

The 6X Reservoir Simulator

A Solution for Unconventionals that combines Geomechanics,
Hydraulic Fracturing and Flow simulation in a Single Model

May
Webinar

Private & Confidential

Outline of Presentation

What are the Objectives of Unconventional Simulation?

What makes 6X different?

- Integrated Approach to Unconventionals

- Parallel Performance

- Nested Refinement and Coarsening

- Multiple Realizations

6X^{online}

6X Simulator Inputs & Outputs

Summary

Objectives of Unconventional Simulation

Development planning, including

- Well Spacing optimization

 - including vertical and horizontal interference

 - Frac. size vs. Spacing optimization

- Infill Offset Well interference impact

- Refracturing Evaluation

- Huff and Puff Feasibility and Pilot Design

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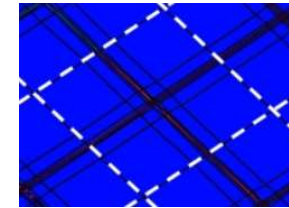
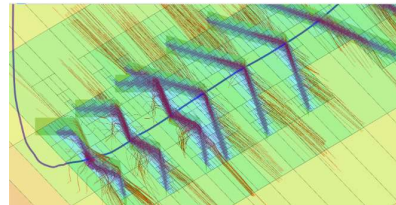
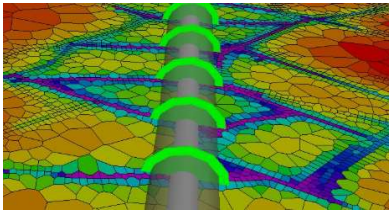
- Huff and Puff Feasibility and Pilot Design

ALL need a realistic representation of dynamic well interactions!

Unconventionals – Traditional Approach

Frac Design software -> Reservoir Simulator

- Frac Design software
 - Focused on determining detailed fracture properties:
 - Shape, Half length, Height growth, conductivity, etc.
- Reservoir Simulator
 - Inherits frac dimensions
 - Grid geometry conforms to frac
 - Saturation properties assigned
 - Predicts production



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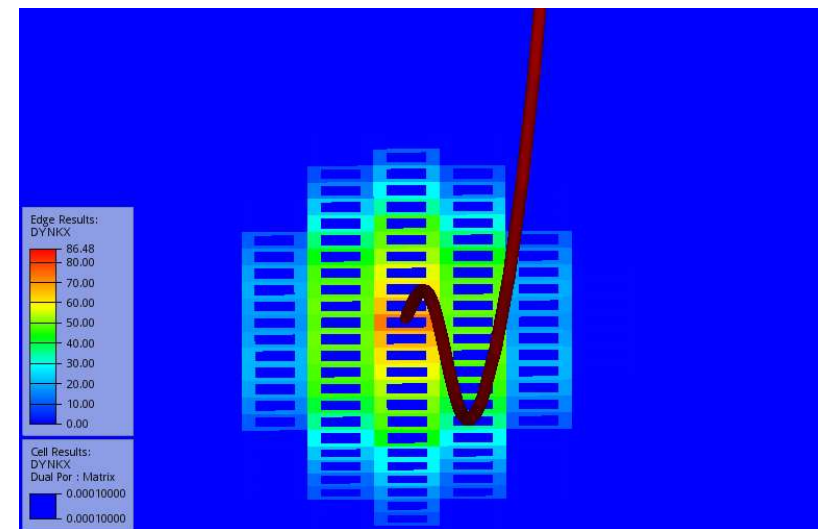
What's the problem?

- Difficult to merge frac designs for multi-well models
- Simulation starts post frac
 - Artificially defined saturation
 - Where did the energy that was injected go?
- How to incorporate geomechanics?

Unconventionals – 6X uses one model

6X unique approach:

- One model incorporating
 - Geomechanics
 - Frac design
 - Production
- Stress and Flow dynamics solved together
- ... on a multi porosity simulation grid
- ... with Integrated Geomechanics

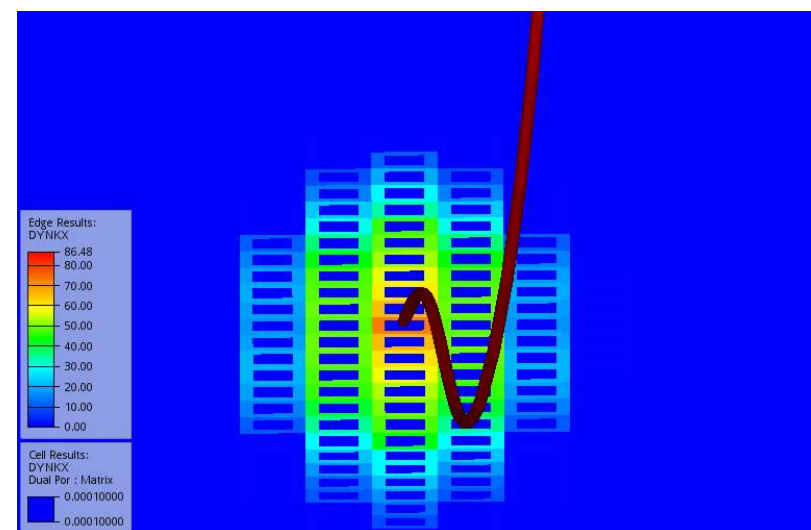


Dual or multi porosity grid

Unconventionals – 6X uses one model

6X unique approach:

- One model incorporating
 - Geomechanics
 - Frac design
 - Production
- Stress and Flow dynamics solved together
- ... on a multi porosity simulation grid
- ... with Integrated Geomechanics
- Focus on production related decisions
 - 6X does not use a discrete fracture network
 - DFN captured in background grid properties
 - Frac growth represented by grid property enhancements
 - Frac closure represented by hysteretic enhancement reduction

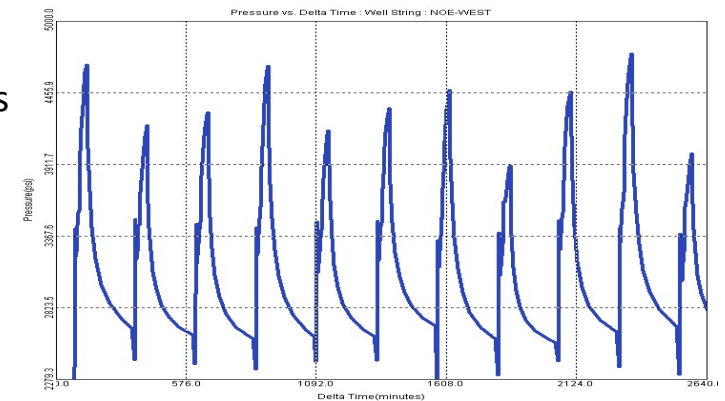


Dual or multi porosity grid

Unconventionals - What makes 6X different?

Model the pumping schedule of the wells

- Inject fluid into simulation model at stage locations
- Model the leak-off into the matrix
- Capture the energy injected as pressure



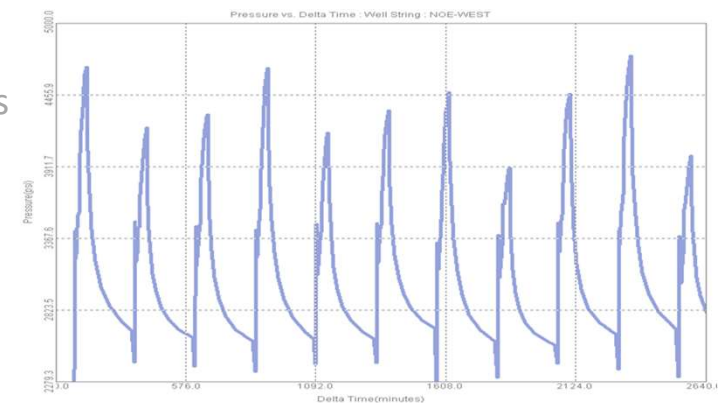
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Model the rock breaking during fracturing

- Model geomechanics
- Create both tensile & shear fractures



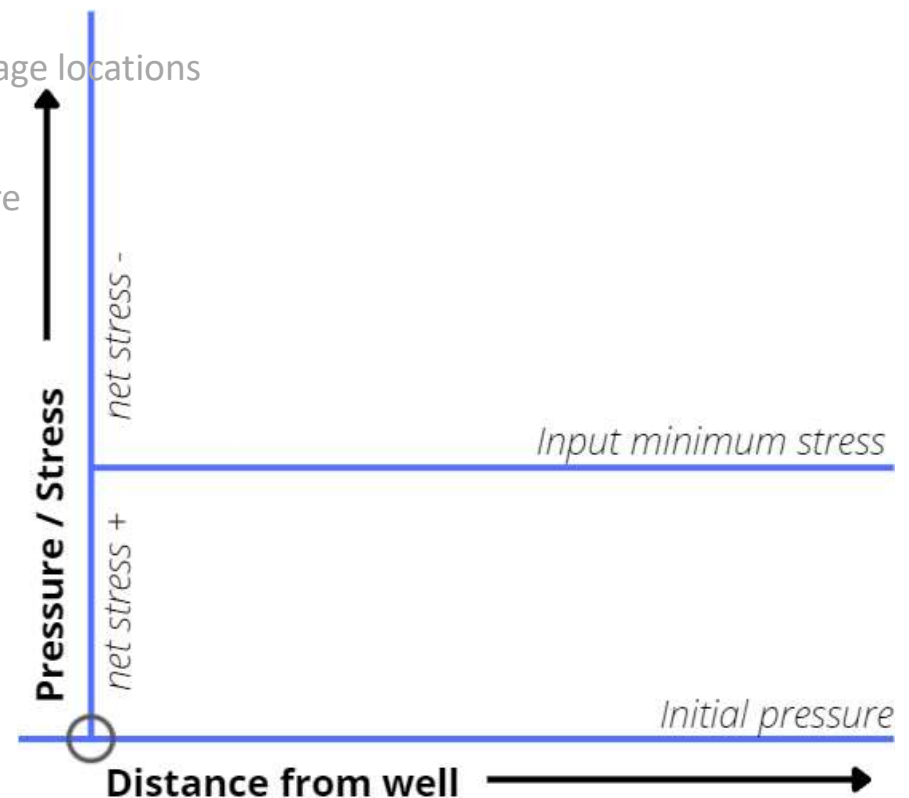
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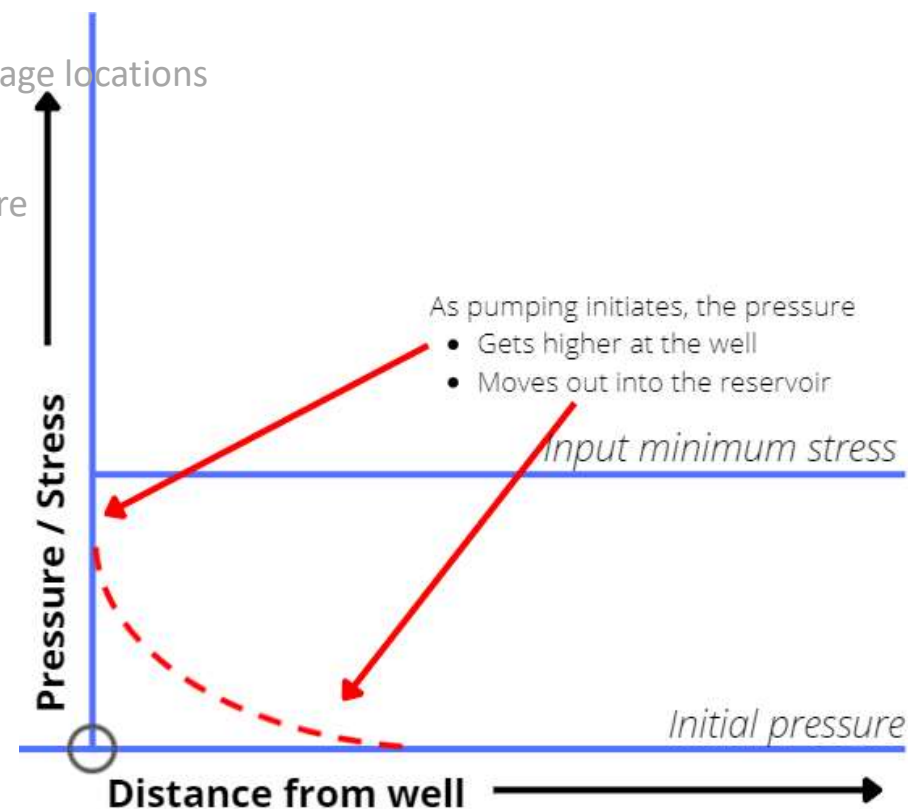
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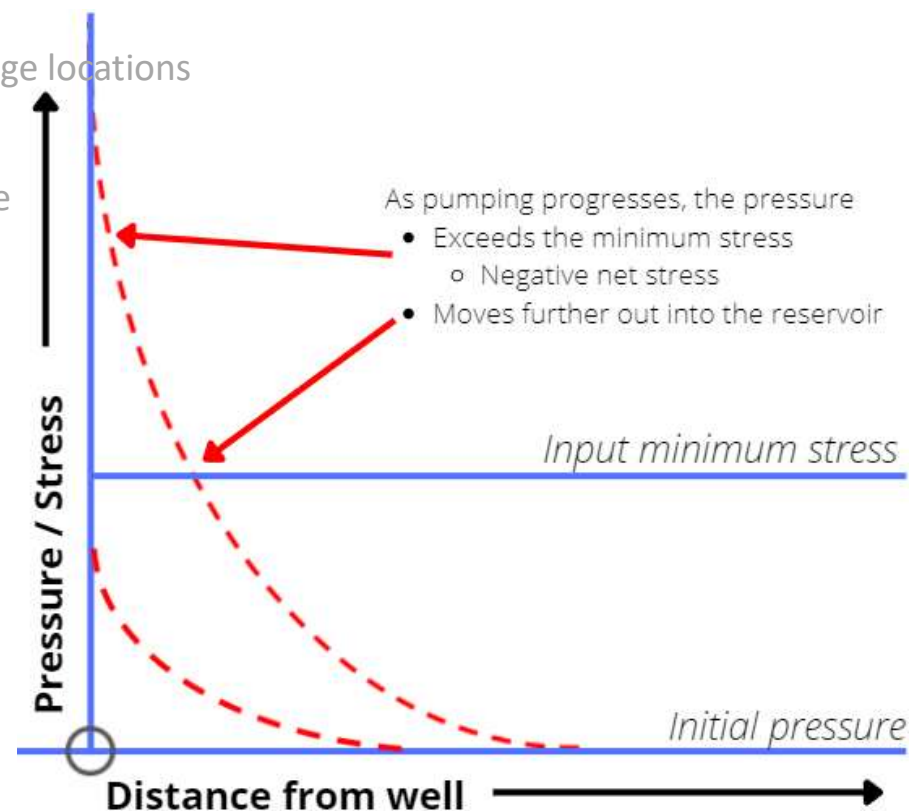
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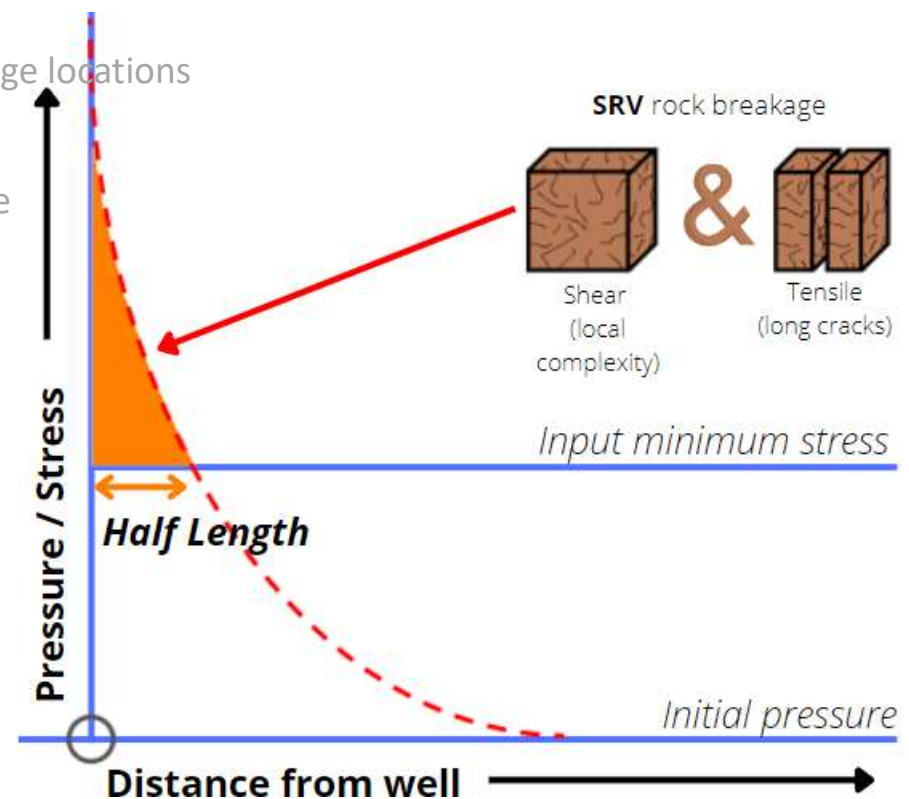
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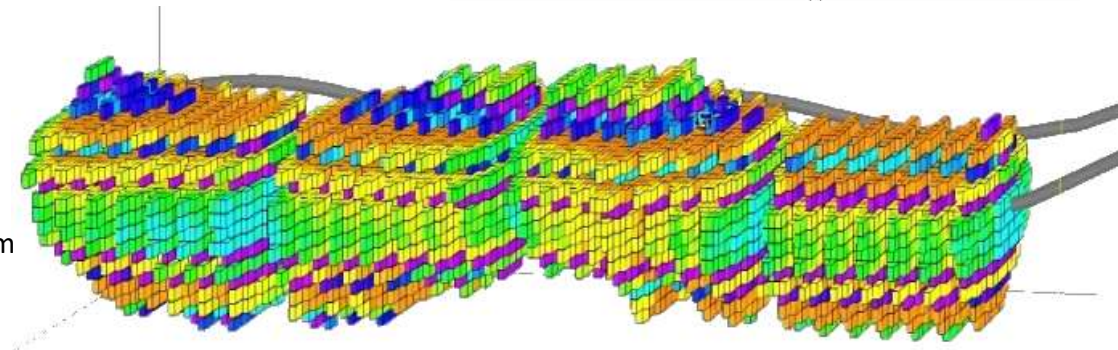
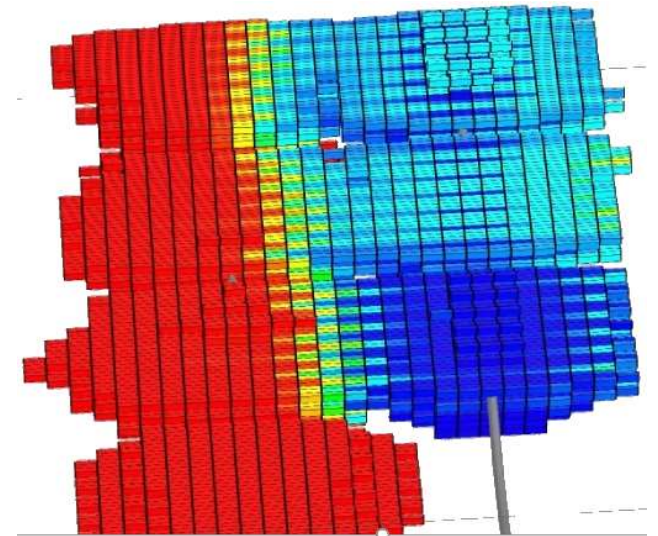
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Ultimately, we can model

- A full well
- Multiple wells,
 - and the interactions between them
- Across entire drilling units



Unconventionals - What makes 6X different?

We solve the poroelastic equation...

- Either mean stress or full stress tensor
- Fully coupled with the flow equations
- Implementation based on TOUGH2 (Wang et al)
- Requires geomechanical properties
 - E.g. Poisson's ratio & Young's modulus
- Calculates the *change* in the input stress(es)
- Allows a dynamic net stress to be derived

Mean stress change equation:

$$\nabla \cdot \left(\frac{3(1-\nu)}{(1+\nu)} \nabla \delta \sigma_m \right) - \sum_k \left[\nabla \cdot \left(\frac{2(1-2\nu)}{(1+\nu)} \alpha_k \nabla \delta P_k \right) \right] = 0$$

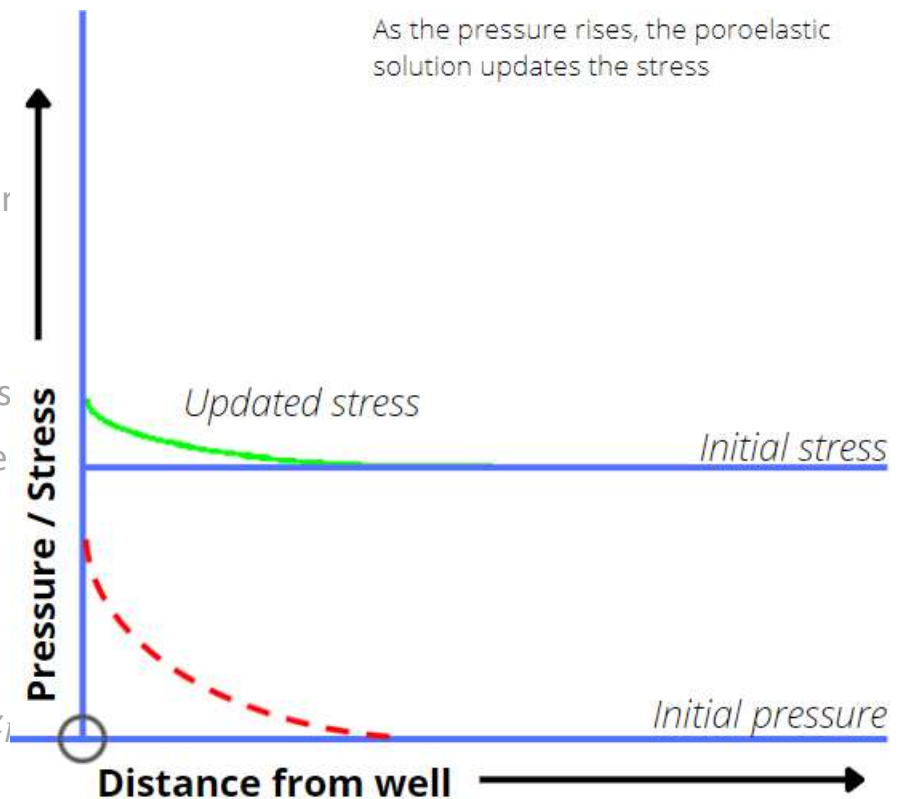
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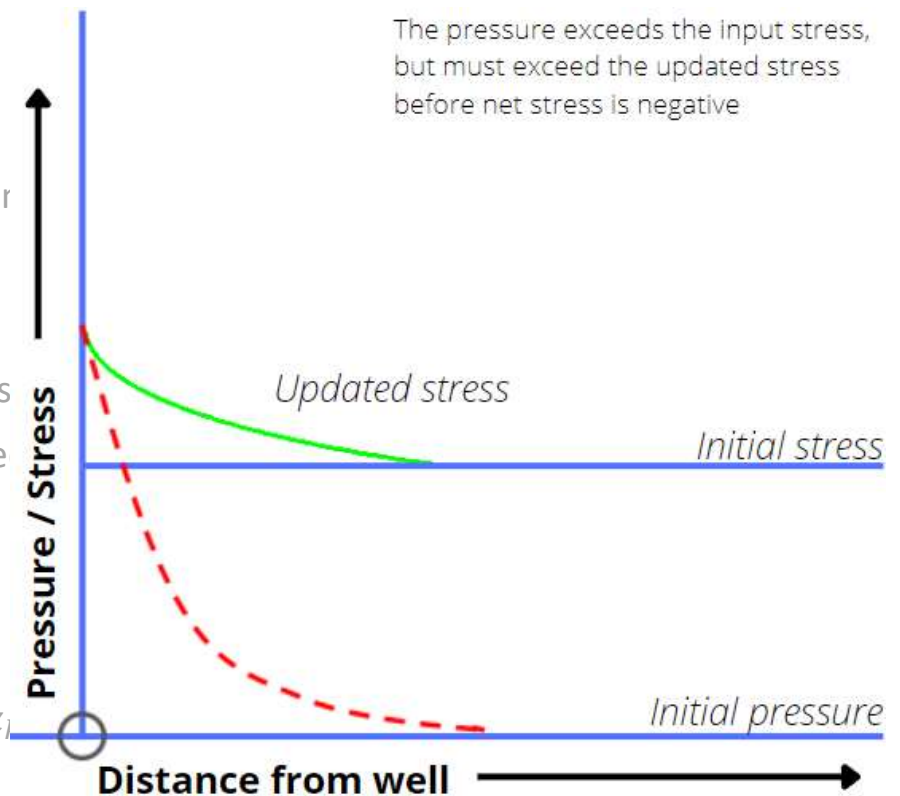
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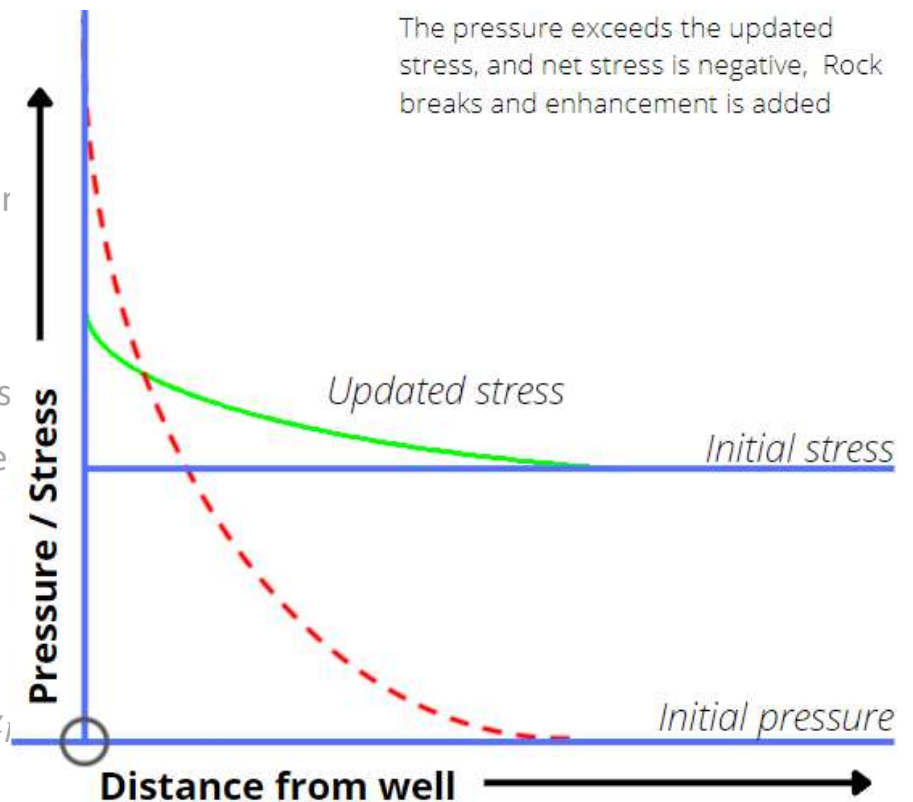
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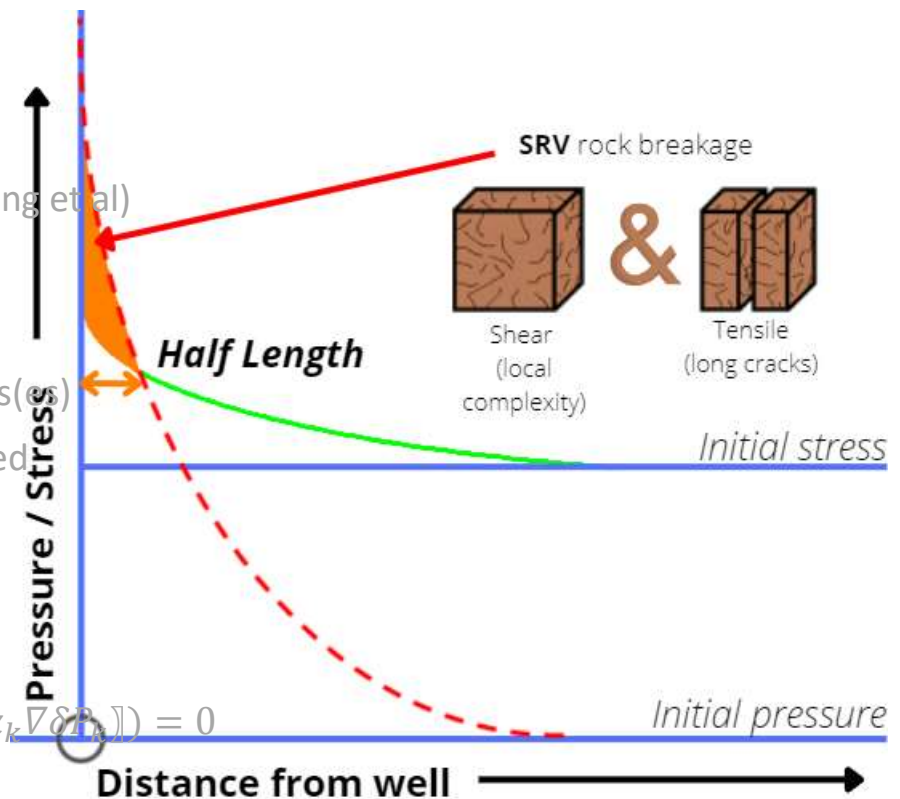
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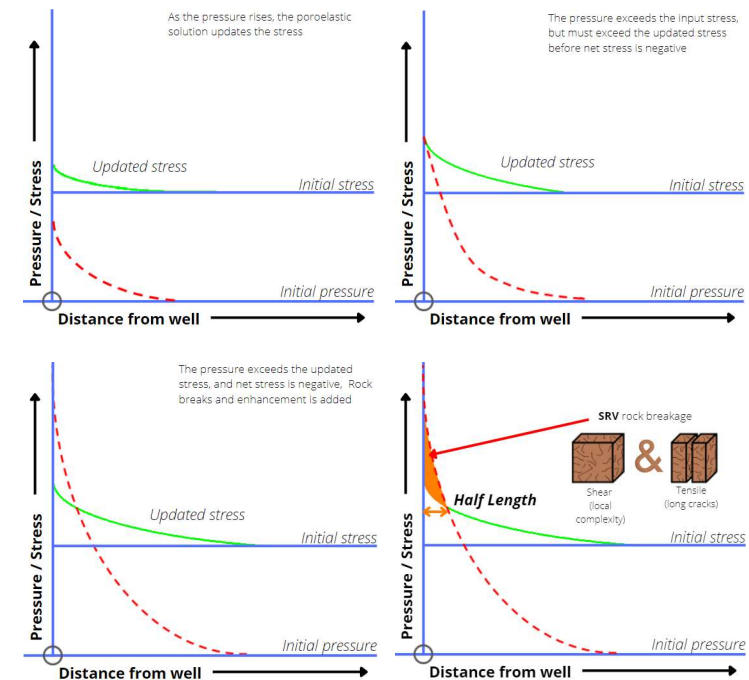
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Captures the effect of pressure changes on stress, including

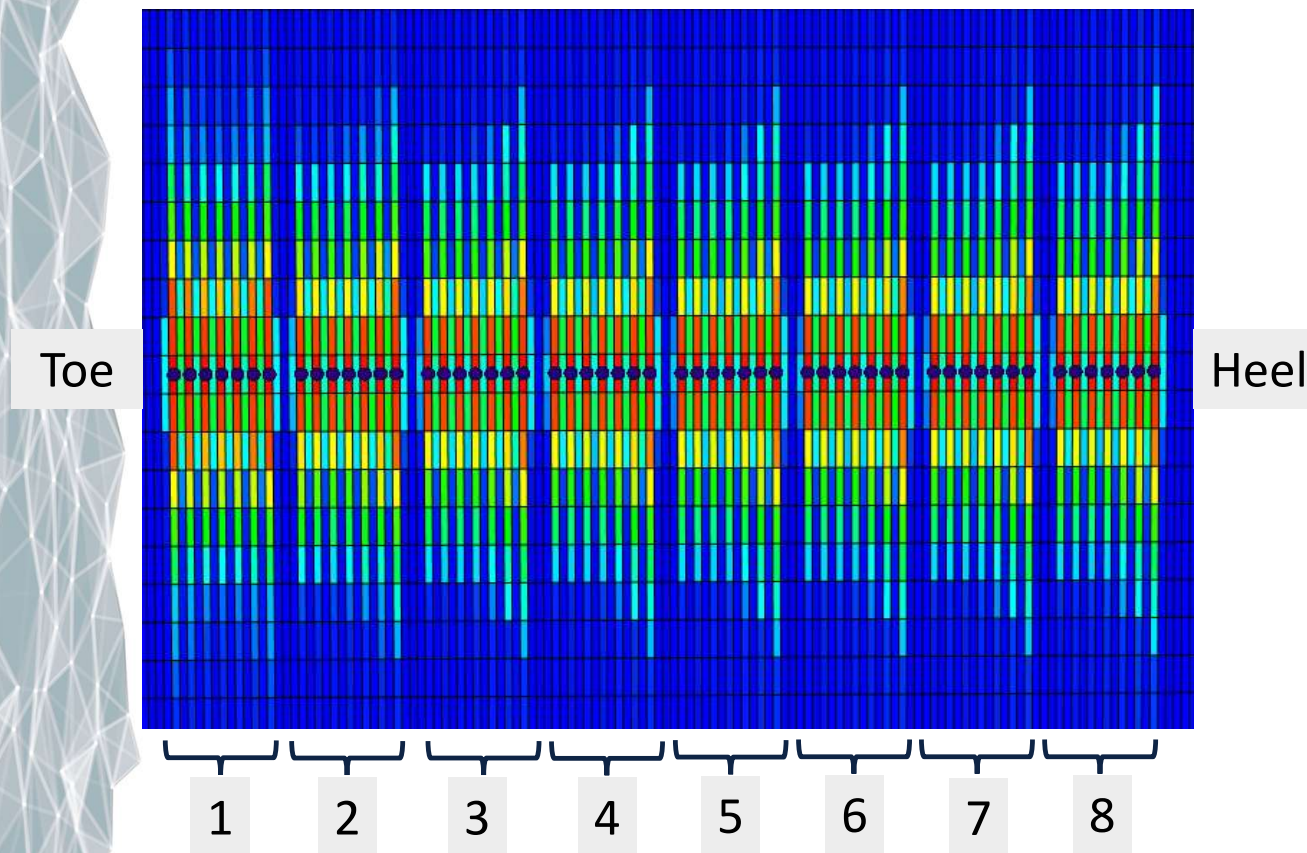
- Stress increase during pumping
- Stress reduction due to depletion

Allows a more realistic model of rock breaking



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Unconventionals - Full Stress Tensor solution



Stress Shadowing

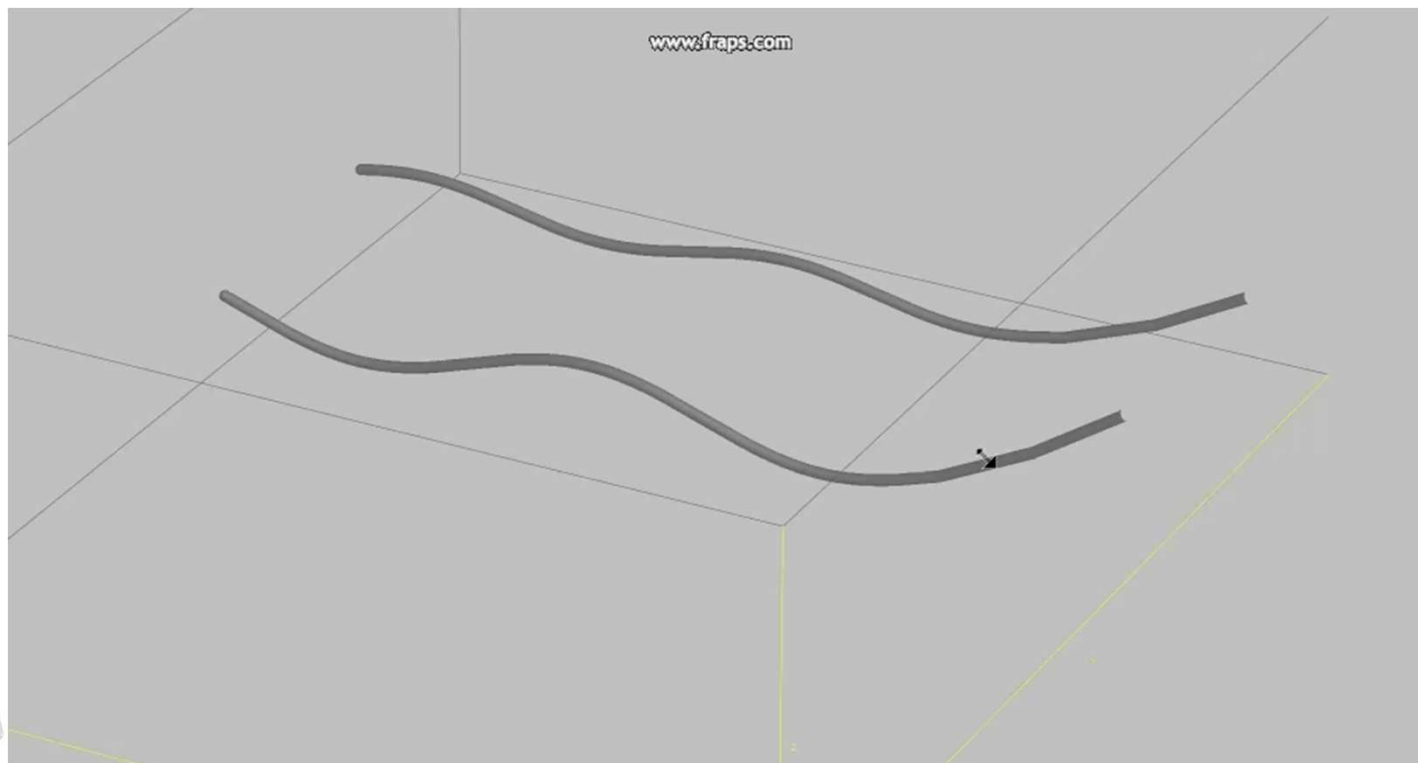
Stage 1 is symmetrical.

The cluster of stage 2 nearest the toe is impeded by the induced normal stress from stage 1. This effect tapers off towards the heel end of stage 2.

The pattern repeats for subsequent stages

Unconventionals - Optimization of well spacing

Step 1: Parent well fractured and depleted



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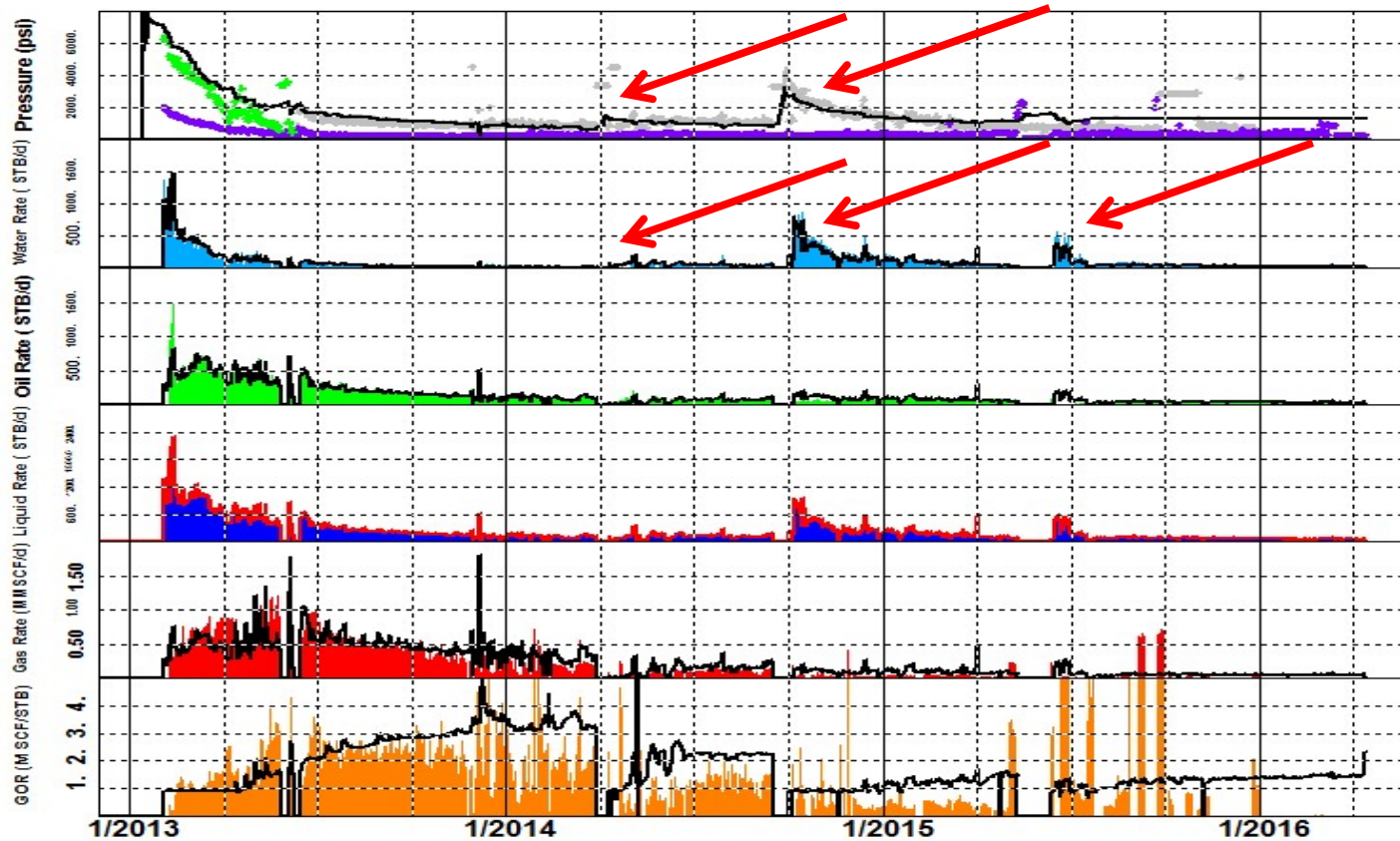
Unconventionals - Optimization of well spacing

Step 2: Child well interference with the parent well



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Unconventionals - What makes 6X different?

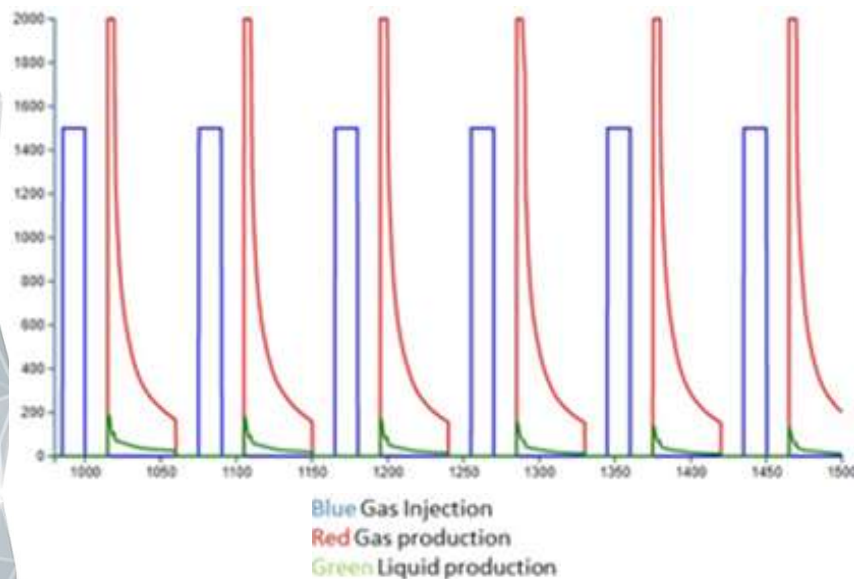


Multiple wells, Frac hits

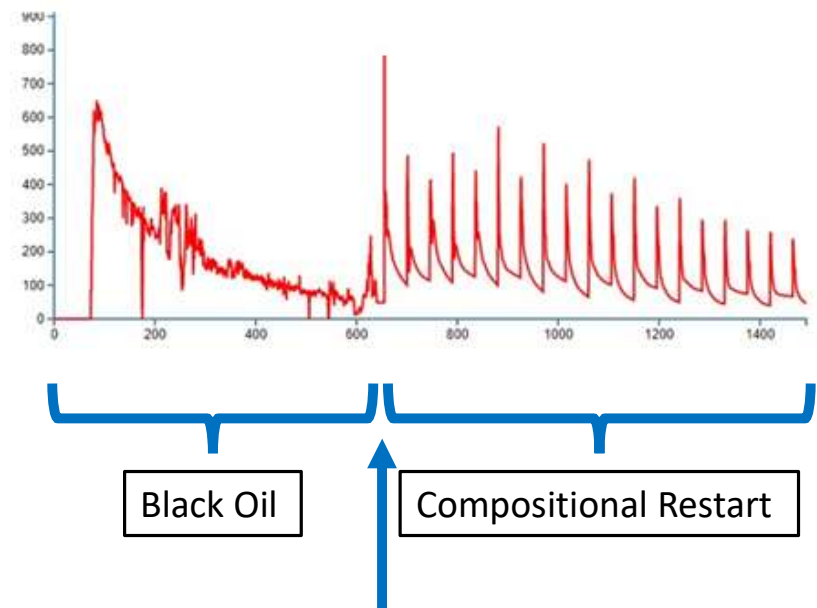
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6X Unconventionals - EOR cyclic gas injection

Single well pilot test



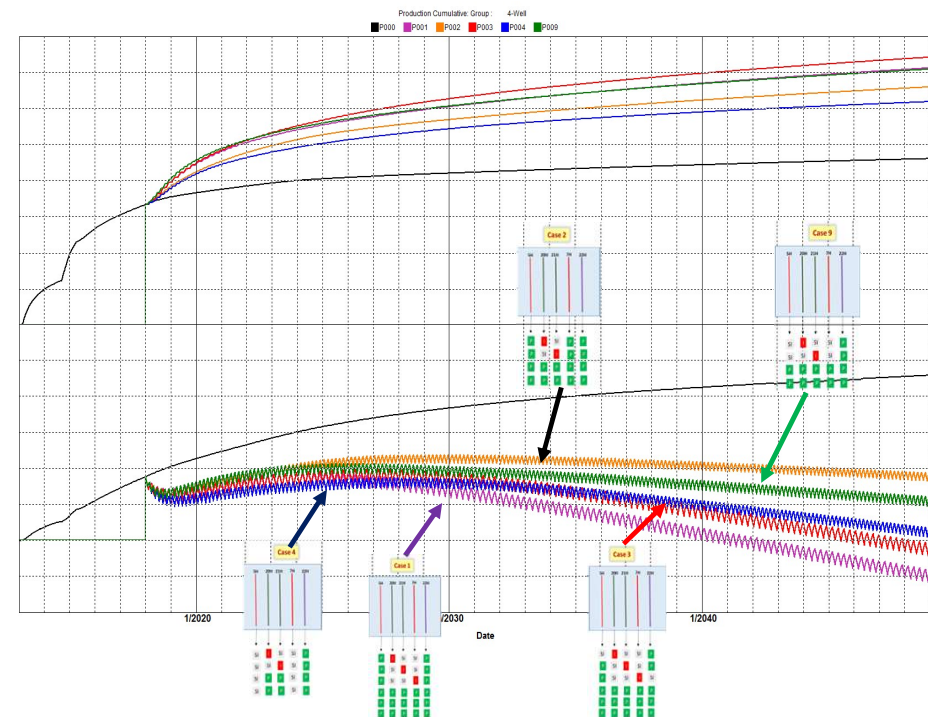
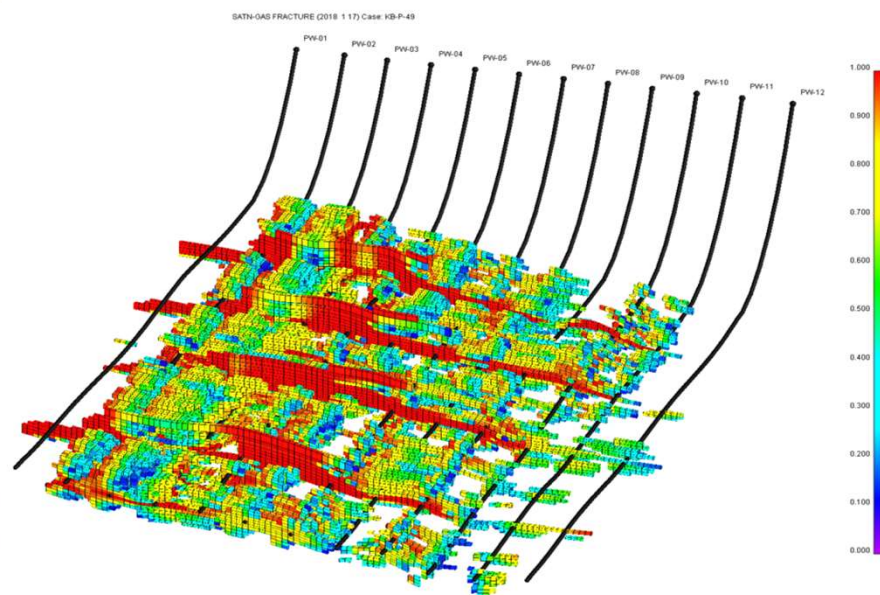
Predicted field oil production
(real world example)



6X Options:

Robust BlackOil <-> Compositional converter

6X Unconventionals - EOR cyclic gas injection



Monitoring of Multi-well EOR Pilots

Impact of Well Injection Scheduling on EOR Outcome

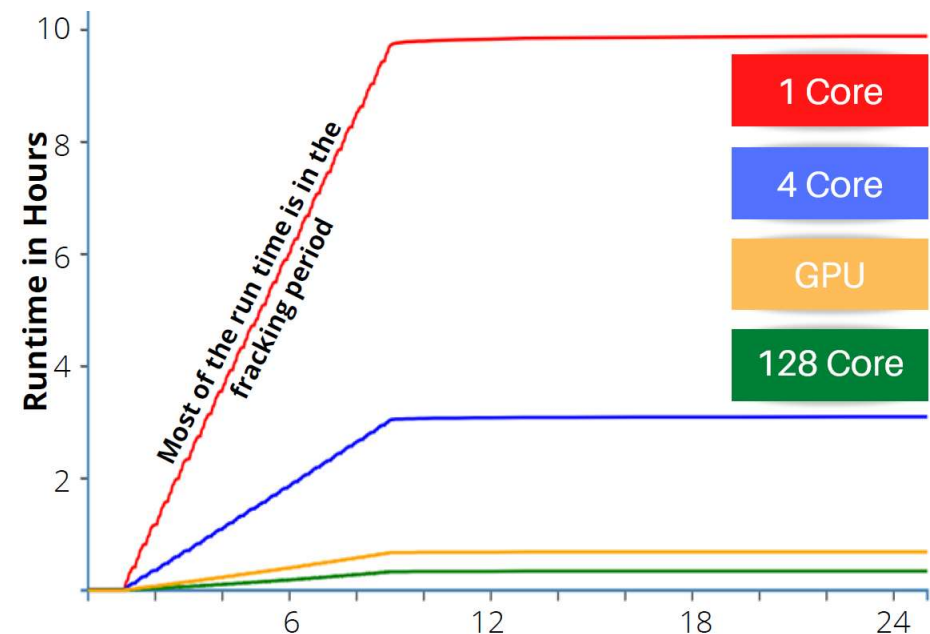
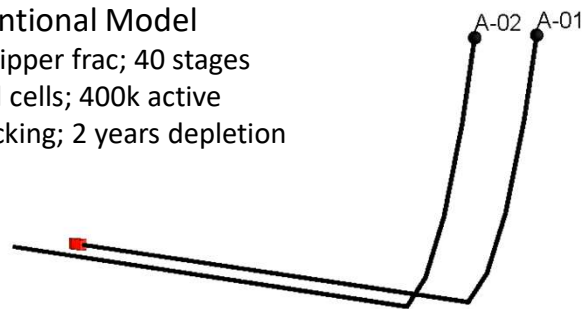
6X - Parallel Performance

6X architecture designed to be

- Massively parallel
 - Runtime scales well
 - Low latency
- System agnostic
 - CPUs or GPUs
 - Linux or Windows

Unconventional Model

2 wells – zipper frac; 40 stages
1.4M total cells; 400k active
9 days fracking; 2 years depletion



One license enables all functionality*

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6X - Nested Refinement and Coarsening

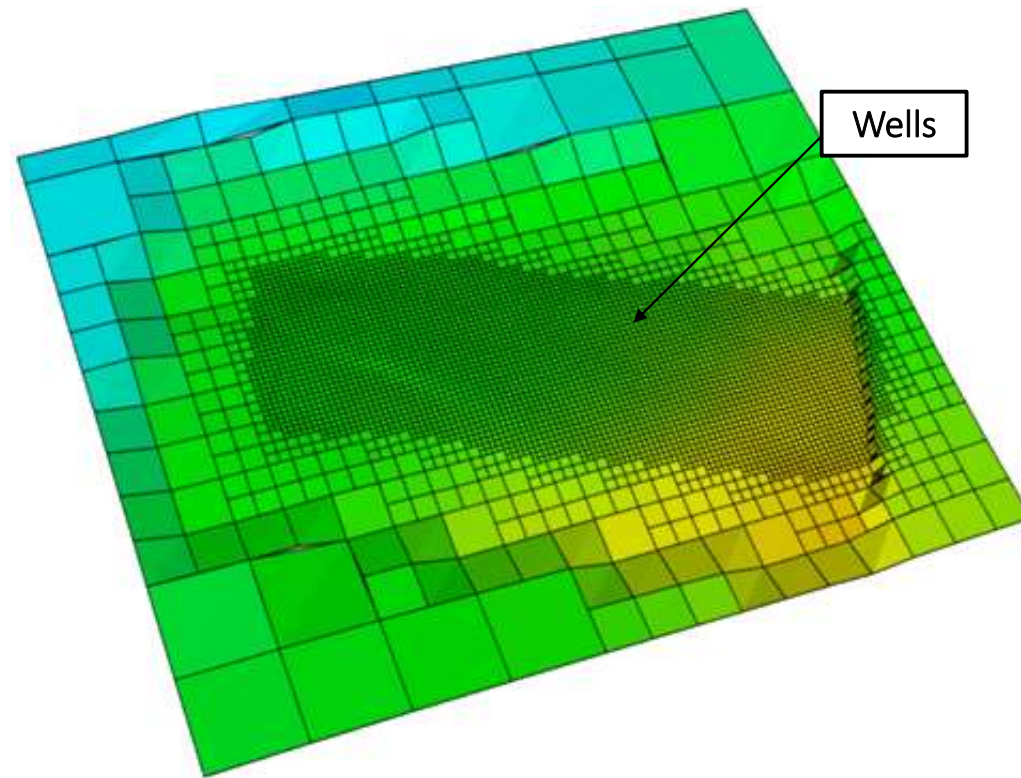
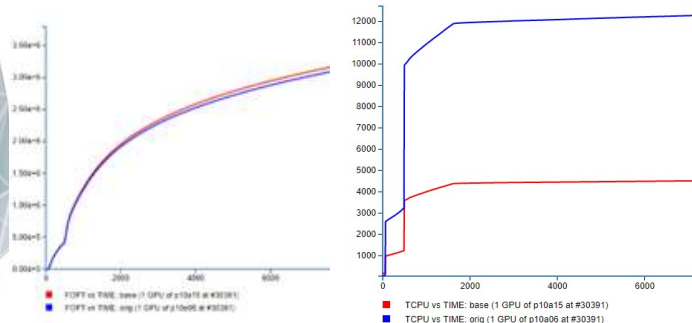
Automated upgridding & upscaling

- Nested factors of 2x2 areally
- Automatically updates
 - properties
 - well connections

Increase or reduce resolution

- Smaller cells in active areas
- Larger cells in remote areas

Consistent results, significantly faster



6X - Multiple Realizations

Integrated MR workflows

- Sensitivity Analysis
- Experimental Design
- Optimization
 - Assisted history matching
 - Development optimization

Dataset driven set up

- Keyword parameterization
- Integrated job control

One license enables ALL functionality

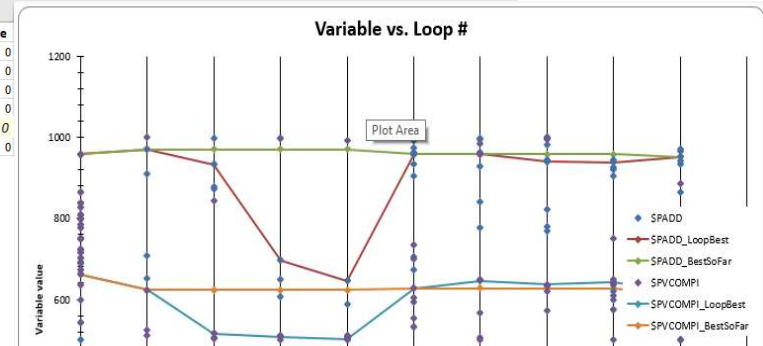
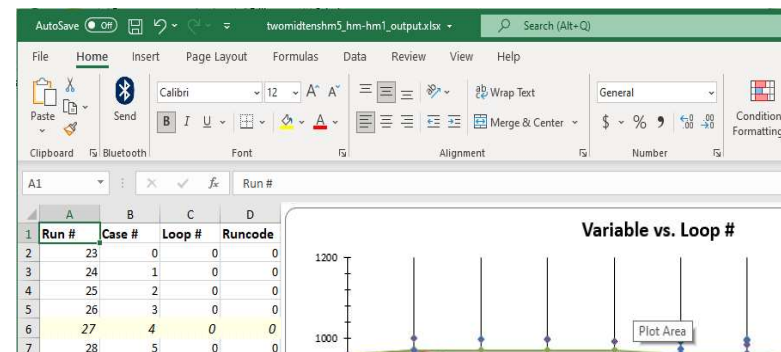
- Including multiple simultaneous runs

```

MRCONTROL
  SENSITIVITY SENS_ONE /
/
MRSENSITIVITY SENS_ONE
  TYPE COMBINATION /
  VARIABLESET SET1 /
  VECTORS WBHP /
  OUTPUT EXCEL /
  PLOTS /
/
MRVARIABLES SET1
-- Vname Vtype Dtype def min max n
XPERMB REAL UNIFORM 1000 300 2000 3* 3 /
PVCOMP REAL UNIFORM 800 500 1000 3* 3 /
/

RKSROCKTAB 1 BRST
-500 -5 0 500
$PVCOMP $PVCOMP 100 100
$PVCOMP $PVCOMP 100 100
/

```

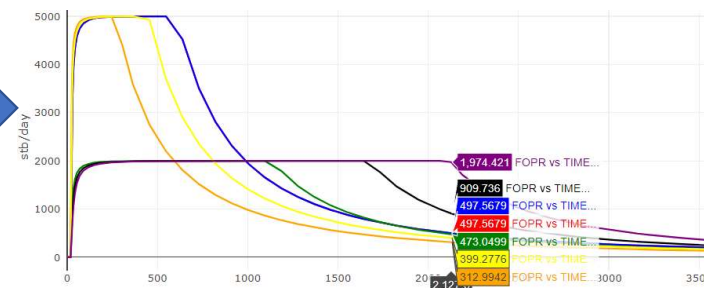


6X^{online}

- A web application to enable routine workflows
 - Supports **limited functionality** on layer cake models
 - Runs 6X simulator
 - Locally or on an external server or on the cloud
 - Cases can be exported and customized to access advanced functionality



The screenshot shows the 'Reservoir collection' interface with a sidebar on the left containing 'Reservoirs', 'Wells', 'FracJobs', 'Scenarios', 'build', 'save', 'load', and 'options'. The main panel has tabs for 'formation', 'fluid', 'stress', 'layer', 'rock', 'poroPerm', 'geomech', and 'scal'. The 'formation' tab is active, showing fields for 'Name' (Formation (global)), 'top depth' (9000), 'pressure' (7200), 'horizontal refinement' (2), 'goe' (8900), 'woc' (9300), and 'extent' (1). At the bottom are buttons for 'import reservoirs', 'rename', 'copy', 'delete', and 'export'.



1st Public Demo (10th February 2022)

- Single stage
- Single well; multi stage
 - Sensitivity of production on number of stages

2nd Demo (30th March 2022)

- Injection rate optimization
- History Matching / Calibration to well performance

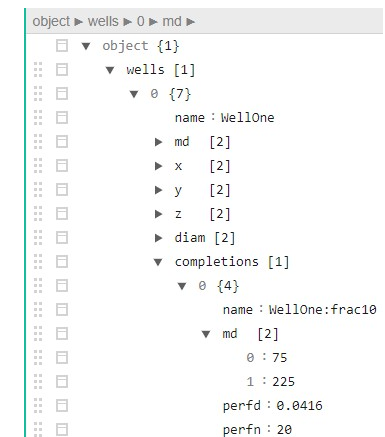
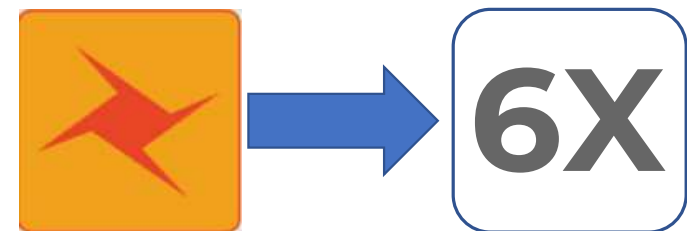
3rd Demo (June 2022)

- Multi well – well spacing
- Proppant sensitivity

6X - Simulator Inputs (“pre-processing”)

Input Formats

- ECLIPSE compatible keywords
 - Editable plain text
 - Generated from Petrel RE, RE Studio, etc.
- JSON formatted data
 - 6X can consume field (X / Y / Z) location data directly, e.g. well trajectories
 - Generated from Spotfire dashboard, or
 - Generated by 6X^{online}
- Combination
 - Merge 6X^{online} case with geomodel

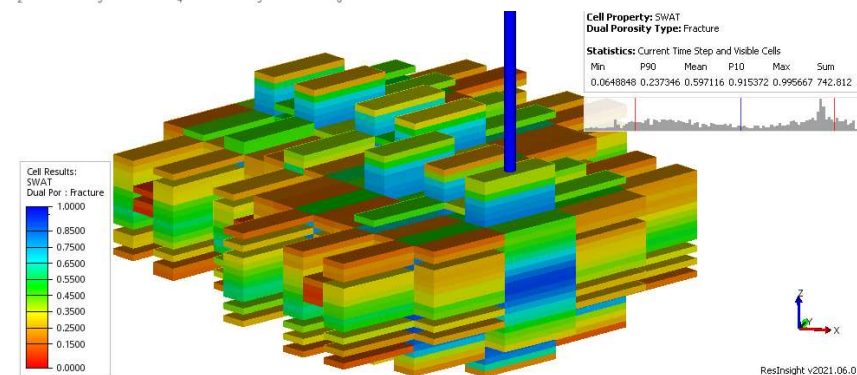
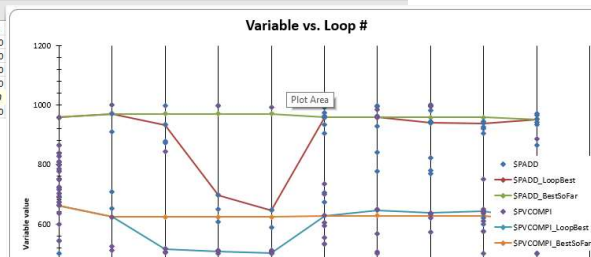
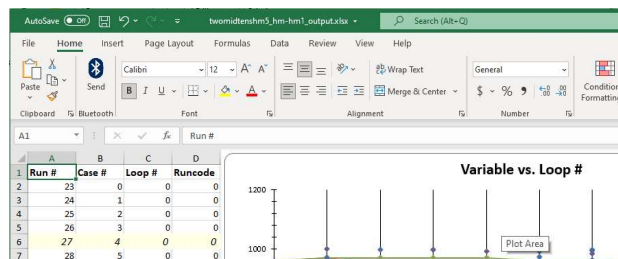
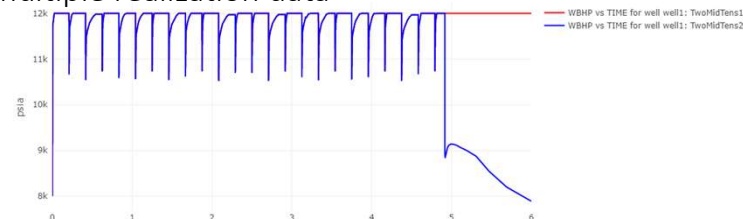


6X - Simulator Outputs (“post-processing”)

Web enabled output for line plots (.html & .js files); 6XV – our 3D viewer

Output formats:

- ECLIPSE compatible Restart (static and dynamic 3D arrays) & Summary (line plot data)
 - Works with Petrel, ResInsight, Coviz, Tecplot RS, RE Studio, etc.
- Microsoft compatible line plot data and multiple realization data
 - Excel output files
- JSON compatible line plot data
 - Works with 6Xonline, Python, etc



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6X - Summary

A Solution for Unconventionals that combines Geomechanics, Hydraulic Fracturing and Flow simulation in a Single Model

Fracture generation based on pumping schedule and stress

Full stress tensor poroelastic solution

Black Oil or Compositional fluid modeling

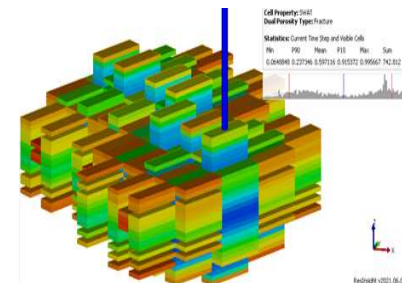
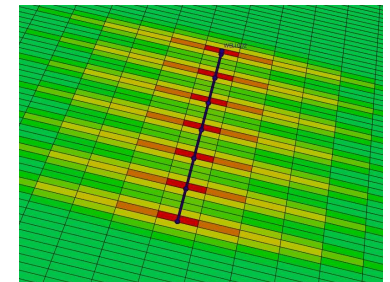
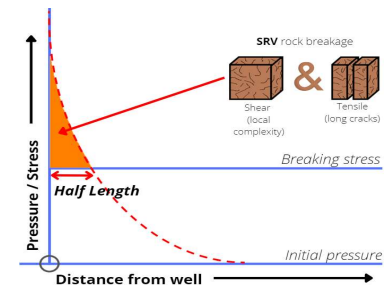
High performance and high throughput enabled by

- Massively parallel design

- Efficient Nested Refinement and Coarsening

- Multiple Realizations

Industry standard data preparation and results processing



6X - Benefits

A superior field planning workflow

- Linking fracture design to production

- Single well modeling

- Parent / Child well spacing and interference modeling

- Enhanced Oil Recovery modeling

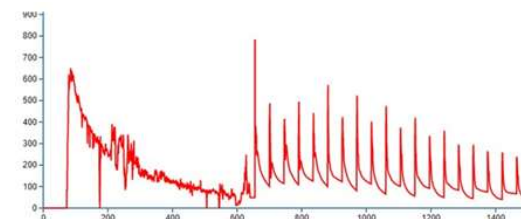
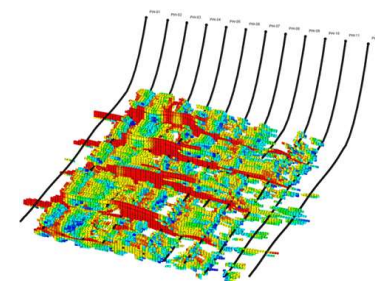
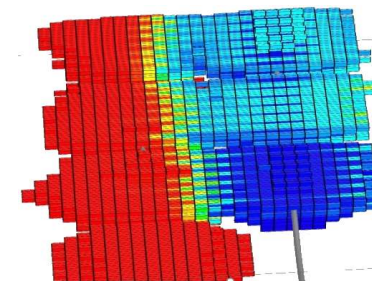
Supporting management decision making around

- Well count and spacing

- Completion strategies

- EOR planning and implementation

To minimize expenditure and maximize recovery



Questions?

Contact

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