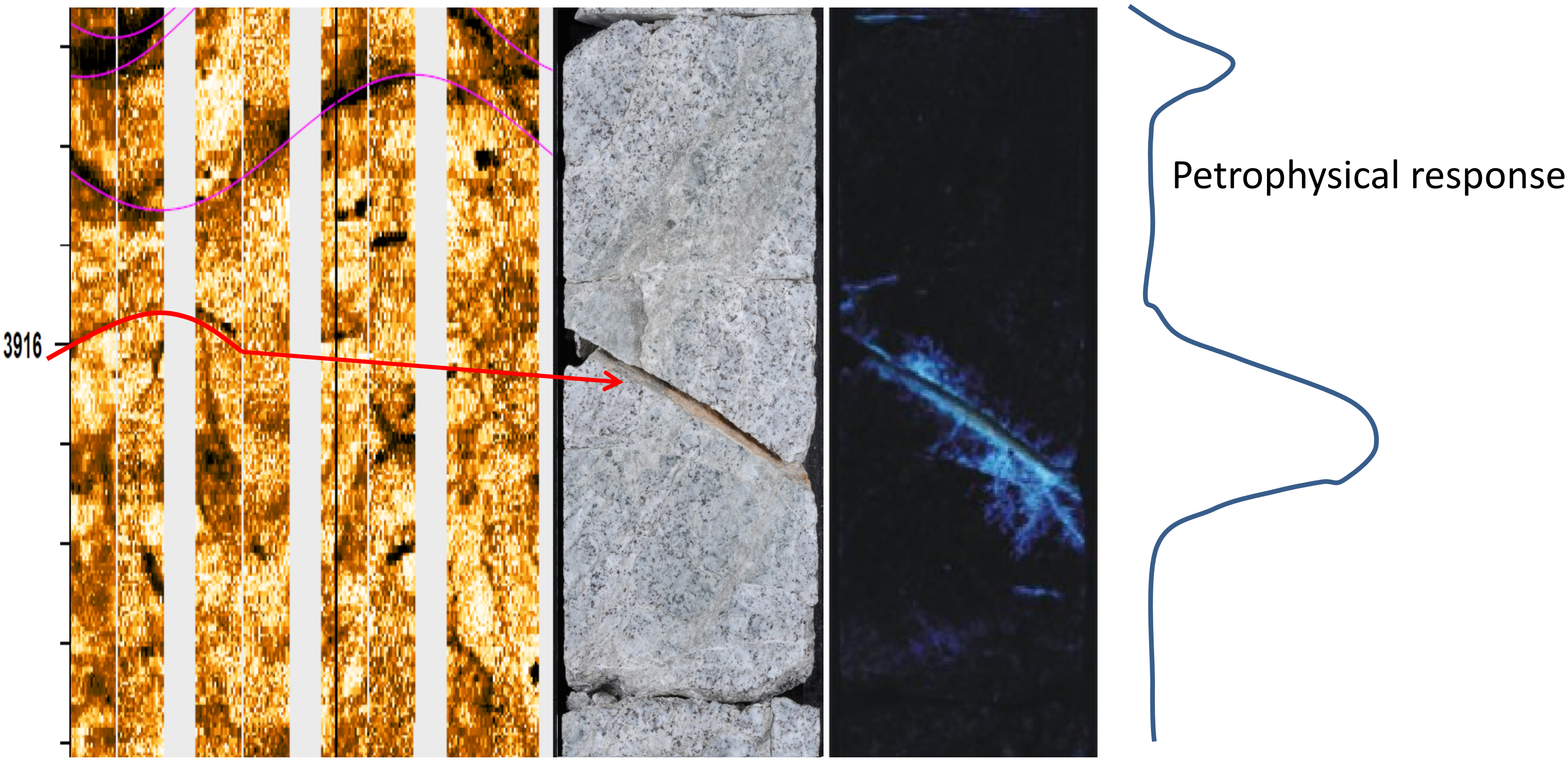








Identify lineaments in core



A small discrete fracture on Image log has a wider alteration halo and partial mineralization along fracture surface. Calibrating aperture size, mineralization and alteration halo is key to accurate DFN modelling

Separating Fracture Aperture/porosity from total porosity log response is a challenge

DSTs should include fluid losses

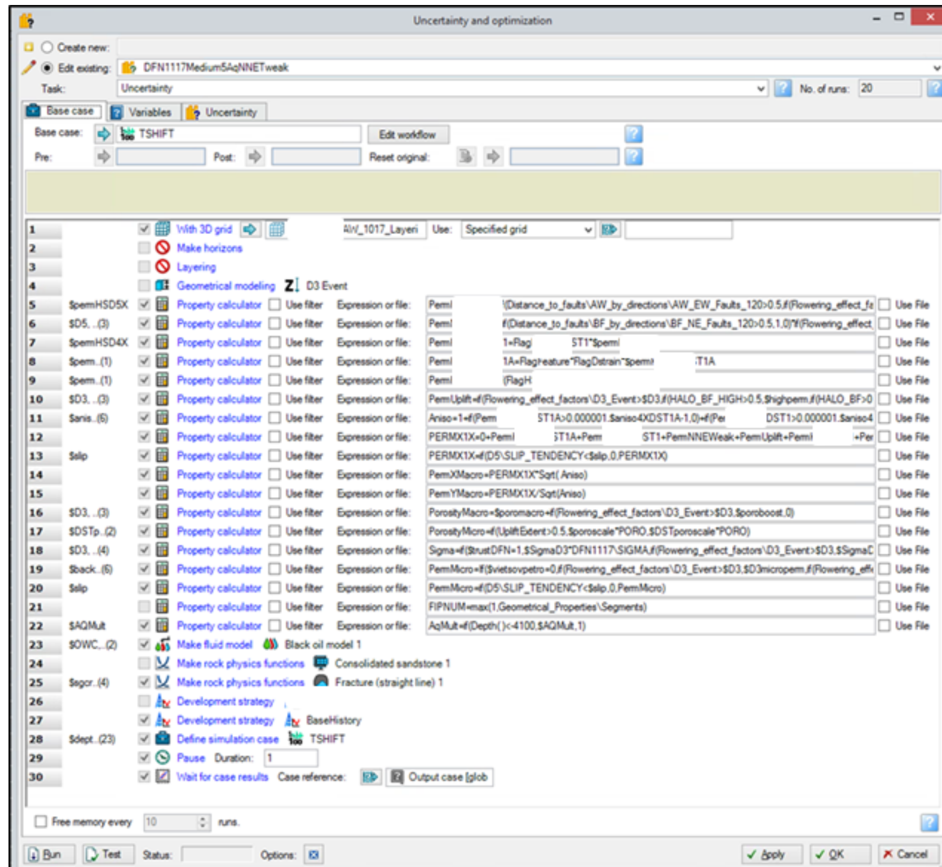
1. In fractured basement reservoirs, fluid losses indicate high productivity
2. Wells are drilled for total losses.
3. If a well doesn’t get total losses, side track.
4. Losses will overcharge the reservoir prior to the DST
5. Overcharge linked to extent of fracture, and fracture porosity
6. Leak off linked to sigma and background permeability

History Match

Build attributes:

- Orientation of faults
- Orientation of lineaments
- Distance to each type of fault and lineament
- Slip tendency
- Uplift from each tectonic event.

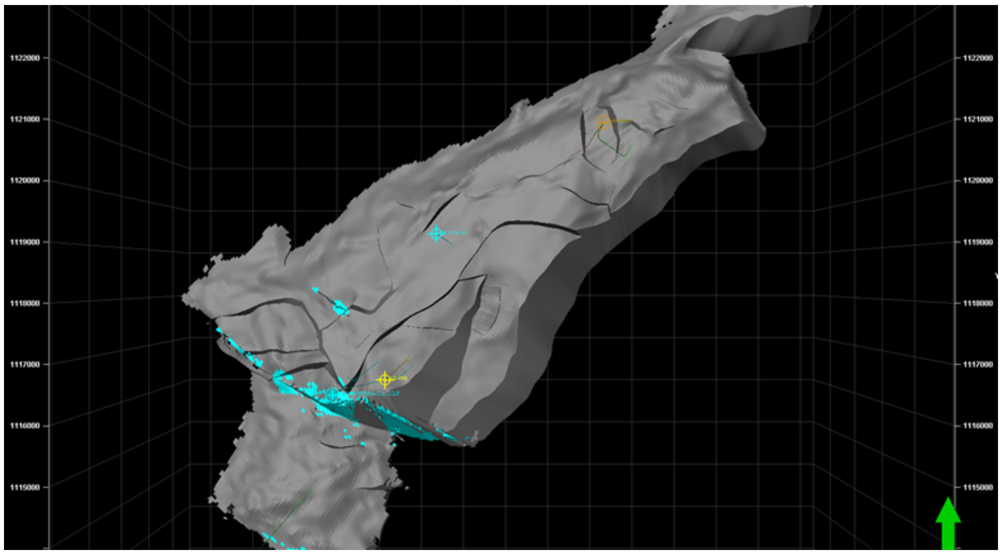
Supply to workflow:



Ideal combination

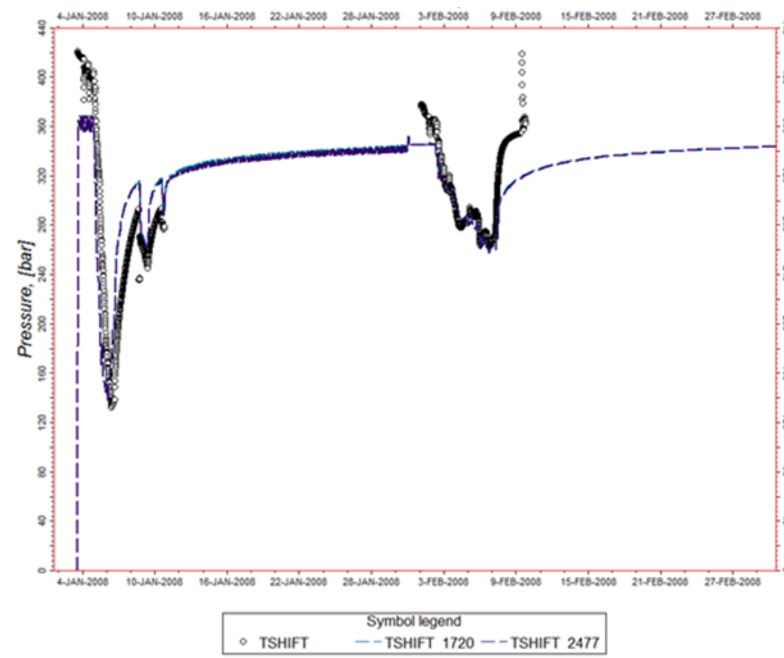
DST with one lineament.

Lineament only intersects one well.



Well A is the only well to intersect NW-SE fault

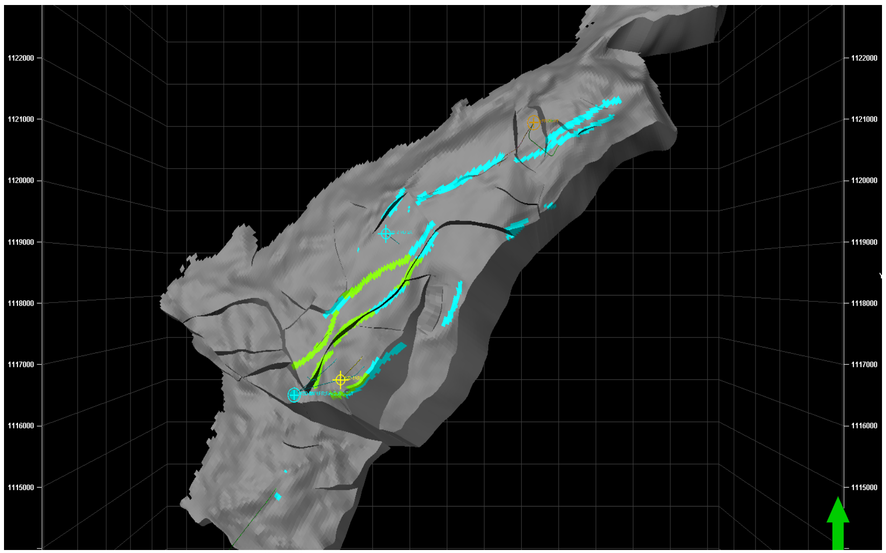
Well A DST interval includes only NW-SE fault.

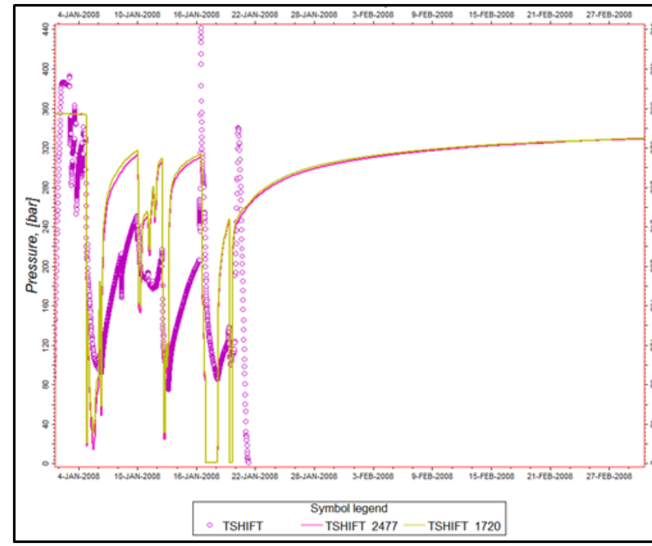


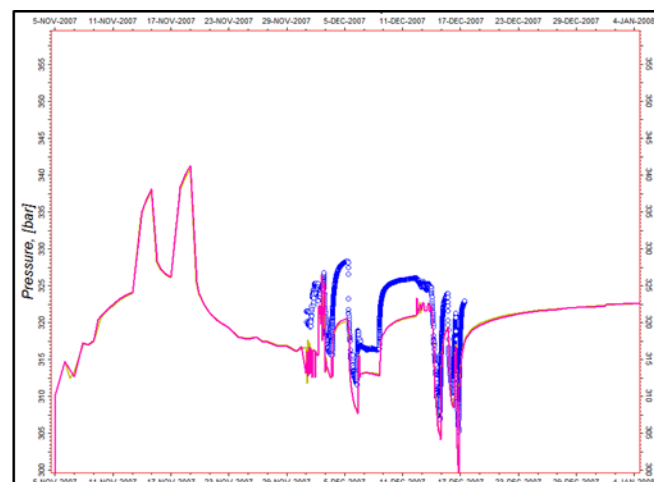
Less ideal combination

Each well has mutiple lineaments

Each lineament intersects multiple wells







8 different systems:

NE or NNE lineaments,
Visible on top structure or visible in ant tracking
In Tectonic Event 3 or Tectonic event 5 uplift events.

Impact two wells.

History Matched model

1. 1500 cases for history match.
2. Event based history matching to identify key matches
3. Workflow to track variables, build batches of 50 cases/ day
4. 2 months of calendar time.
   - Iterations on slip factor
   - Iterations on tectonic events and their areal extent
5. **Constant integration between geomechanics, geophysics, geomodel**

Uncertainty and Prediction

1. Test alternative geomodels: 3
   - Reference and 2 alternative history matches

2. Test infill wells and combinations: 32
   - 5 different options identified, technically 32 options to try including base case.

3. Test water flood : 12
   - 4 from water strategy: 3 different injector locations, and base case
   - 3 from high/medium/low relative permeability, as this is a null space in the history match

4. Total is 3x32x12 = 1152 cases
   - 24 core hours per case, or 1 core day.
   - 96 cores of MR licensing and cluster.
   - 12 days of simulation.
   - Technically could have saved time using restarts (slb – please improve!)

Summary

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