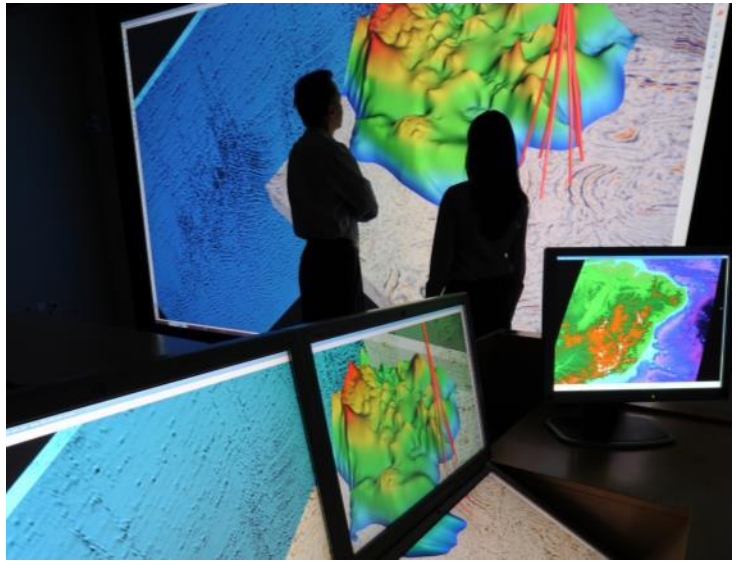

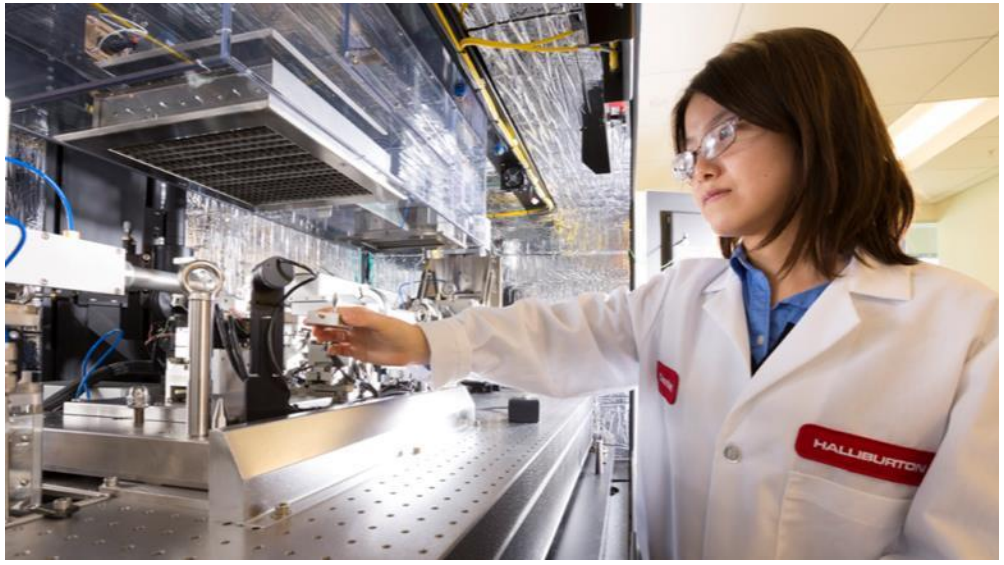

GOHFER® Fracture Modeling Software

3D Multidisciplinary Integrated Geomechanical Fracture Simulator and Completion Optimization Tool

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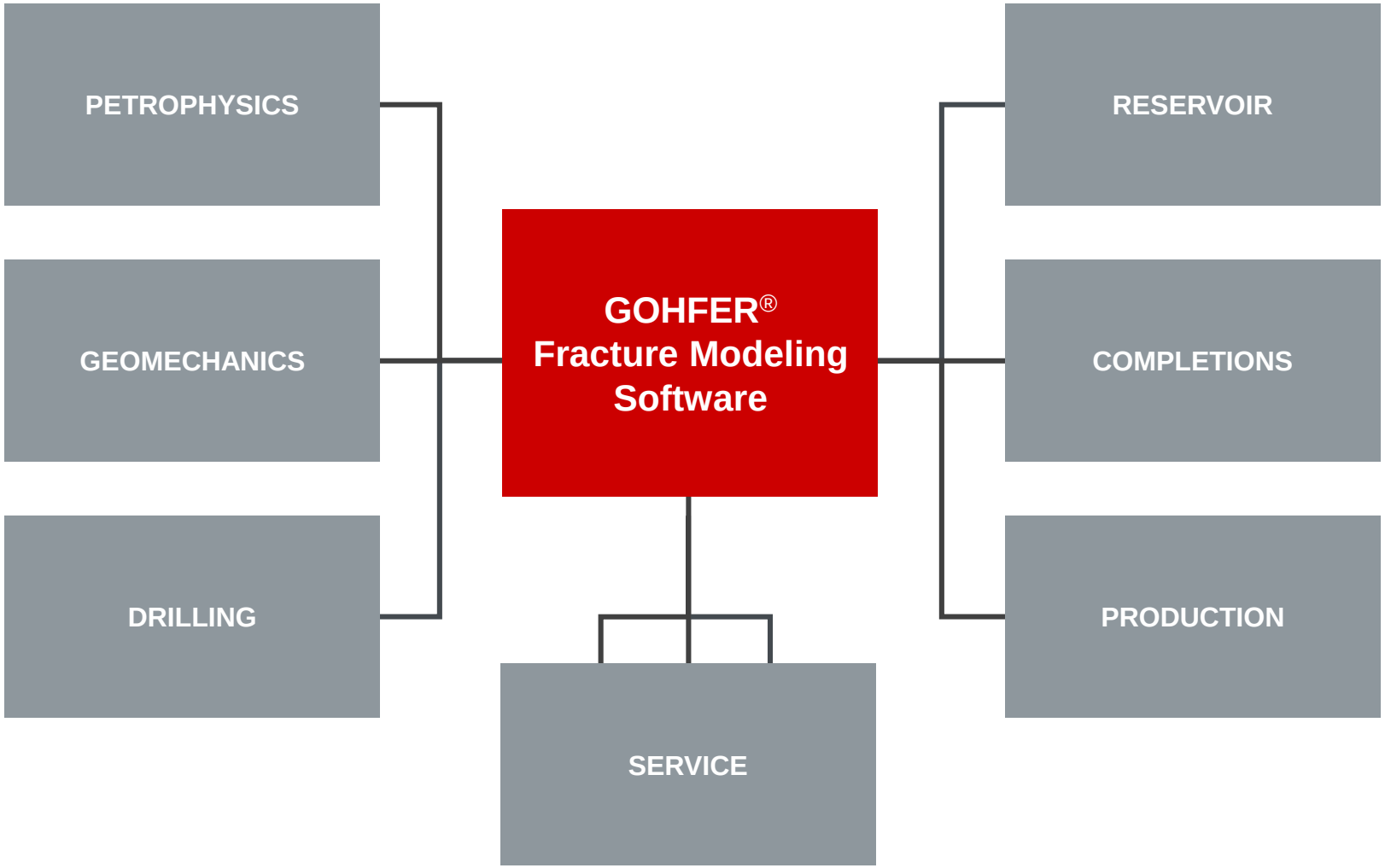
3D Multidisciplinary Integrated Geomechanical Fracture Simulator & Completion Optimization Tool



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Integrated Geomechanical Fracture Design Simulator – Requirements

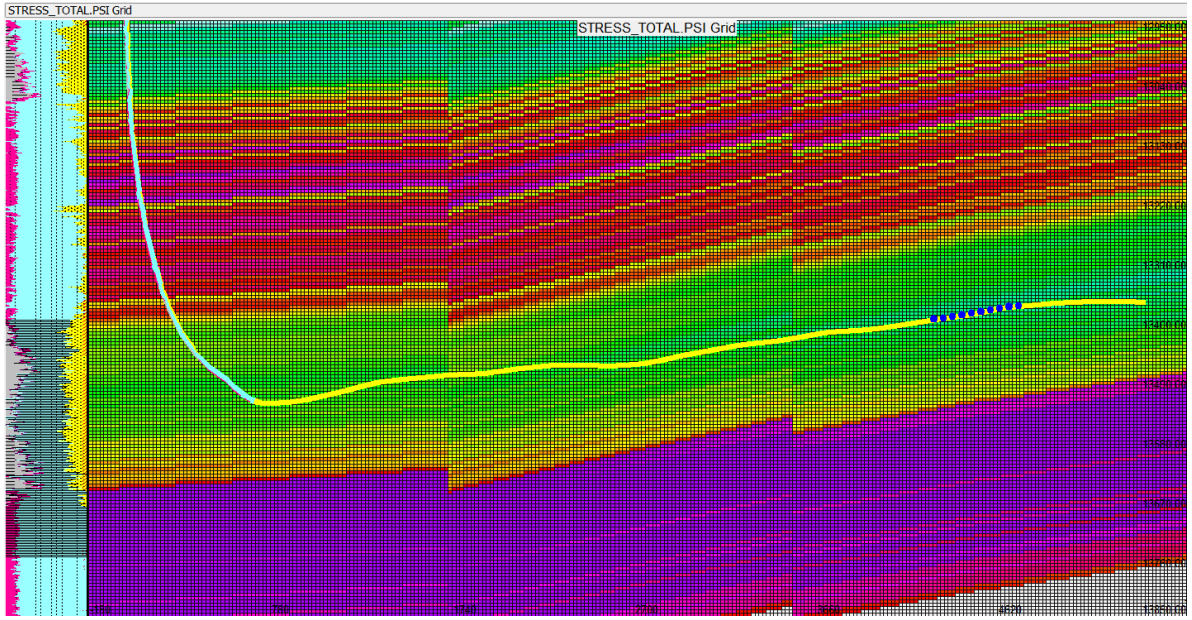
- Describe/Include the basic physics of all important processes
- Ability to predict (not just mimic) job results
- Provide decision making capability
  - Understand what happened
  - Isolate causes of problems
  - Change necessary inputs
  - Predict results
- If your simulator can’t do this, why run it?

GOHFER® Fracture Modeling – Software Capabilities

- A multi-well planar 3D geometry fracture simulator with a fully coupled fluid/solid transport simulator
- All formulation used in GOHFER 3D is publicly available in order to foster peer review
- Used extensively in all regions w/o requiring special “tuning”:
  - Shale reservoirs
  - Hard rock/tight gas environments
  - Naturally fractured reservoirs
  - Soft-sediment frac-packing
  - Moderate perm oil sands
  - Acid-frac designs in carbonates

What does Grid Oriented mean?

- A regular, planar grid structure (in the horizontal and transverse direction) is used to describe the entire reservoir, similar to a reservoir simulator
- This grid is used for both the elastic rock displacement calculations as well as a planar finite difference grid for the fluid flow solutions.
- Fluid composition, proppant concentration, shear, leakoff, width, pressure, viscosity, and other “state variables” are defined at each node at each time
- Allows vertical/lateral variation and complex geologic structure



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GOHFER® Fracture Modeling Software – Design Advantages

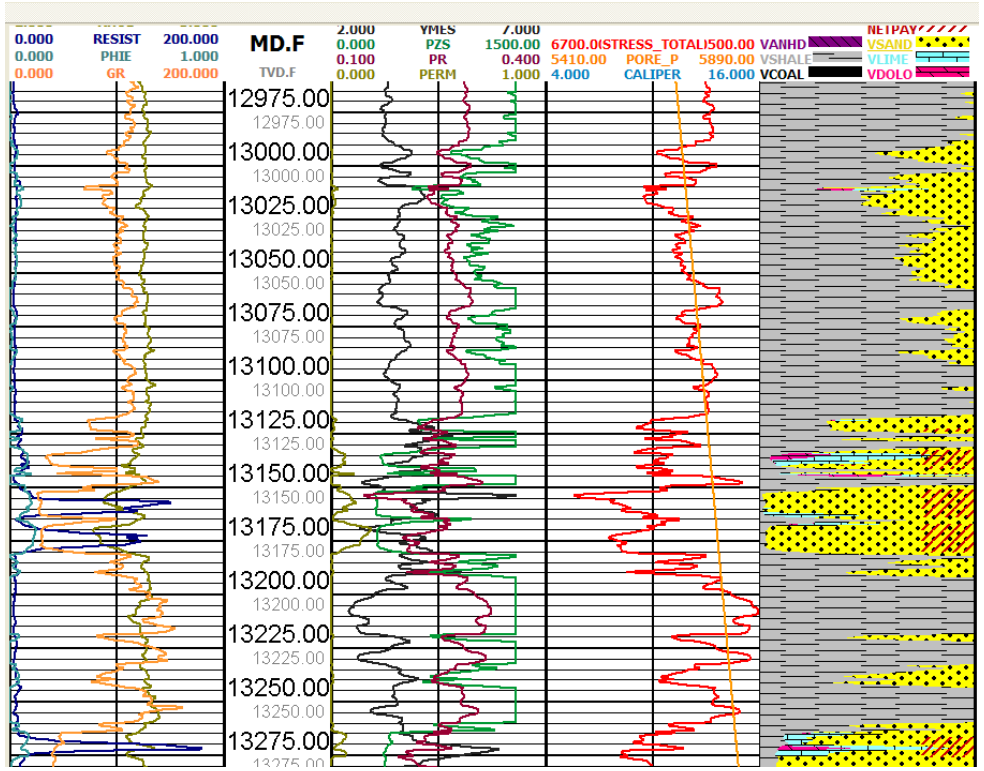
- Direct integration, evaluation and processing of digital log data or “core” from 3D earth model
- Multiple wells, including vertical and horizontal, in the same model
- Multi-layer completions, zipper-fracs, and offset depletion effects
- Horizontal and asymmetric fracture modeling, including complex reservoir geometry
- Full 3D geo-mechanical earth model input (from Petrel GSLIB file) or optional input of 2D surface map with reference well logs
- Variable inter/intra-stage fracture stress shadow interference between each fracture and stage on each well
- Multiple Perforated Intervals:
  - Limited entry design
  - Allows modeling of multiple fracture initiation sites simultaneously
  - Shows diversion between perforations, properly simulating limited entry designs
  - Models perforation erosion

GOHFER® Fracture Modeling Software – Design Advantages

- Most effective tool for modeling fracture treatments in unconventional tight gas shales and coal
- Vertical and horizontal anisotropy
- Geo-steering of laterals and engineered completions
- Allowance for vertical and lateral variation in leakoff and rheology across the fracture
- Models filter-cake erosion and equilibrium leakoff
- Pressure Dependent Leakoff – Models the local increase in leakoff caused by dilation of fissures
- Models the impact of 100-mesh FLA
  - Handles density driven flow (convection) and particle settling
  - Fracture acidizing model
    - » Predicts acid reaction kinetics, penetration, and etched width

Model Features – Petrophysical Analysis

- Direct importing of digital log data and/or “core” from 3D earth model
  - Vertical variations in data can be directly input from well logs on a foot by foot basis
  - Horizontal variations can be derived from seismic and crosswell imaging data
- Unlimited number of LAS/CSV files can be imported
- Generates complete data set for population of the entire GOHFER 3D grid
- QC or replace poor or absent sonic data
- Built-in correlations for synthetic mechanical rock properties
- Scatter plot capability to generate your own relationships and correlations
- Ability to incorporate core data



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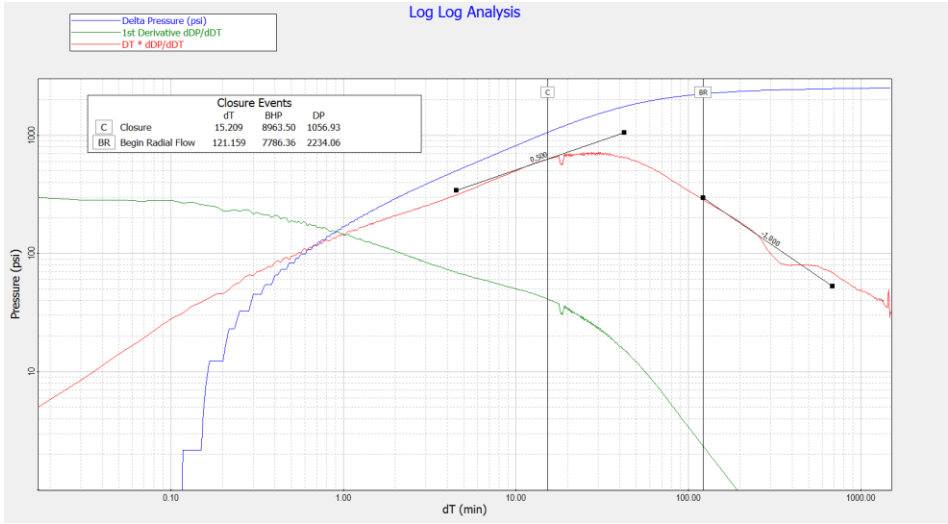
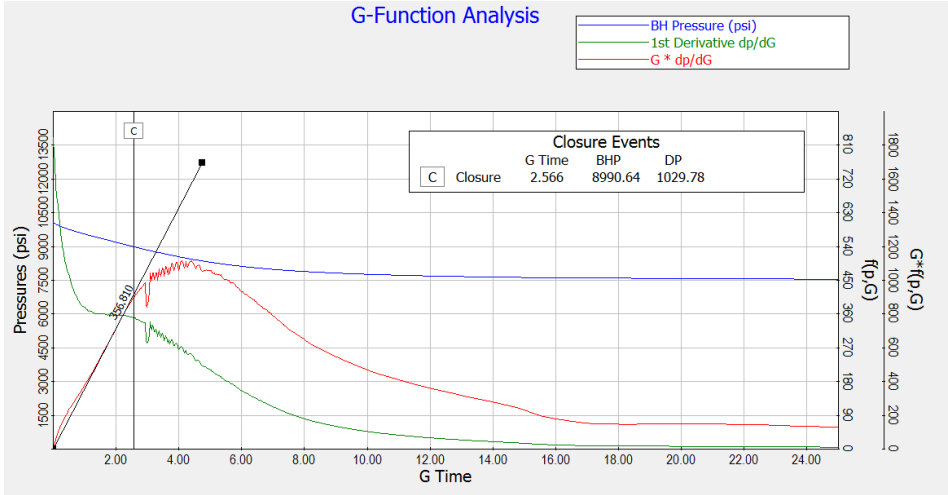
Model Features – Pressure Diagnostics

- SRT Analysis
  - Pressure loss at Perfs
  - Near-Wellbore Pressure Loss
  - Blowdown Analysis
- Falloff analysis (G-Function / SQRT / Log-Log)
  - Determination of closure
  - Efficiency and Leakoff Mechanism
  - Effects of Variable Storage and Tip Extension
  - Horner Plot
- After Closure Analysis (ACA)
  - Pore Pressure and Permeability
- Permeability Estimate from G Function





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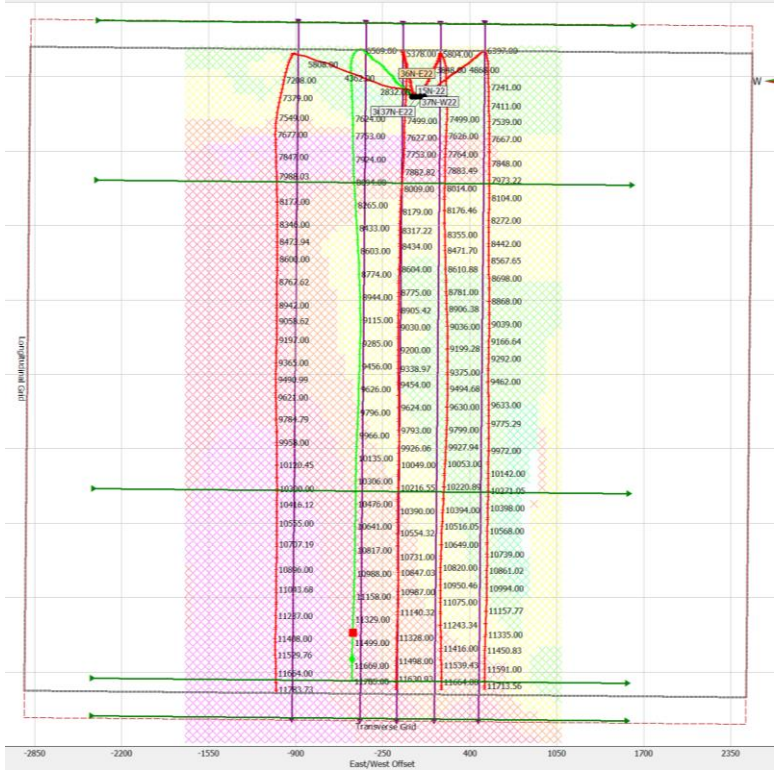
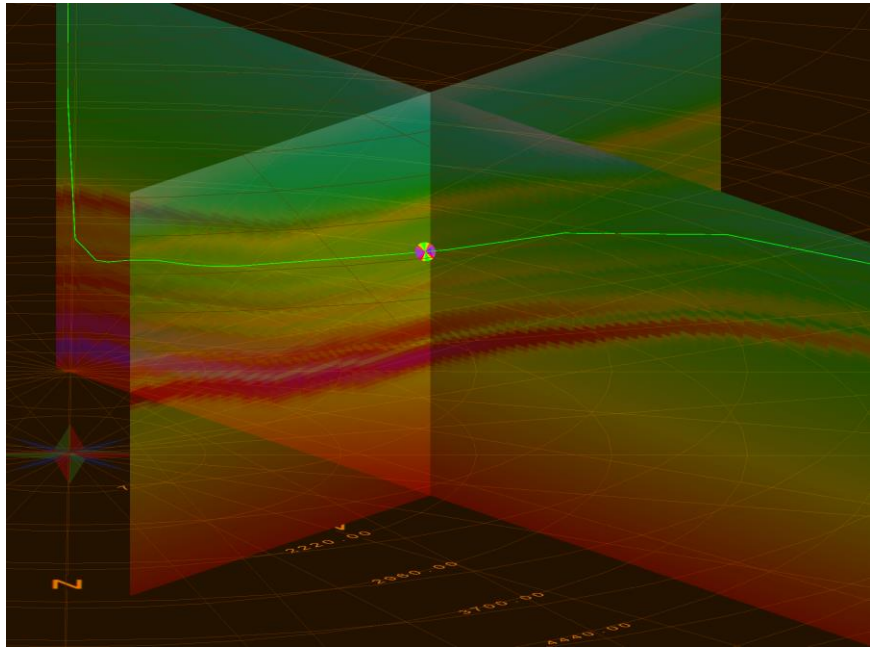
Fully 3D Modeling with GOHFER® Fracture Modeling Software



Example Total Stress Imported from 3D Model



Any layer in the 3D space can be displayed as a map view.
Reference well can be anywhere within the map. Green lines show direction of maximum horizontal stress and positions of transverse grids.

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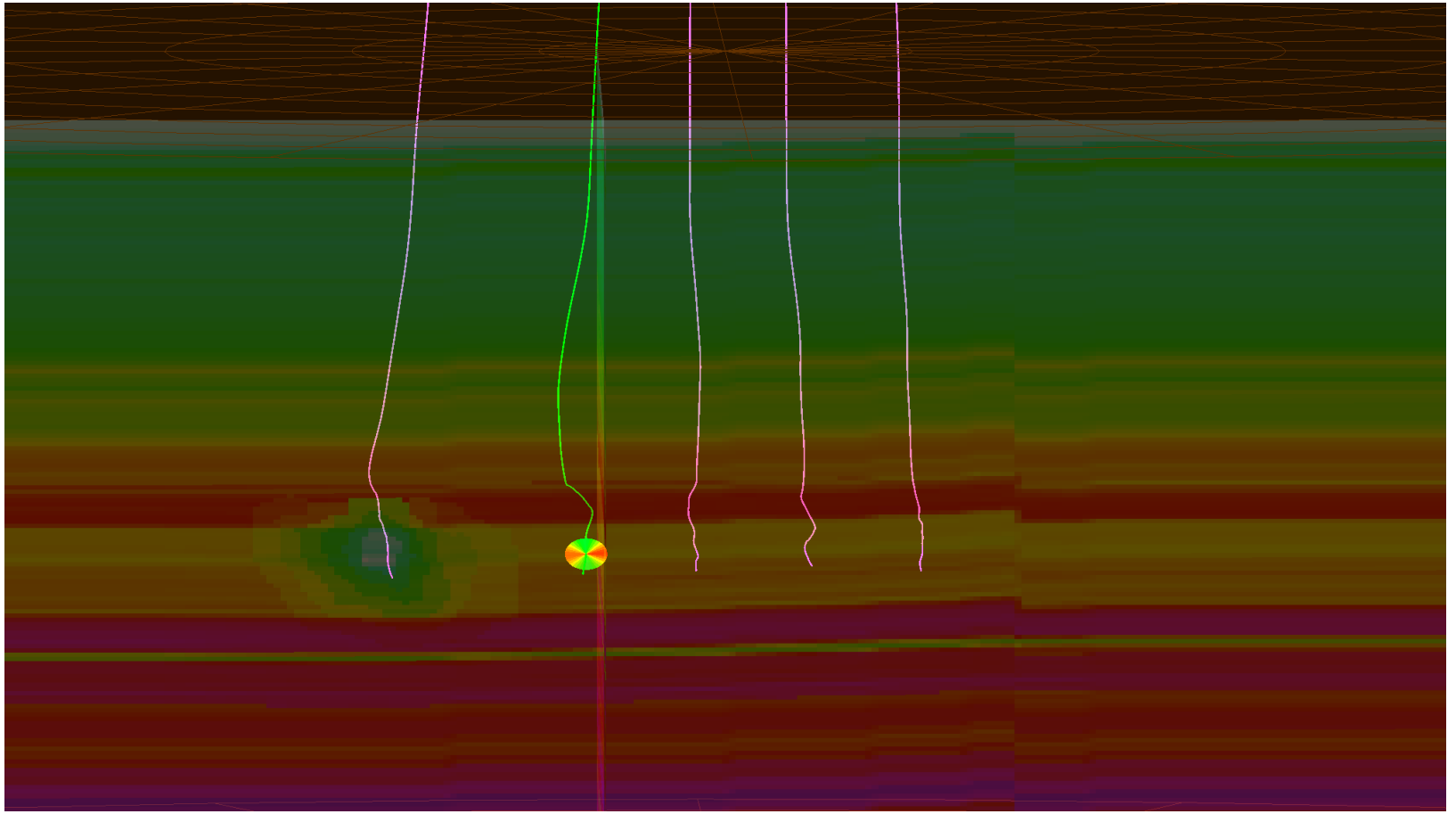
Offset Well Depletion Effect on Total Stress



Any grid property can be displayed in rotatable 3D view, with cross-sections at any point on any well. Note one fault displayed in the section.

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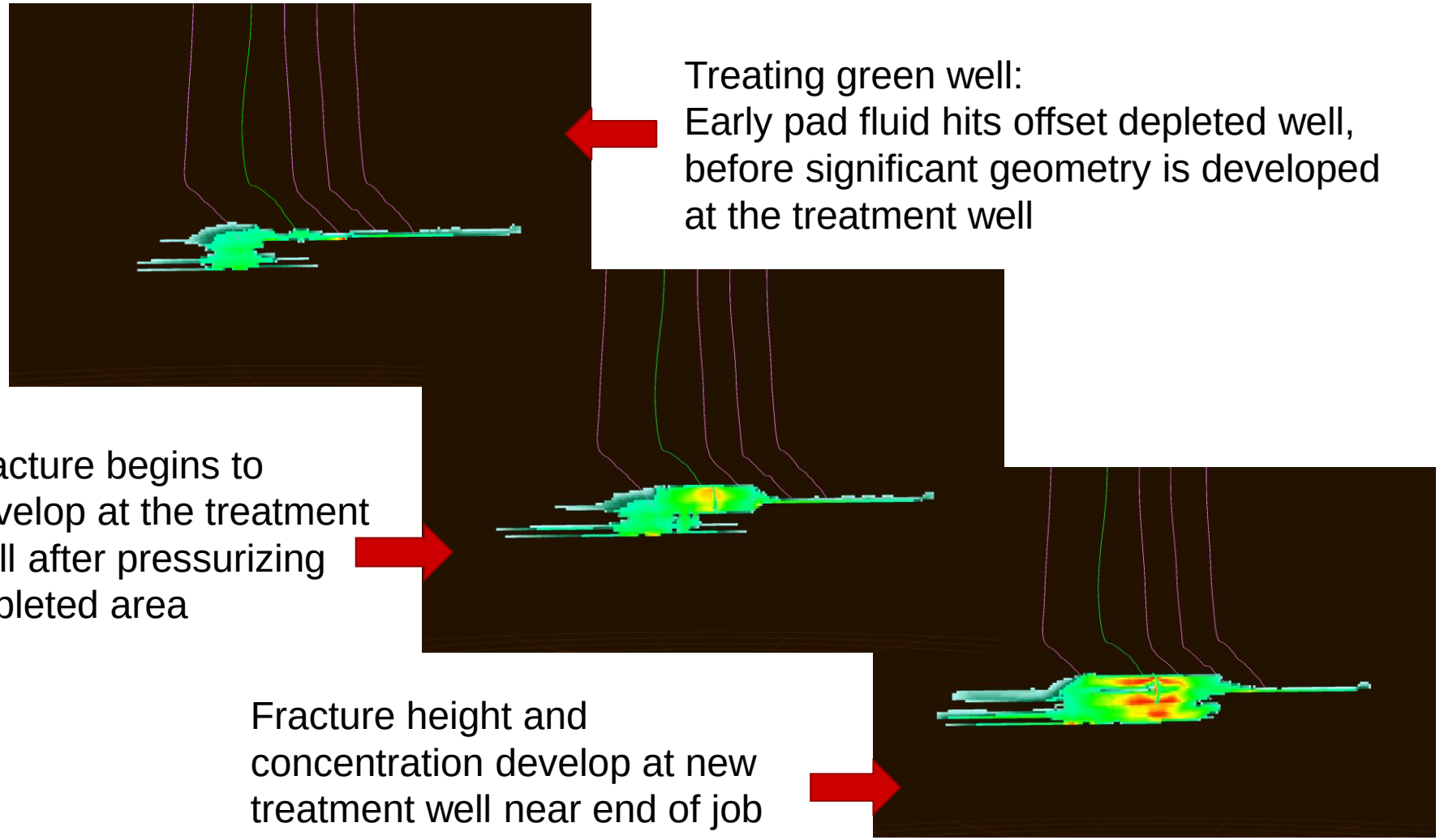
Evolution of Fracture Geometry with Offset Depletion



Treating green well:
Early pad fluid hits offset depleted well, before significant geometry is developed at the treatment well

Fracture begins to develop at the treatment well after pressurizing depleted area

Fracture height and concentration develop at new treatment well near end of job

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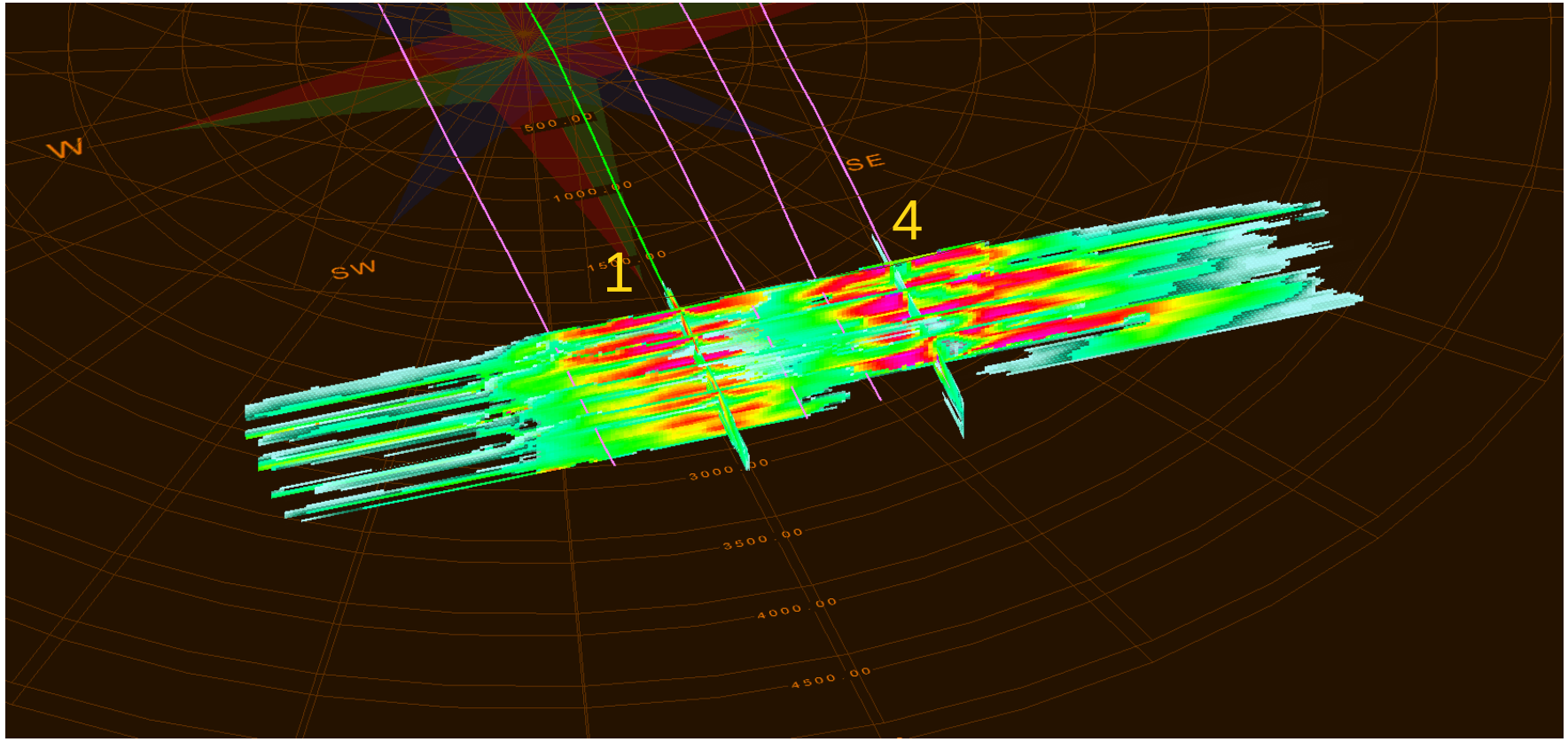
Zipper-Frac Interference



Interference (zipper frac) between wells 1 and 4 cause fracture asymmetry

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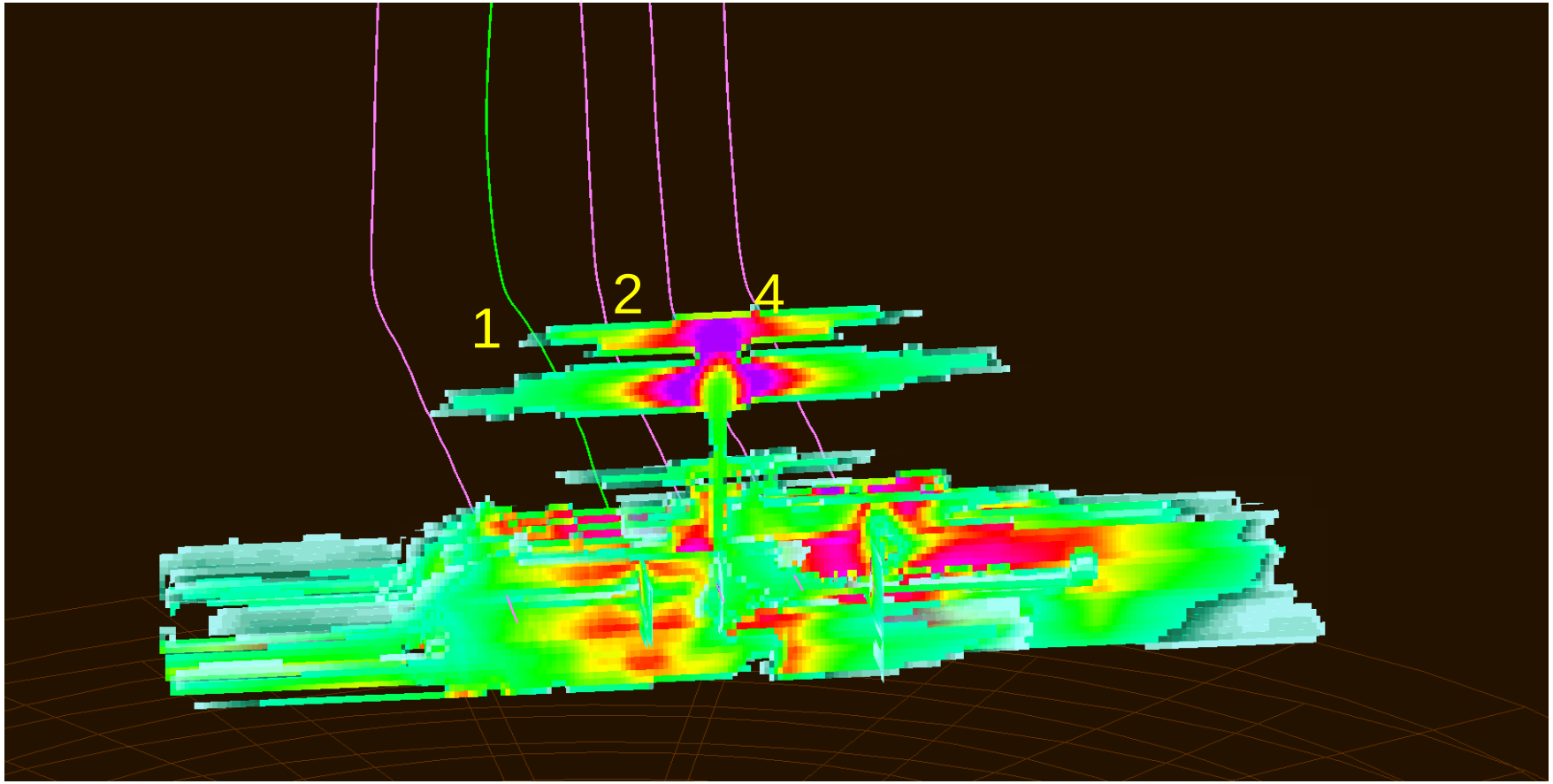
Interference Causing Height Growth



Later fracture treatment on well 2, confined by wells 1 and 4, drives height growth. Timing between fracs is critical.

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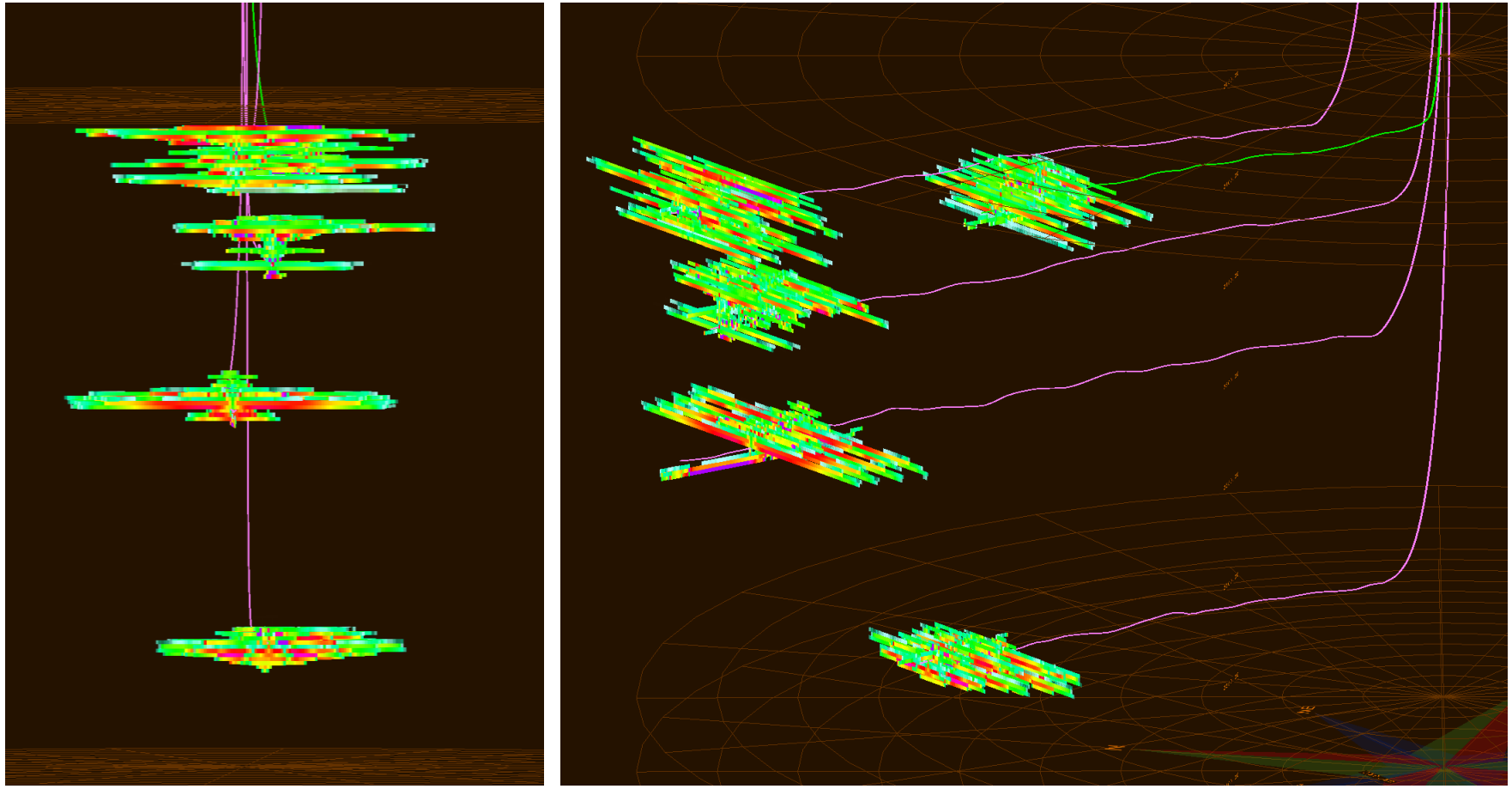
Any Number of Well Layers, Wells, and Stages can be Modeled



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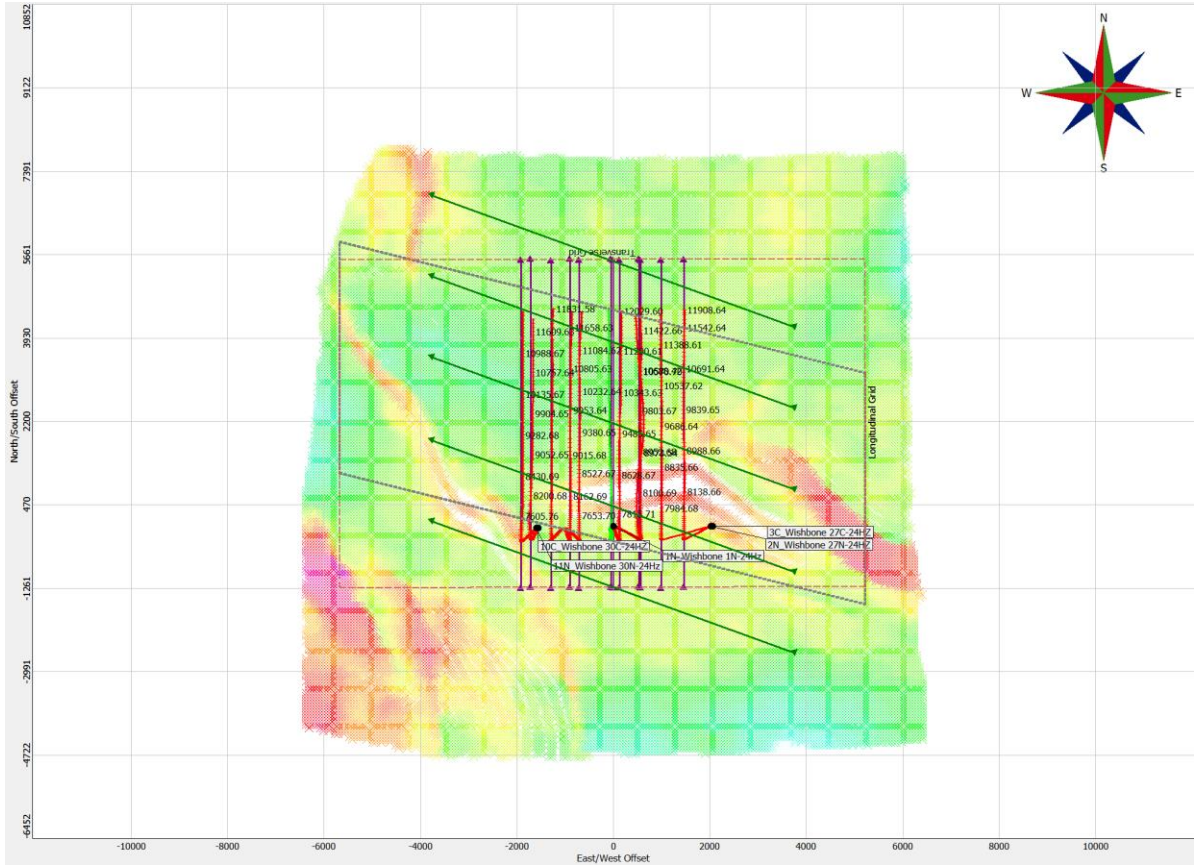
With Great Power Comes Great Responsibility

- All wellhead locations, surveys, surface elevations, and coordinate systems must be specified, and must be consistent
- Metric projects are assumed to have 3D space in UTM coordinates
- “Oilfield” projects are expected in State-Plane coordinates
- Complete earth-space models are preferred



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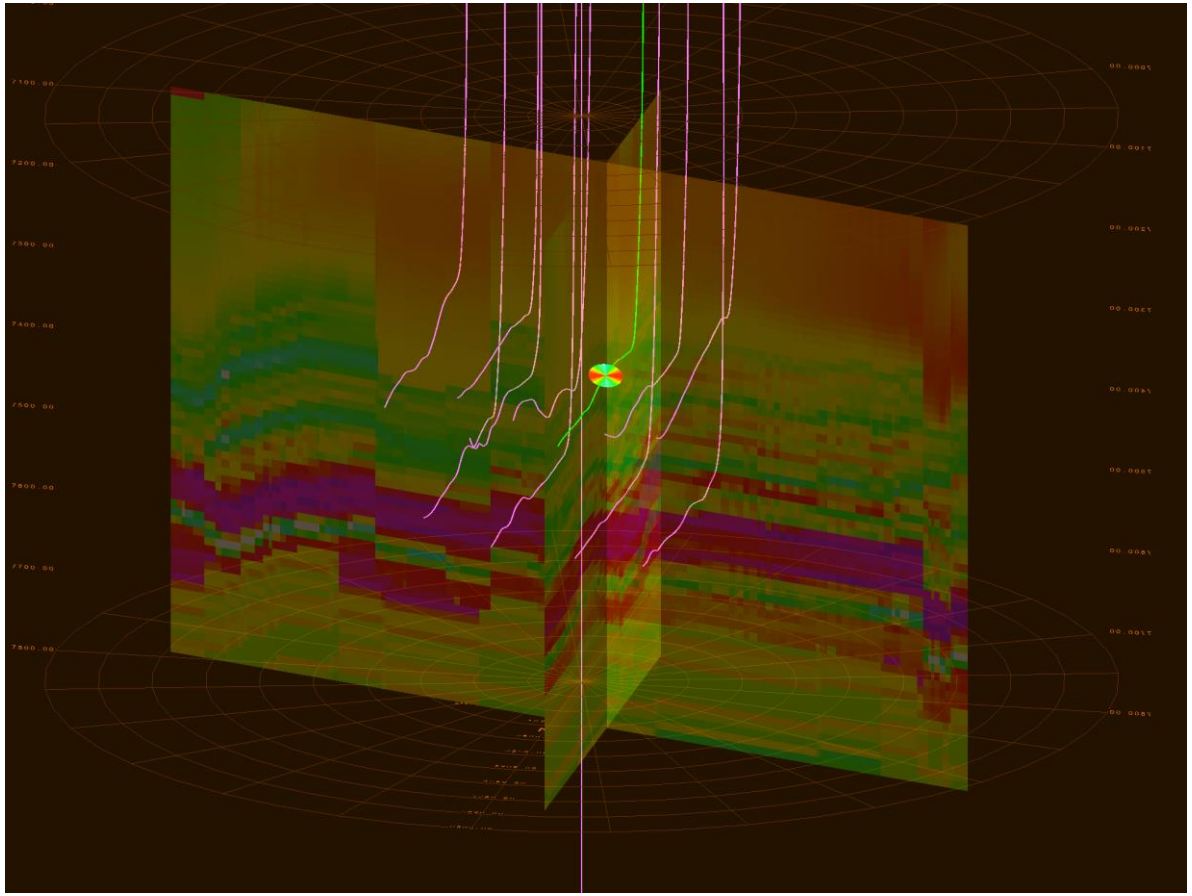
Complex Geology, Well Trajectory, and Completion Choices

- Reservoir and mechanical properties are computed from whatever data is supplied in the 3D model input, and distributed in space.
- All functions in the current GOHFER LAS processing can be applied to the 3D model imported data.



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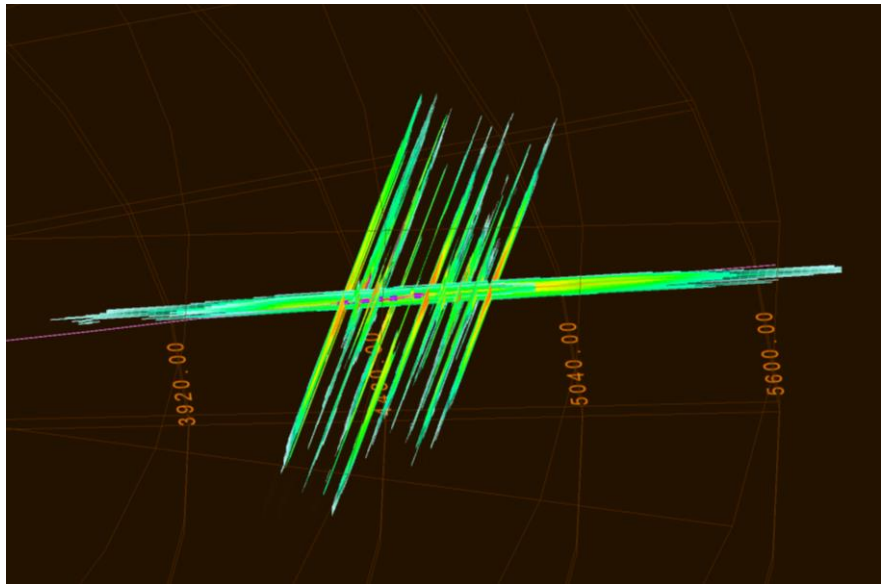
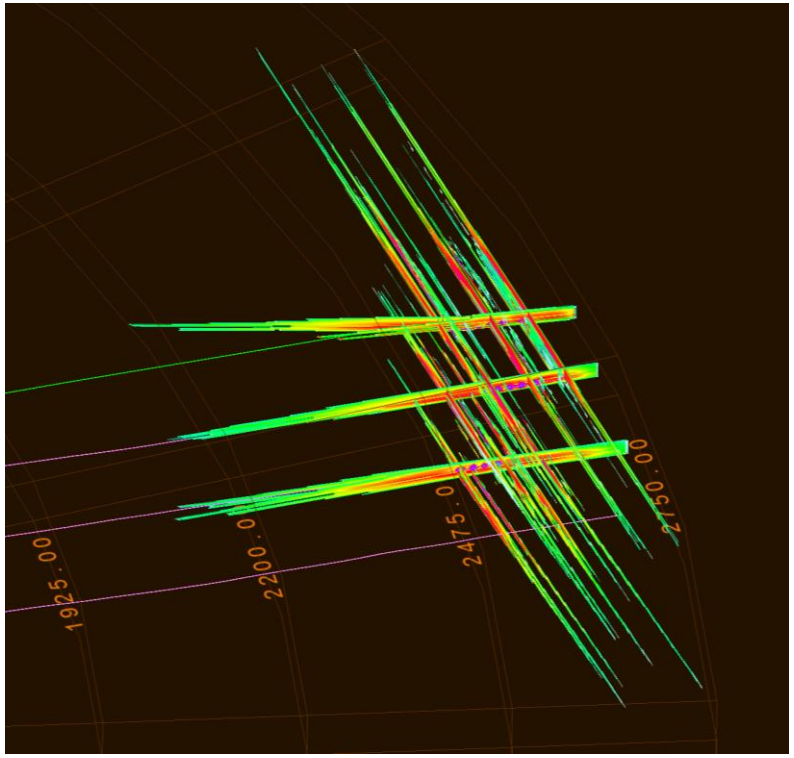
Fracture and Stage Stress Shadowing

Stress interference within a frac stage, and between stages, on multiple wells, is modeled correctly. Asymmetric and non-orthogonal fractures are simulated.





Both longitudinal and transverse, asymmetric and off-angle fractures are simulated in simultaneous development and interaction. Order of treatments, and timing between treatments affects the results.

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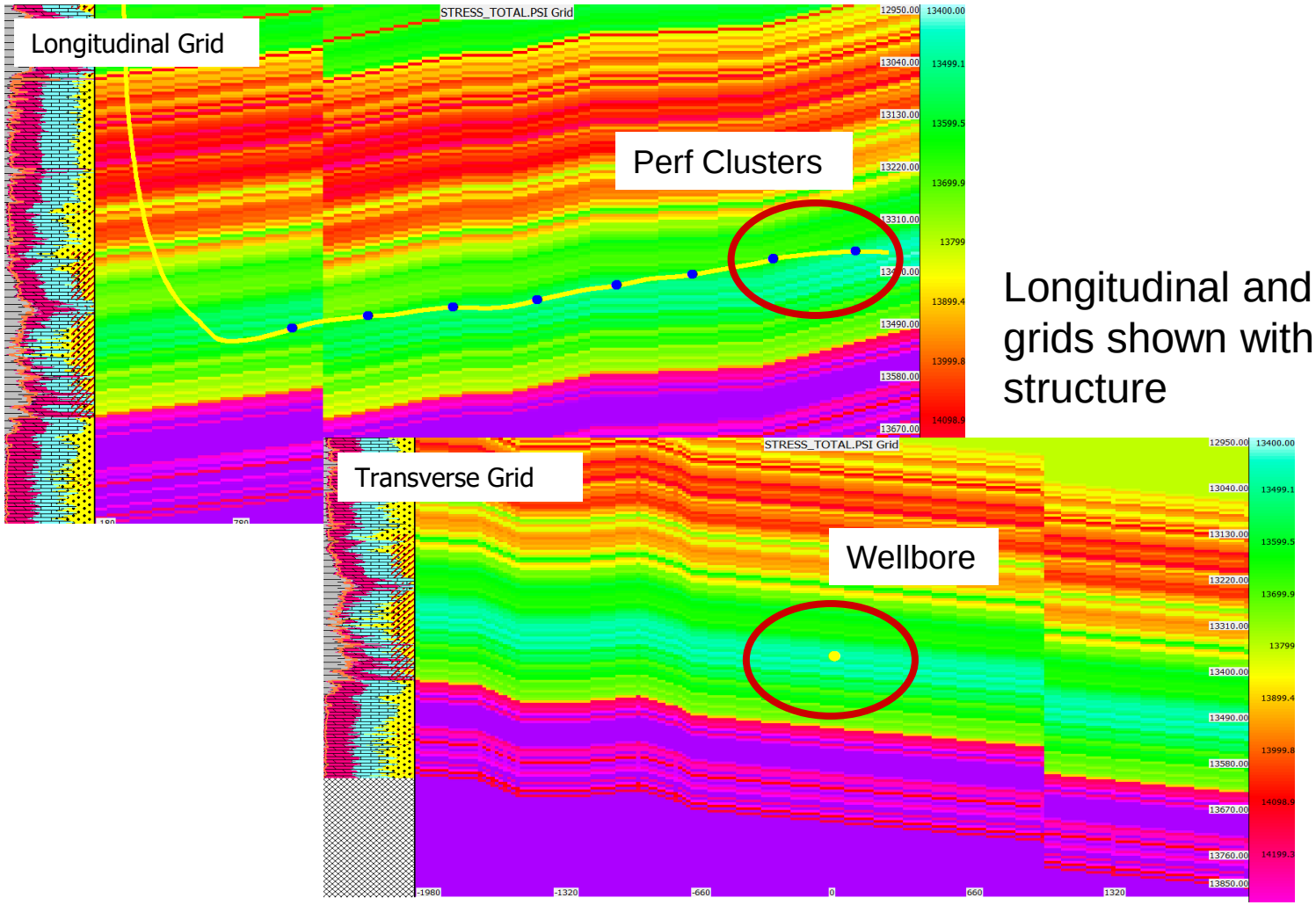
Horizontal Multiple Transverse Fracture Capability



Longitudinal and transverse grids shown with 3D geologic structure

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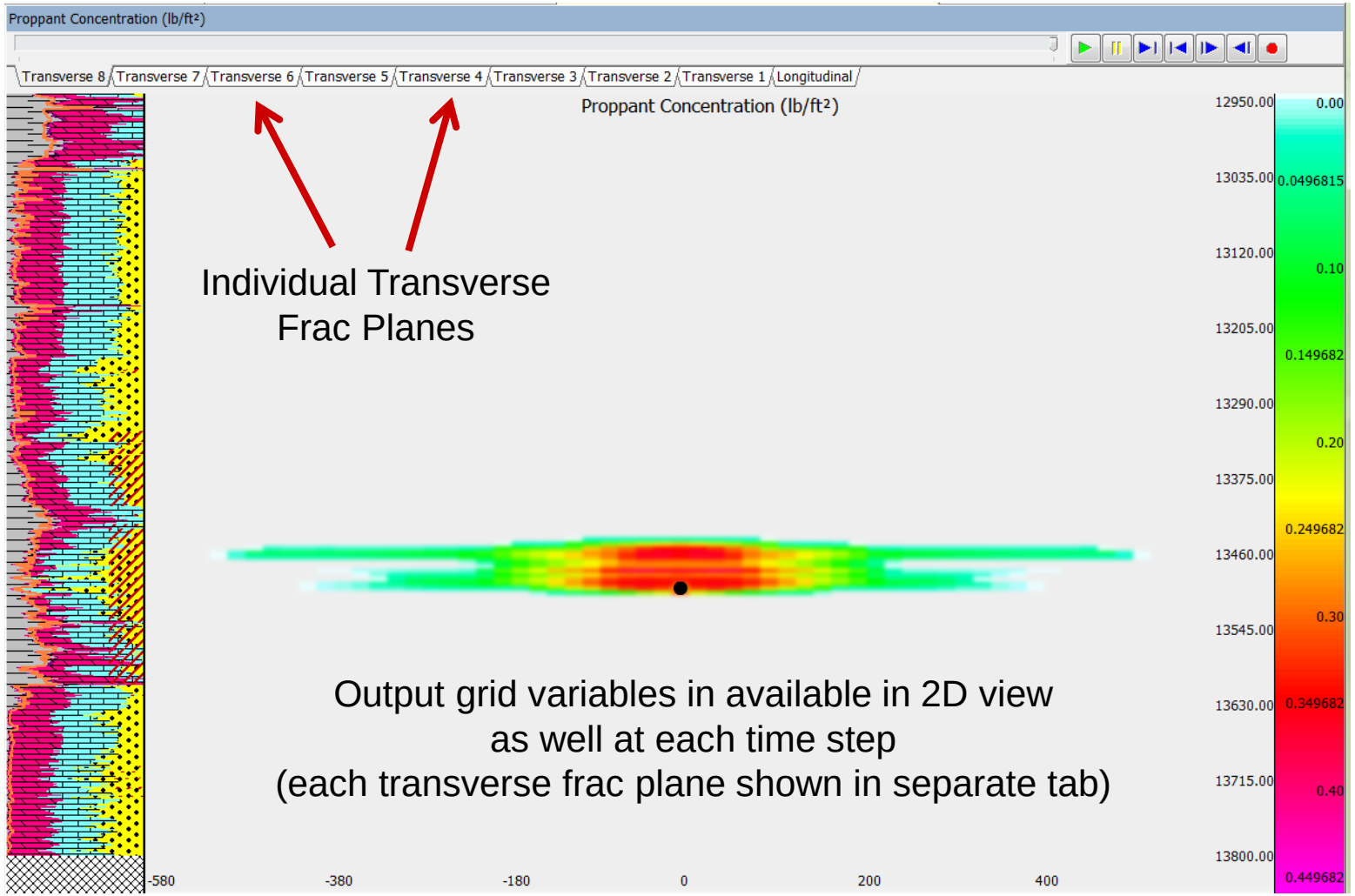
Horizontal Multiple Transverse Fracture Capability



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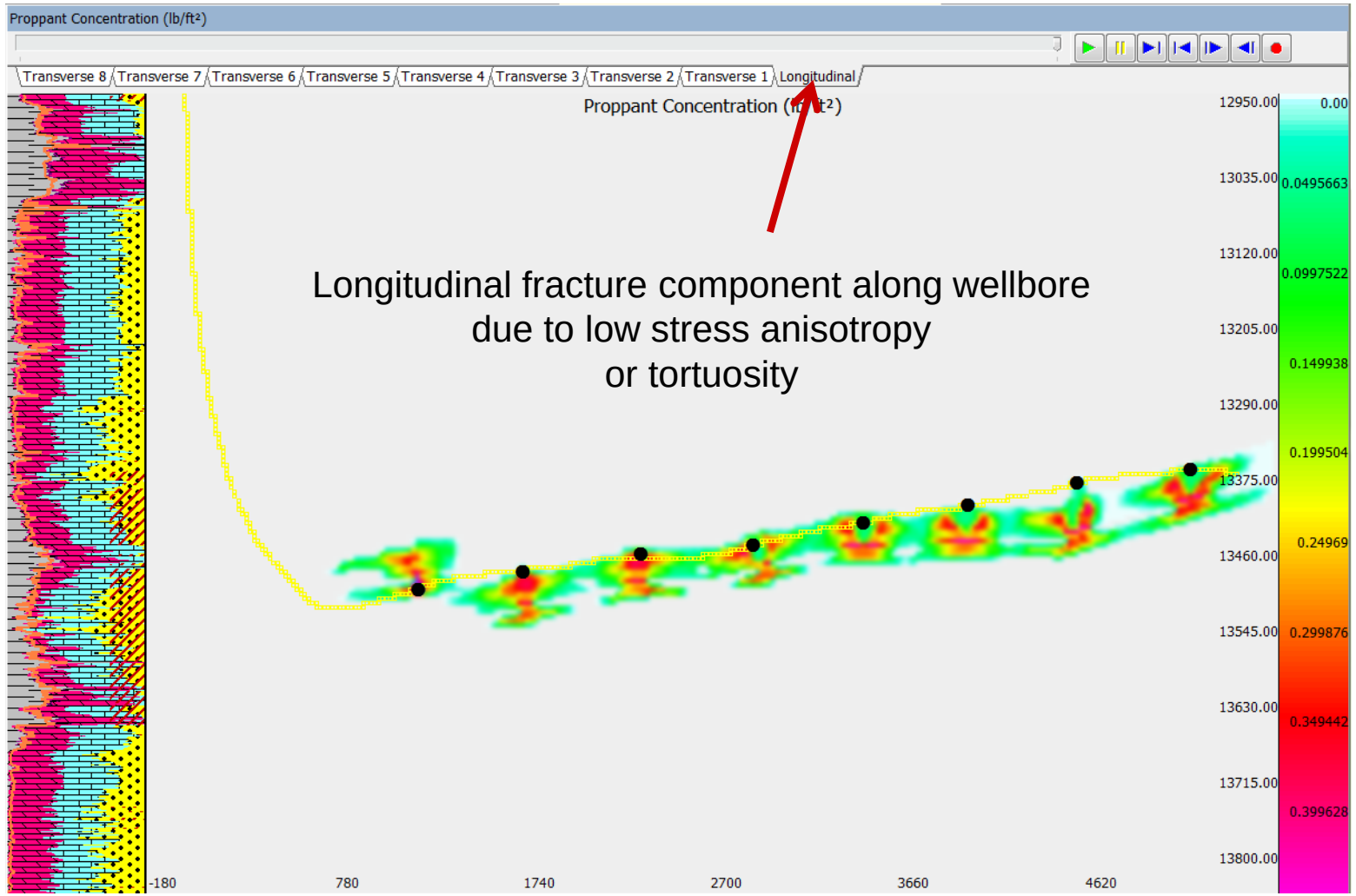
Horizontal Multiple Transverse Fracture Capability



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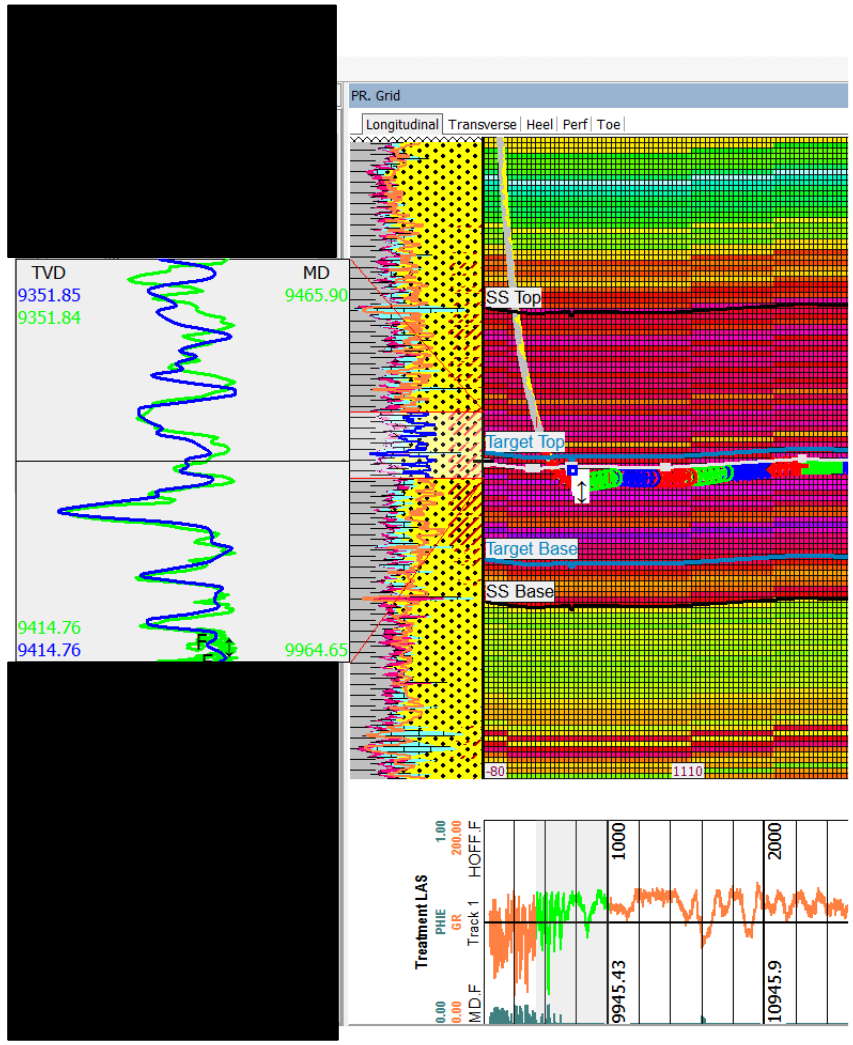
GOHFER® Fracture Modeling Software
Transverse Fracture Capabilities

- Full log processing for treatment and pilot wells
- Complete injection pressure diagnostic analysis for calibration of stress and determination of leakoff and reservoir properties
- Direct import of 3D deviation survey (inclination & azimuth) for treatment and pilot wells
- Full 3D geo-mechanical earth model input (from Petrel GSLIB file) or optional input of 2D surface map with reference well logs
- Ability to model both complex geologic longitudinal and transverse structure
- Ability to define azimuth of max stress and stress anisotropy
- Injection into multiple perforation clusters with limited-entry diversion, perf erosion, and fracture interference
- Multi-well/multi-stage/multi-cluster modeling capability for plug & perf or ball drop simulations
- Variable inter/intra-stage fracture stress shadow interference between each fracture and stage on each well
- Includes longitudinal fracture component along wellbore caused by tensile tangential stress
- Fracture orientation determined by stress azimuth, independent of well direction
- Models crossflow during pumping and after shut-in, up to closure
- Fully rotating 3D view of all output variables updated live during model run

Geosteering

- Geosteering can be used to correlate between the horizontal GR (gamma ray) from the treatment well with the vertical TVD GR from the reference well. This can be used to automatically build geologic structure along the lateral as well as to place the wellbore in its actual location in the reservoir.



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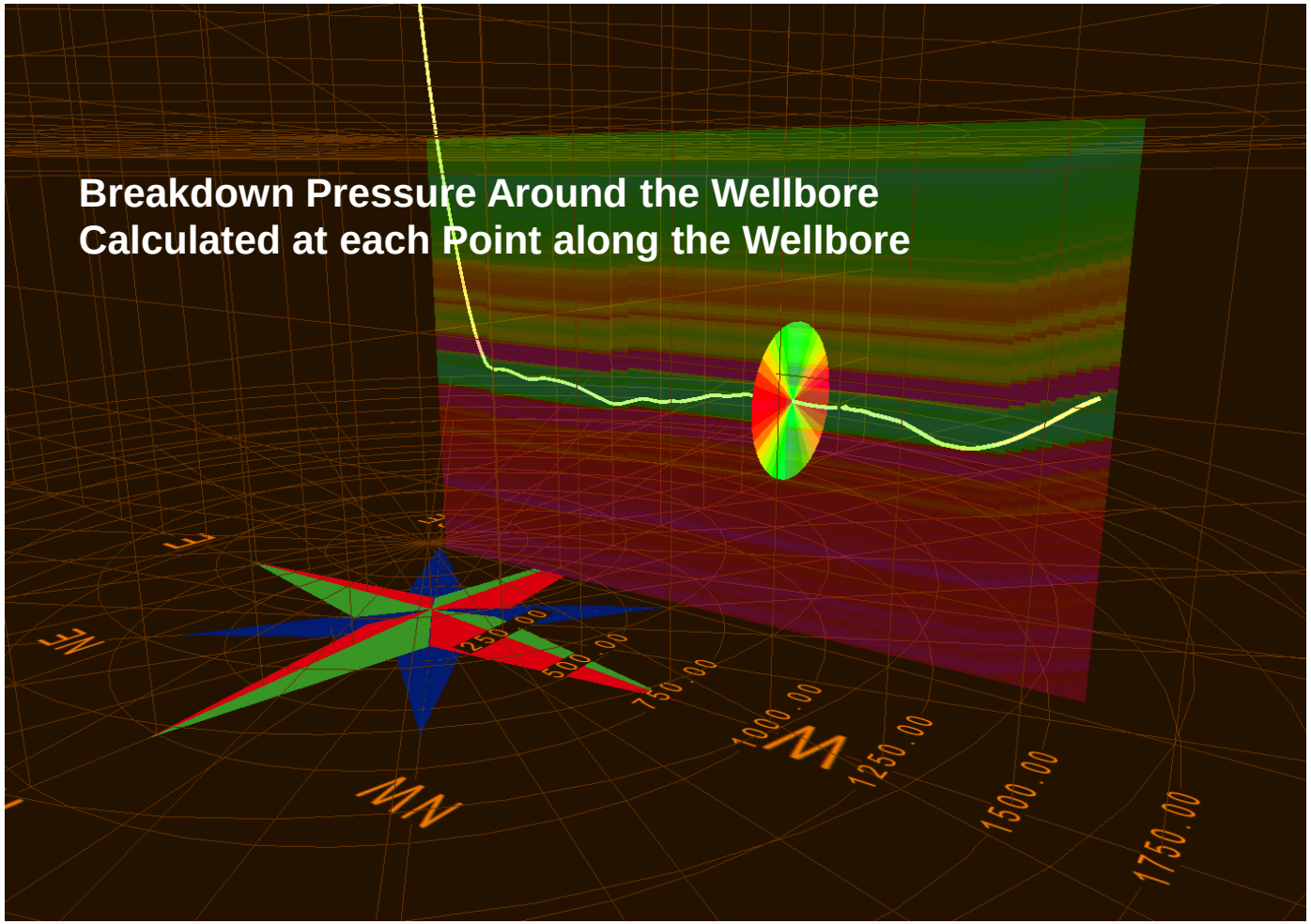
Wellbore Breakdown Pressure & Orientation Calculations



Inputs for stress anisotropy and azimuth of max stress

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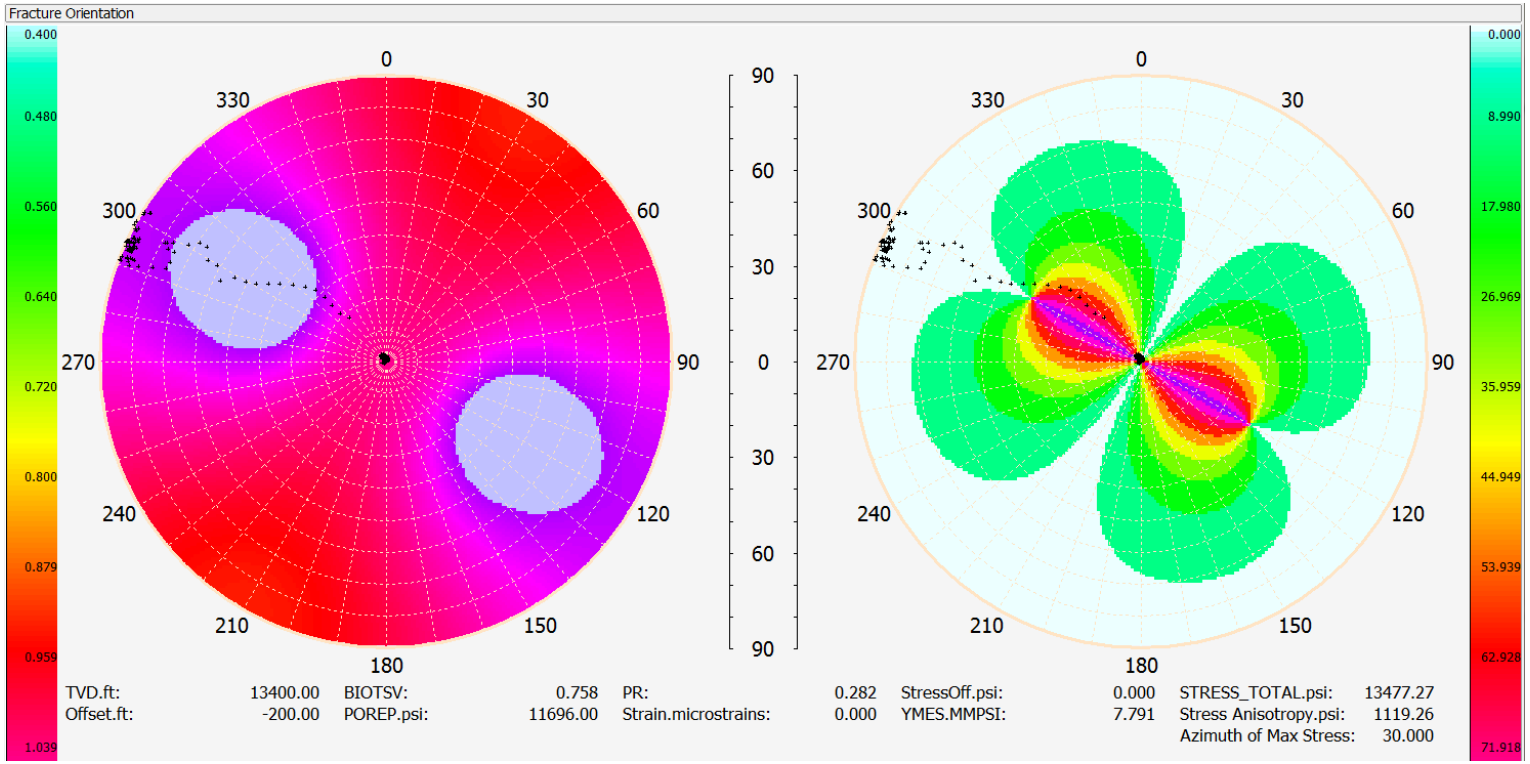
Wellbore Breakdown Gradient & Breakdown Angle Calculations



Calculated throughout the grid to evaluate potential landing zones for the lateral and optimum perf locations for the most efficient fracs

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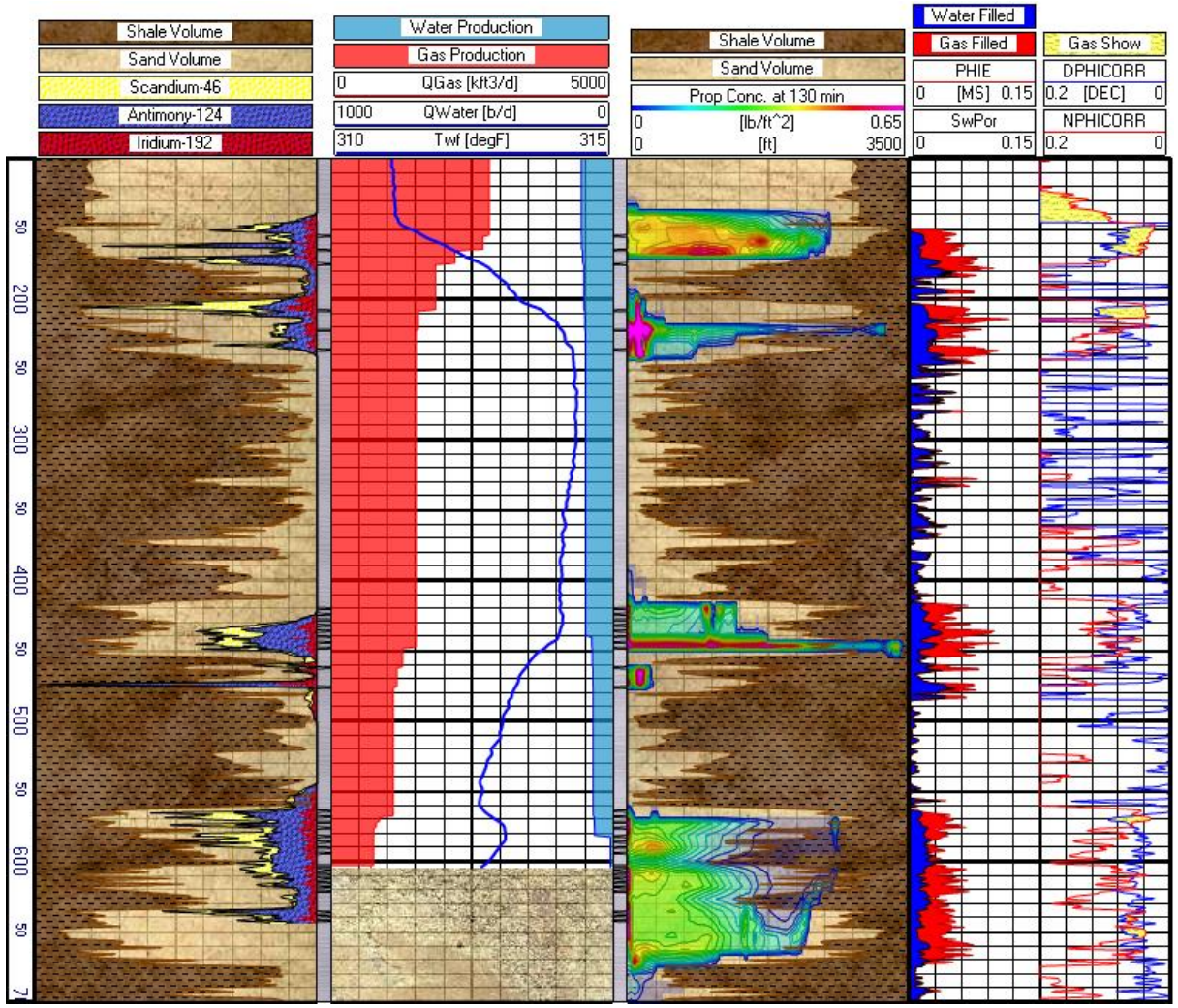
Production Forecasting: Proppant Selection and Dynamic Conductivity

- Integrate proppant pack performance with reservoir transient in-flow performance
- Single phase Agarwal-Gardner type-curve model for finite-conductivity fracture
- Given a set of fracture and reservoir characteristics, the effects of:
  - proppant type and concentration
  - proppant embedment
  - non-Darcy flow
  - multiphase flow
  - gel cleanup
  - are systematically evaluated to make realistic post-frac production predictions.
- Also contained is the most comprehensive database of the physical and performance characteristics of common proppants
- Horizontal (longitudinal and transverse) fracture production and conductivity calculations w/ economic optimization
- Composite production capability to compute total well production from multiple stages
- Acid frac conductivity
- NPV calculations

Completion Diagnostics: GOHFER® Software Results Well Supported By Radioactive Tracer Results



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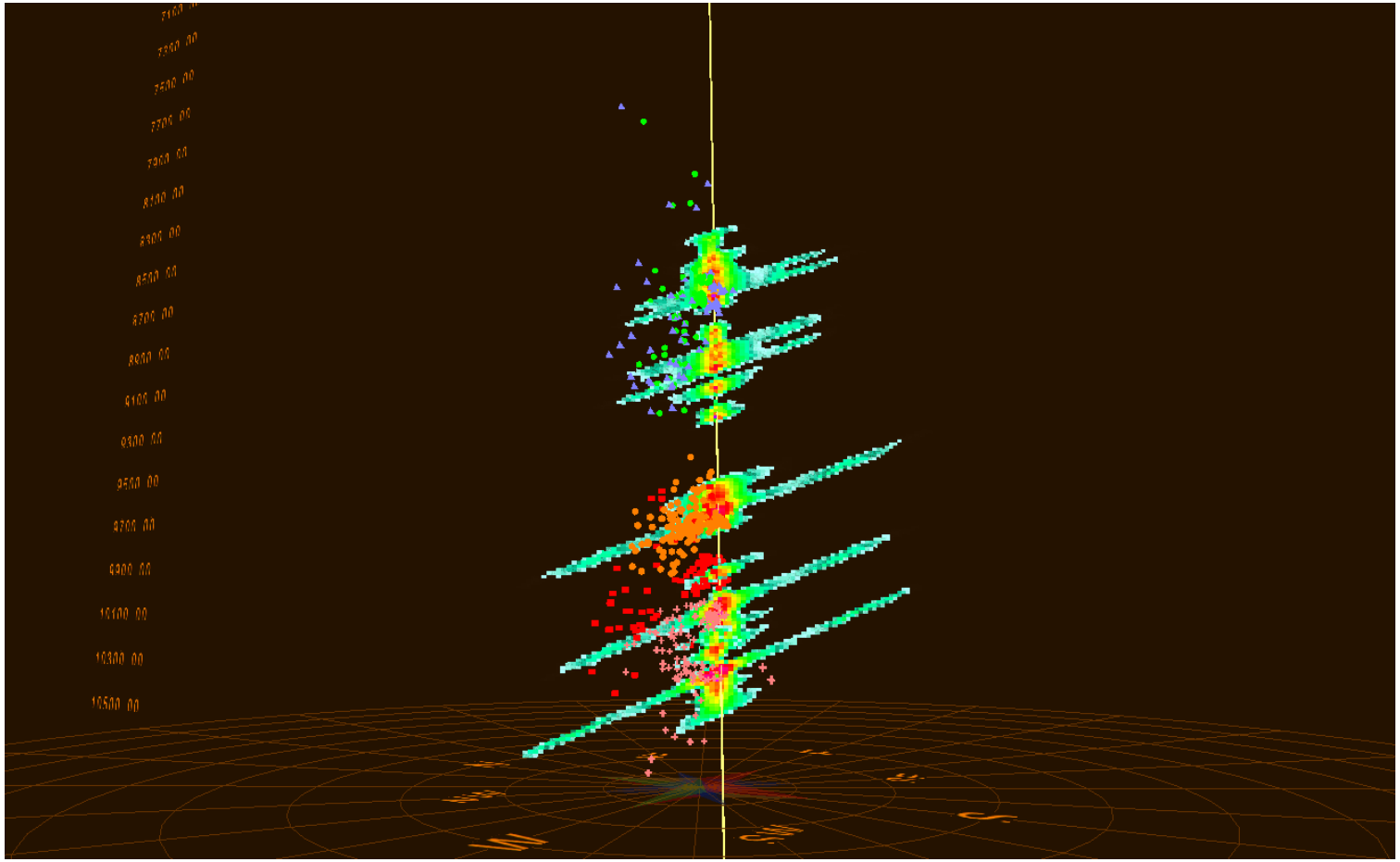
Completion Diagnostics: Microseismic Data



Ability to import microseismic data in 3D view and compare with GOHFER output

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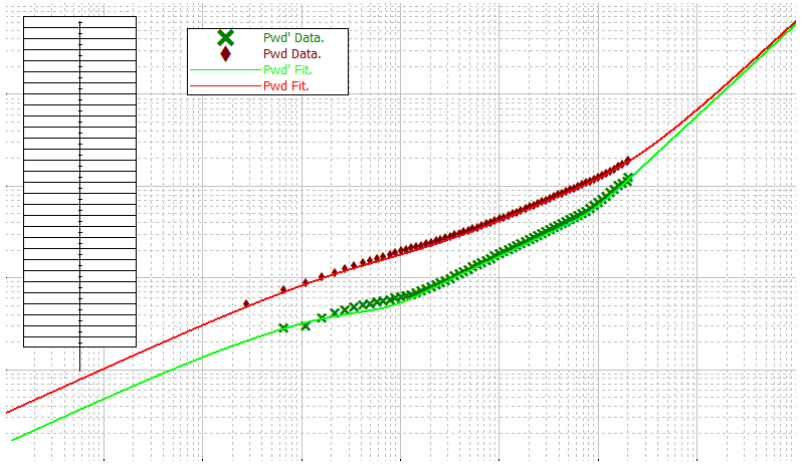
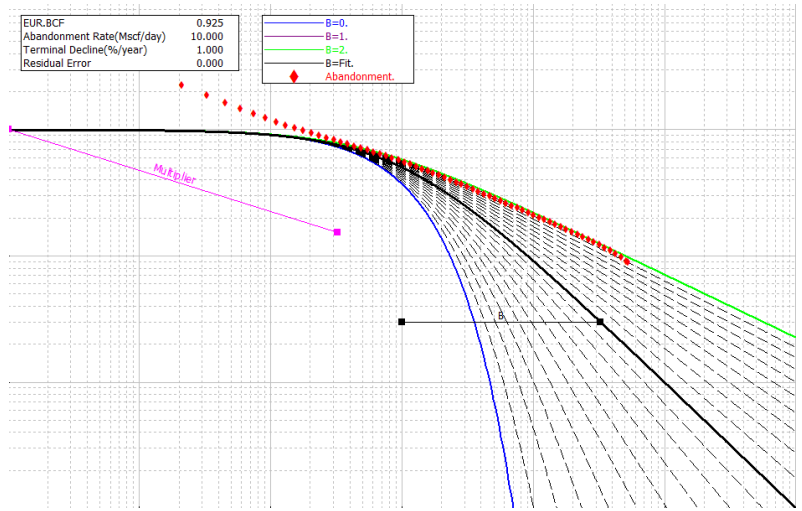
GOHFER® Software Production Analysis (GPA)

- Uses actual production data to analyze post-frac performance and assess stimulation effectiveness.
- Includes rate transient type-curve analysis, decline curve analysis, production forecasting to ultimate recovery and flow regime identification.
- Determines fracture spacing and effective well spacing for horizontal wells along with the fraction of the lateral producing.





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Distinguishing GOHFER® Software Characteristics

- Data Input
  - GOHFER Software imports log data directly and inputs rock properties including elastic moduli, porosity, permeability, fracture extension criteria, and stress averaged over a user specified log height.
- Stress Profile
  - GOHFER Software takes digital LAS file input data, computes rock elastic properties used to generate the closure stress profile
- Fracture Geometry
    - GOHFER Software fracture geometry is based on the assumption, backed by laboratory and field observations including microseismic evidence, that rocks slip and fail in shear
- Fluid/Proppant Transport
  - GOHFER Software iteratively couples the fluid pressure distribution in the fracture to the proppant concentration distribution

Distinguishing GOHFER® Software Characteristics

- Leakoff
  - GOHFER Software computes leakoff at each point on the fracture surface using local values of pressure differential, porosity, permeability, fluid viscosity, and time of exposure
- Effects of Secondary Shear Fractures
  - GOHFER Software incorporates the effects of secondary shear fractures and dilation of shear and existing natural fractures on leakoff through transverse storage and pressure-dependent permeability
- Fracture Conductivity & Post-Frac Production
  - » GOHFER Software fracture conductivity and post-frac production is based on the Stim-Lab database of proppant conductivity measurements at stress and temperature, using a cleanup model that includes gel damage and multiphase non-Darcy flow effects

THANK YOU