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Acknowledgements

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Project Goals

- DOE's NETL has set forth ambitious requirements for the next generation of natural fracture detection and prediction technologies.
  - Quantitative natural fracture characterization beyond the wellbore,
  - Natural fracture properties that can be directly input into a reservoir simulator.
- Goals for "Developing Next Generation Natural Fracture Detection and Prediction Technology" include:
  - Integrate basin modeling, geomechanics, discrete fracture network generation and reservoir simulation
  - Calibrate and validate methods using actual field data
    - Backcast calibration and validation at Table Rock
    - Backcast calibration at Rulison
    - Exploration validation in a new project area.

The Next Generation: Next Gen/NFI

- The Natural Fracture Integrator (NFI) combines diverse information from Geology, Seismic methods and Engineering into gridded, mappable input for use by a reservoir simulator.
- Core modules of NFI are:
  - Geomechanical Model (Poly 3D)
  - Discrete Fracture Network Generator (FracGen)
  - Reservoir Simulator (COMET, others)

The "Next Generation": Next Gen/NFI

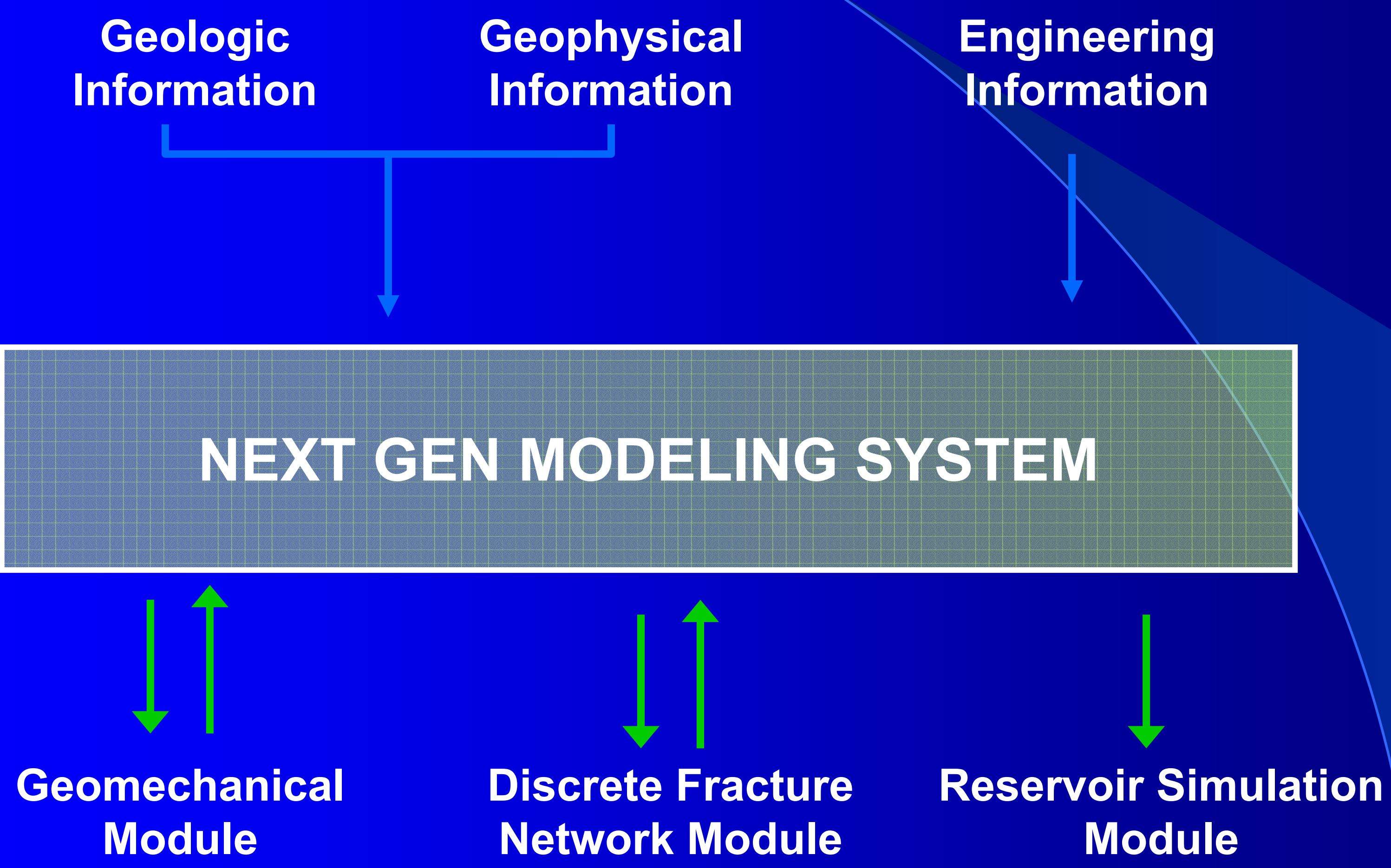


Table Rock Field Validation Area

- Table Rock Field was selected for the following reasons:
  - Seismic data is available and interpreted
  - Basic style of faults and fractures are understood
  - Data from both horizontal and vertical wells are available for fracture analysis
    - FMI logs
    - Core data
  - Production history is available
    - Decline analysis of preliminary Kh calculations
    - Production history available for validation of simulation model.

Table Rock Field Site

The validation site is located on the northeast flank of the Rock Springs Uplift where the Frontier Formation is overpressured and deformed by basement involved faulting related to regional Laramide shortening.

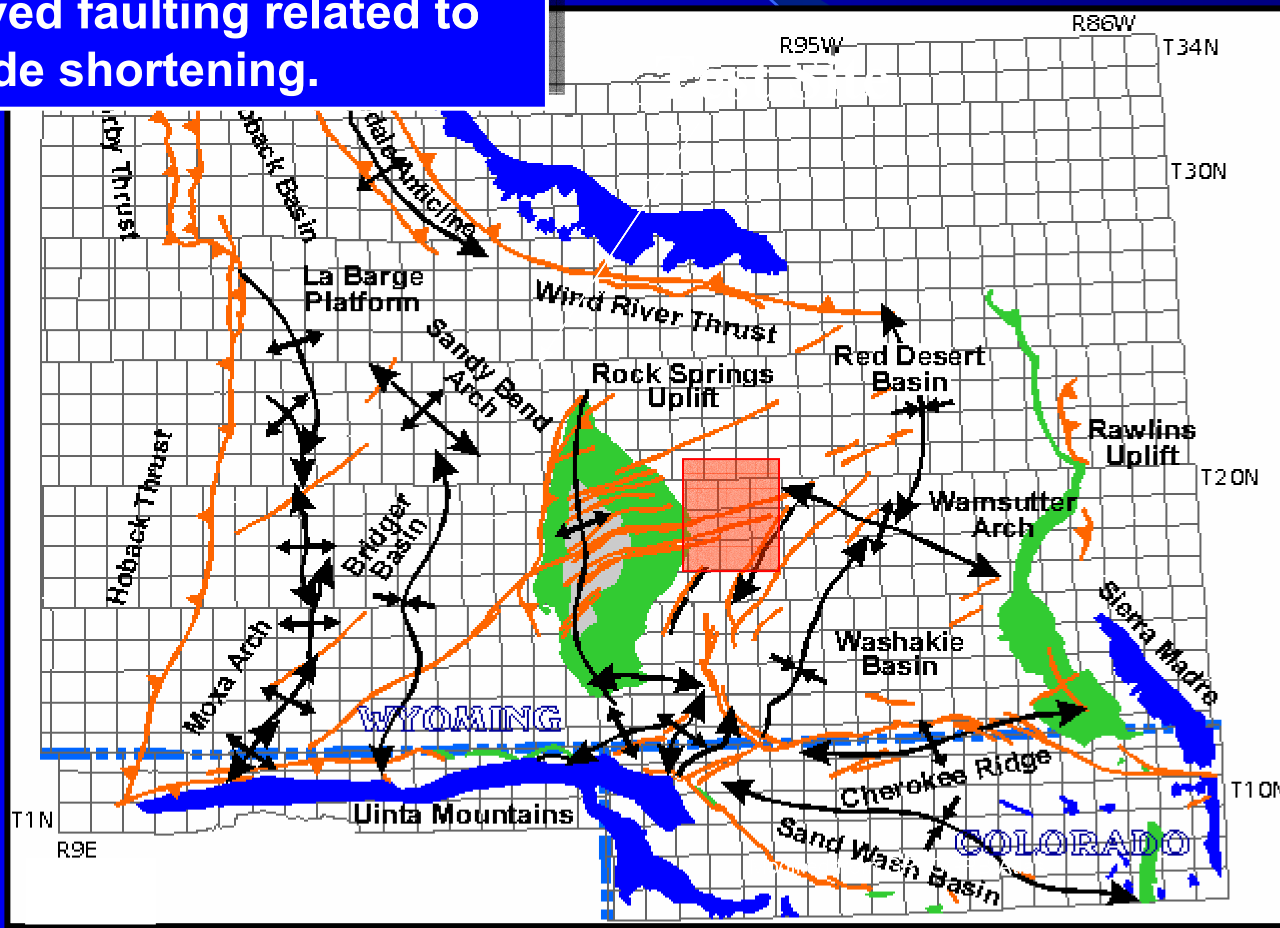
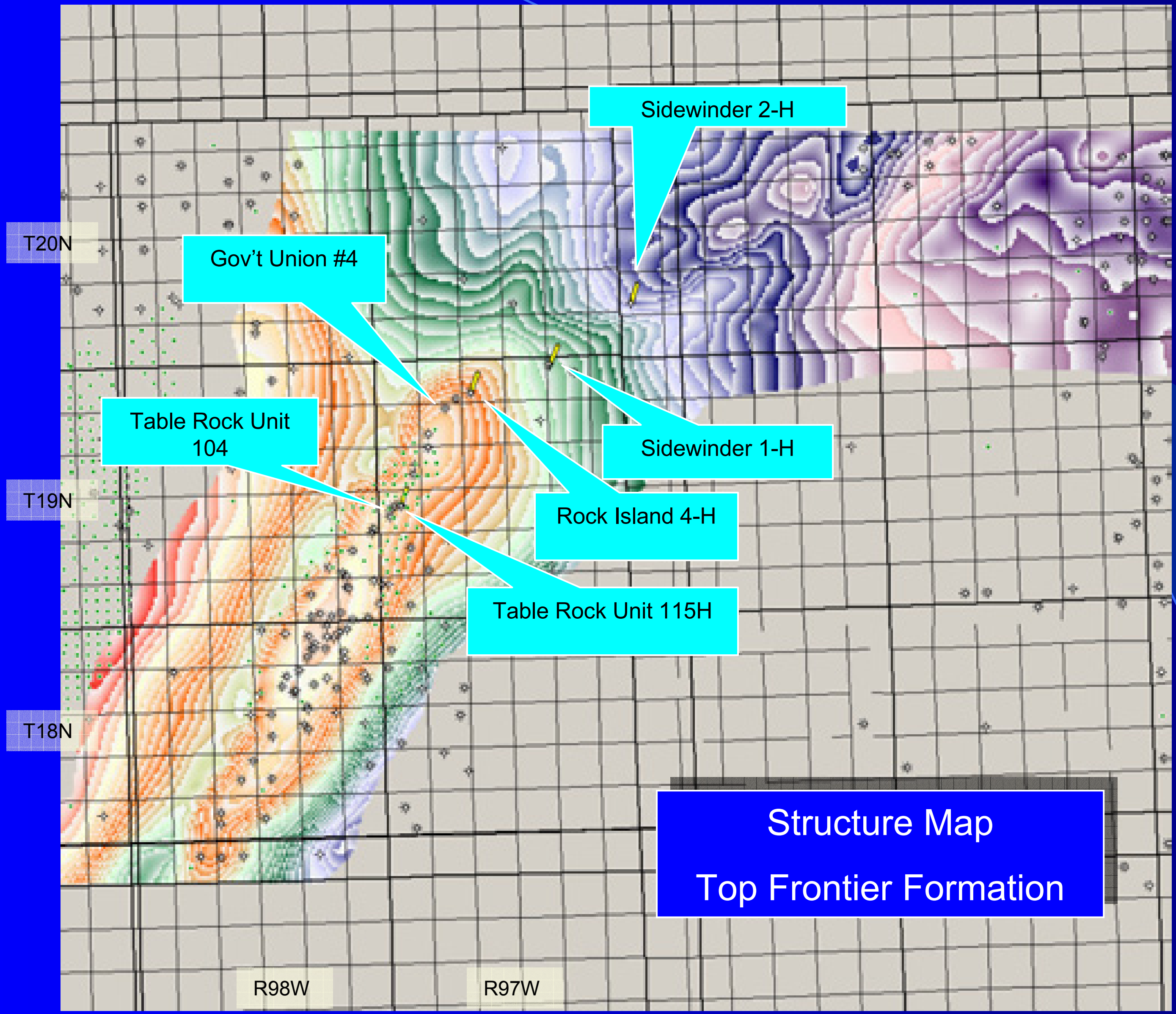
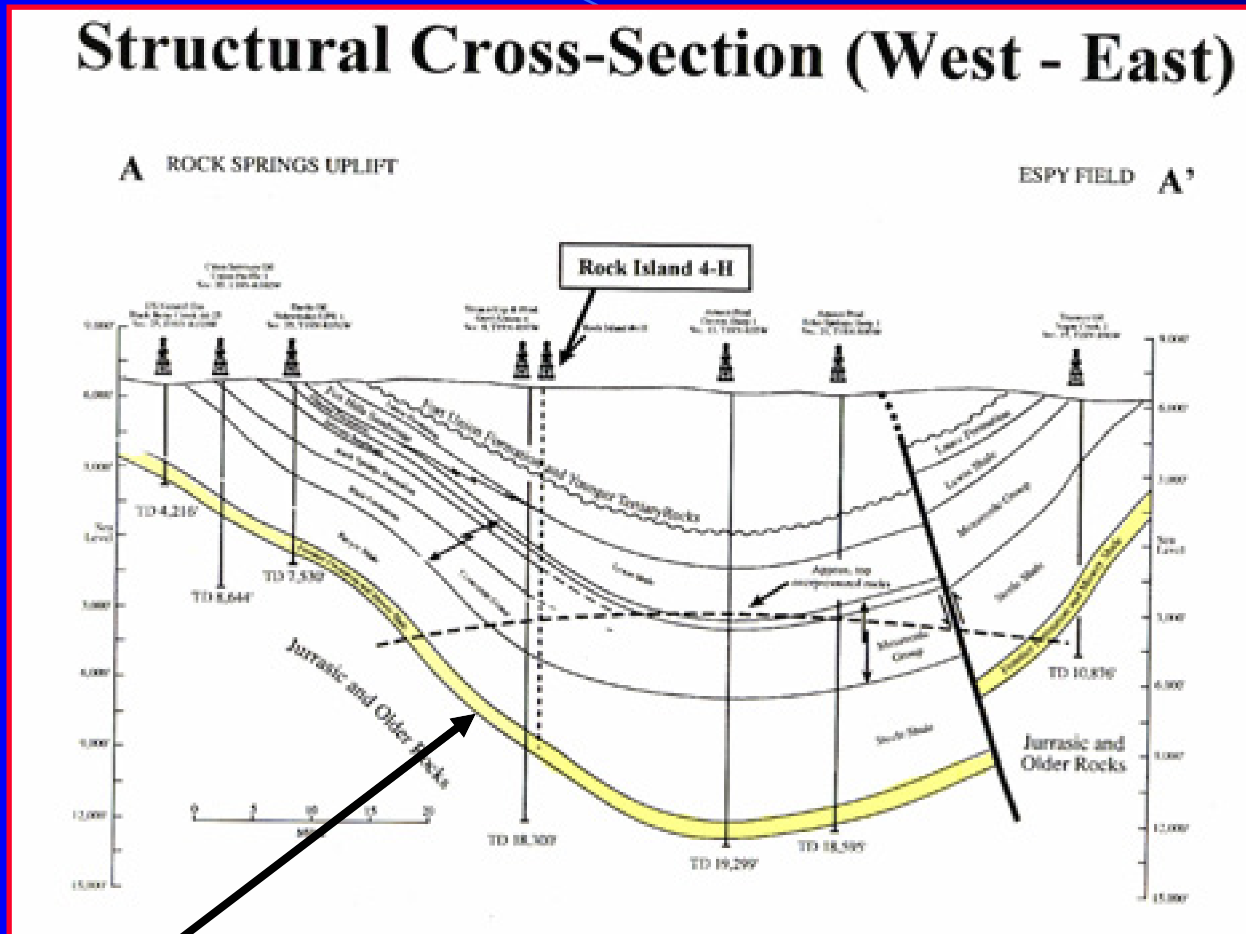


Table Rock Field Site



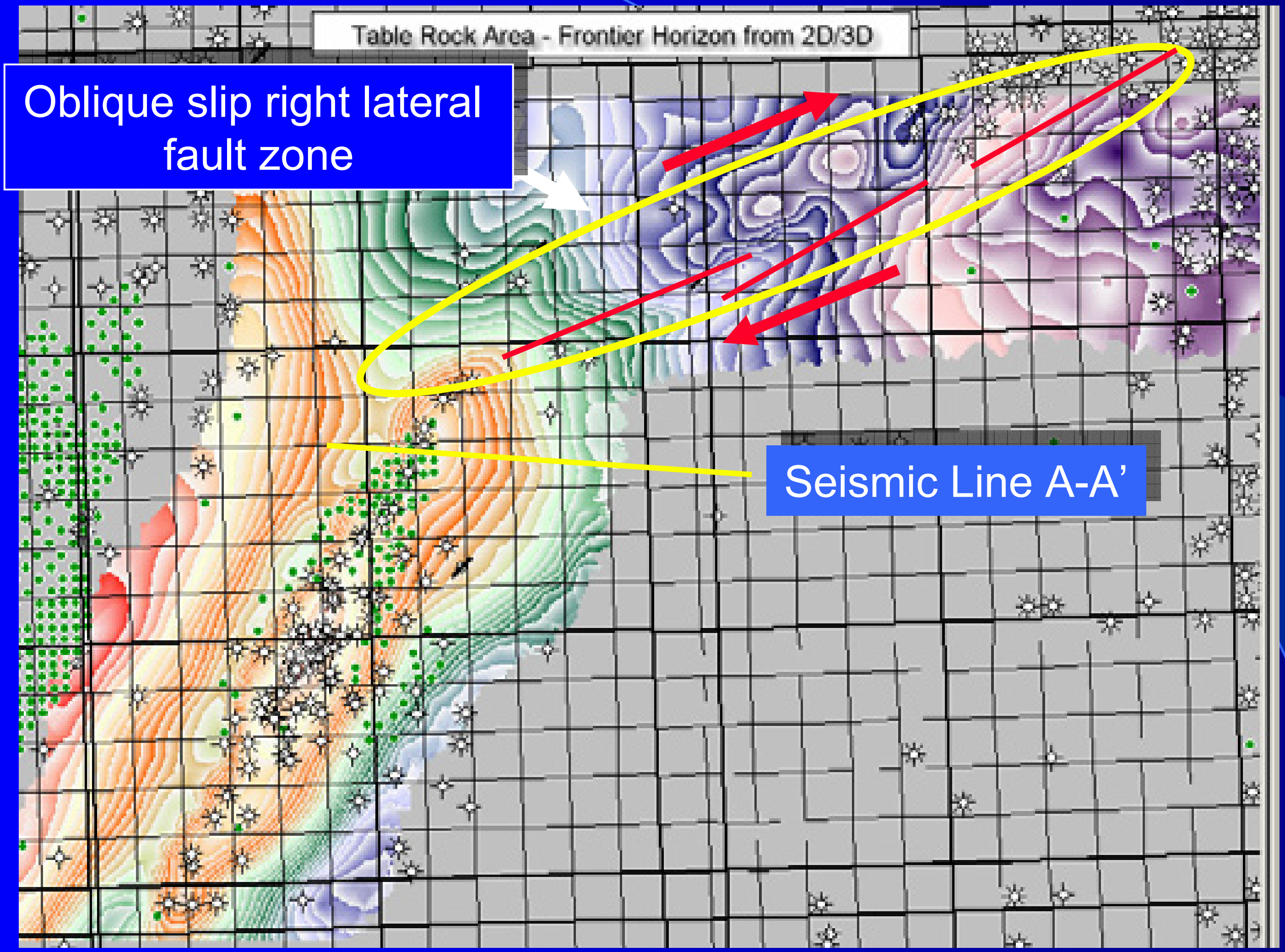
Eastern GGRB Regional Cross-Section



The Frontier Fm at Tablerock is a thin, tight heterogeneous, fractured sandstone reservoir

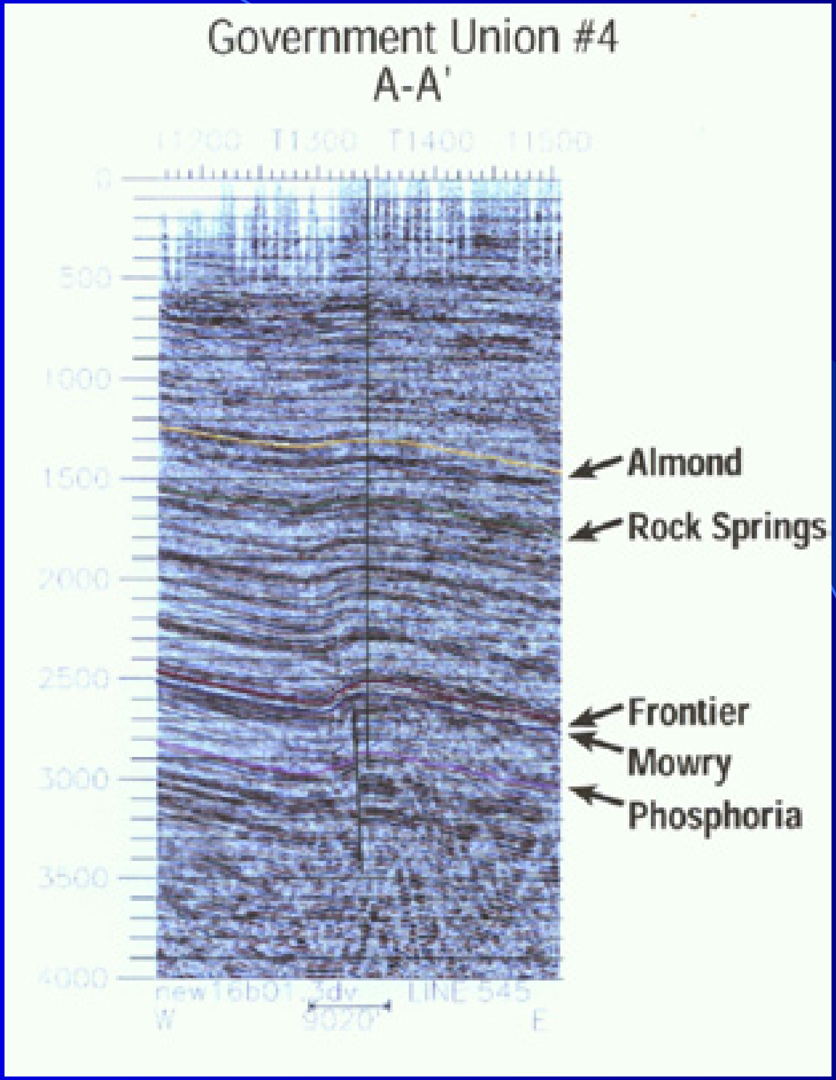
Modified after Kristynik and Lim, 1999

Frontier Depth Structure



Government Union #4 E-W Seismic Transect

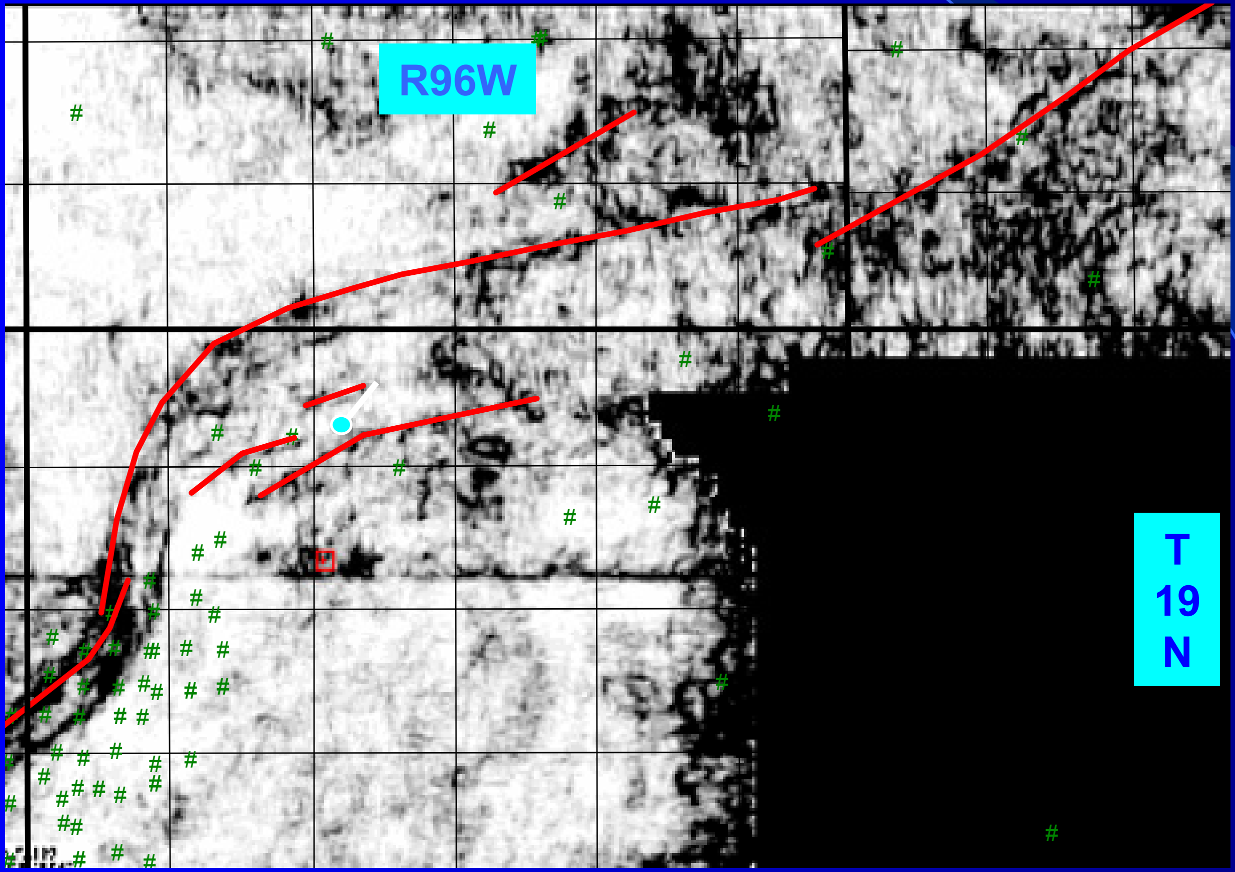
W-E Seismic section near the crest of the Table Rock structure shows a simple forced fold overlying a deep, high angle reverse fault that does not cut the Frontier horizon directly.



Dejarnett et al, 2001

DETAILED FAULT MAPPING

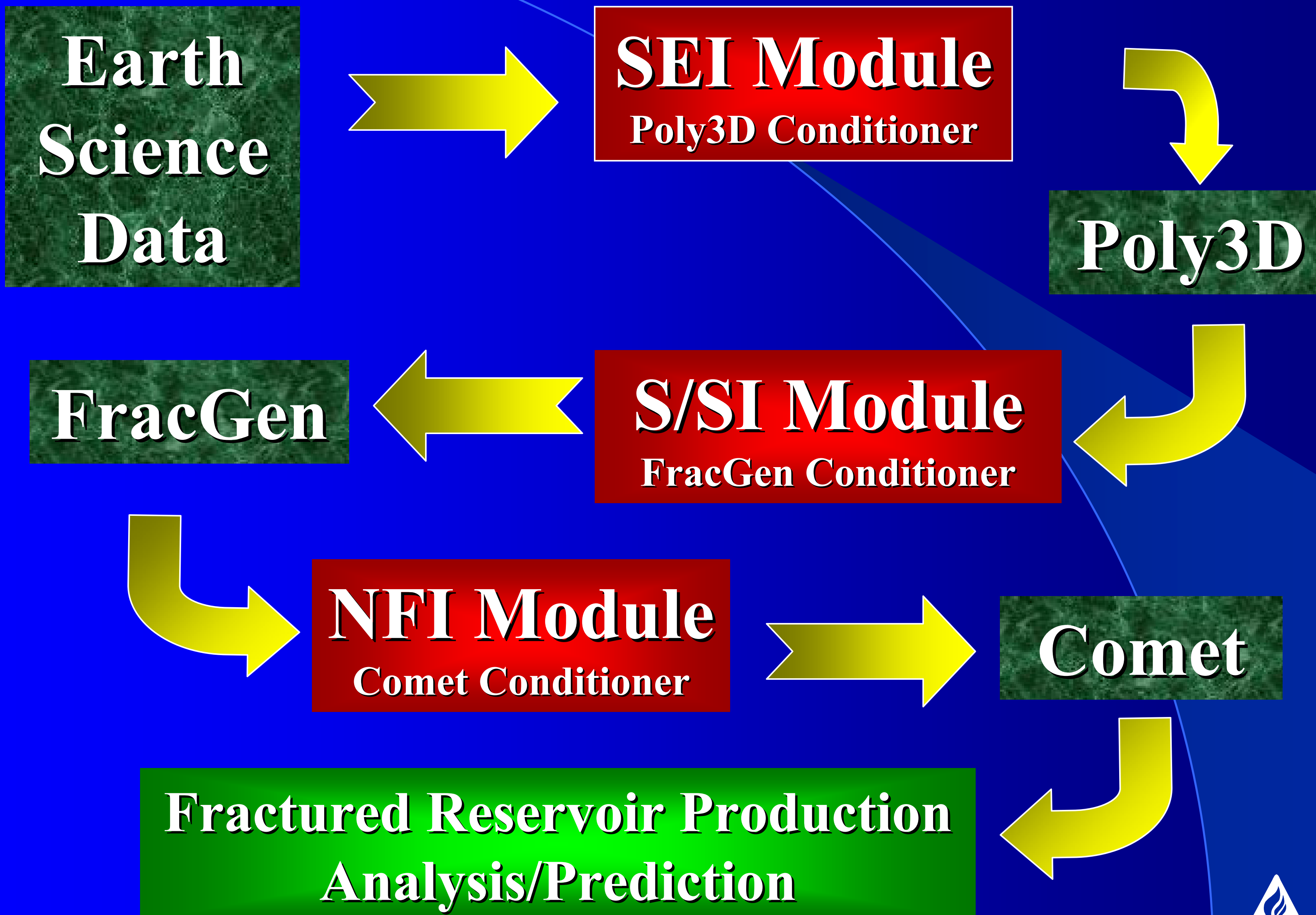
Subtle faults and complex geometry of the main thrust and strike-slip system are revealed with coherency filtering.



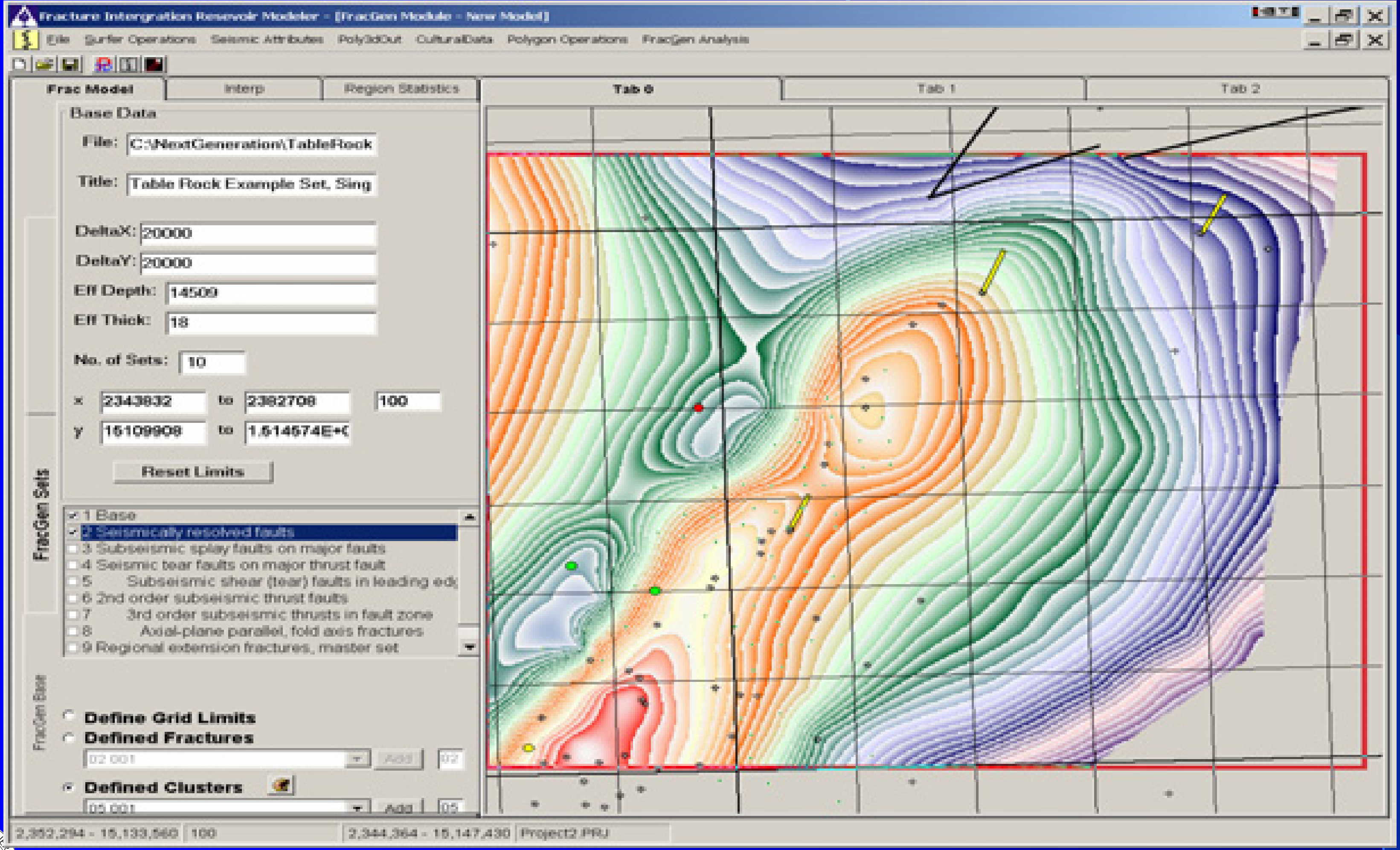
Fracture Summary

- The structural corner where the reservoir is located is an extremely complex intersection of two major fault trends
  - The dominant fracture trend is a SSE/NS regional system
  - Major local activity on the existing strike slip system in the Laramide formed the Table Rock structure and caused accommodation shearing along the pre-existing regional fractures
  - NNE, NE and ENE fault related shearing exists in the reservoir but is not well represented in core
  - A NNE shear trend related to the axis of the major anticline is present along the structural crest and declines towards the NNE
  - Later shear along existing and new fault/folding related shear fractures has resulted in a very well connected fracture system.

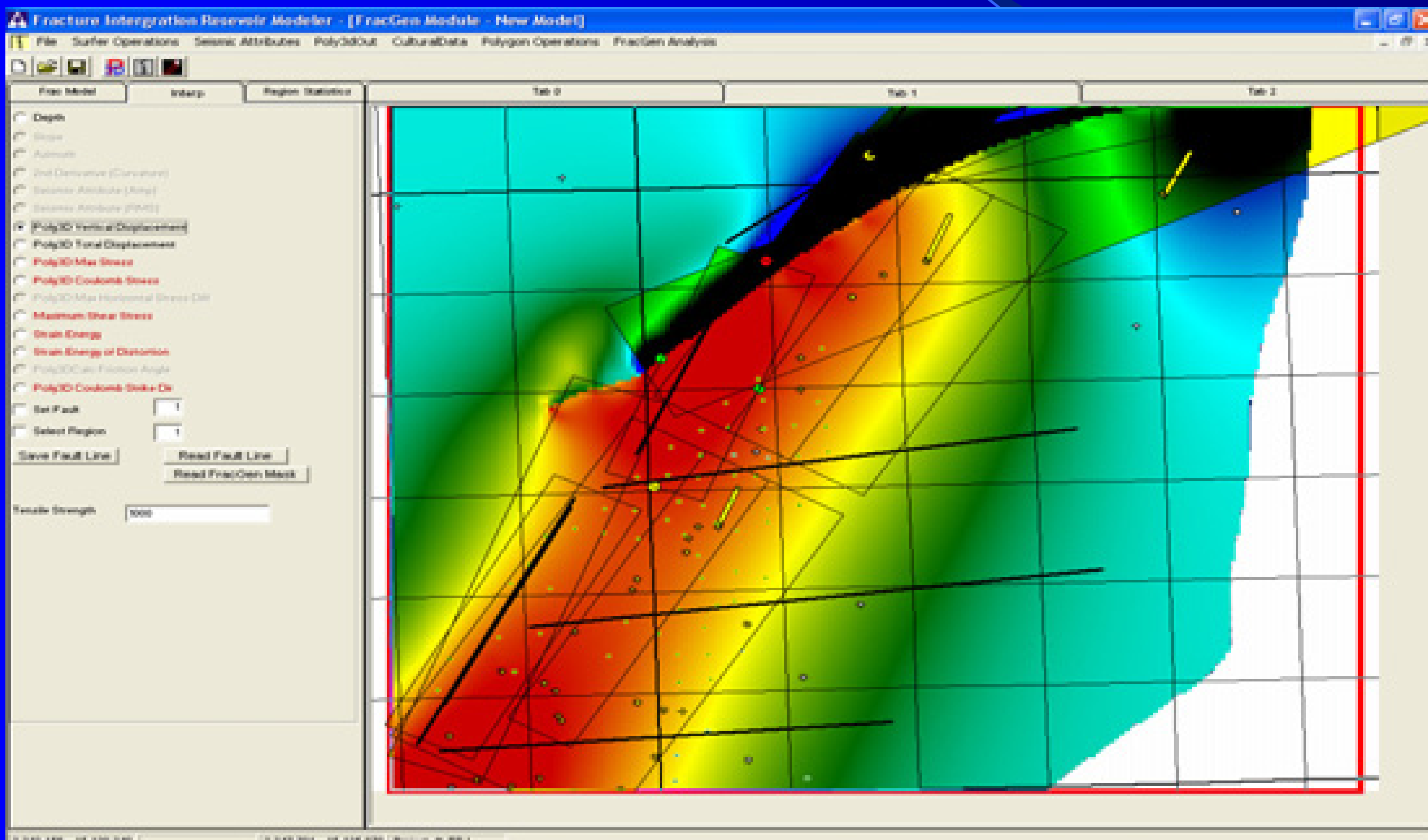
The NextGen System



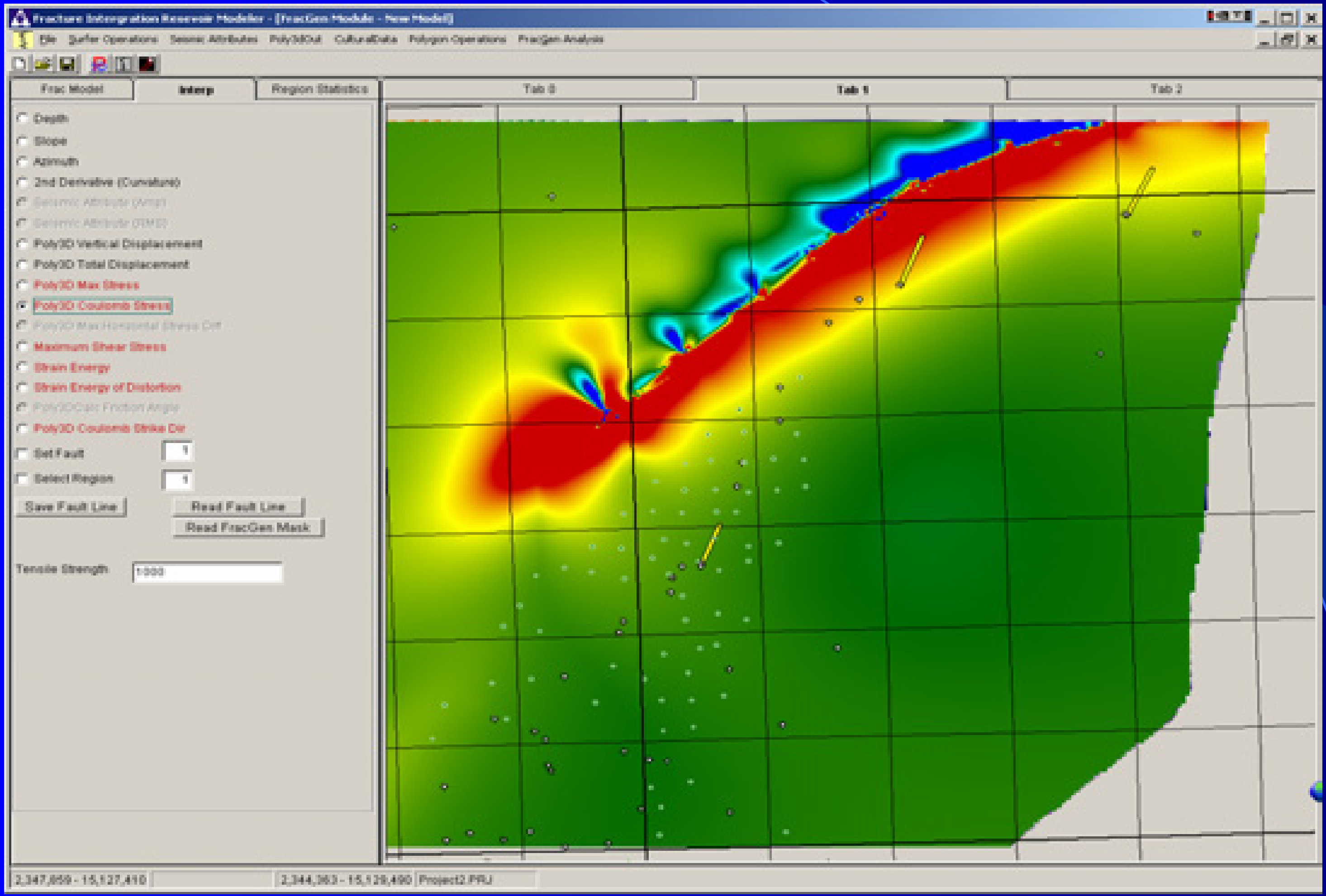
Frontier Structure



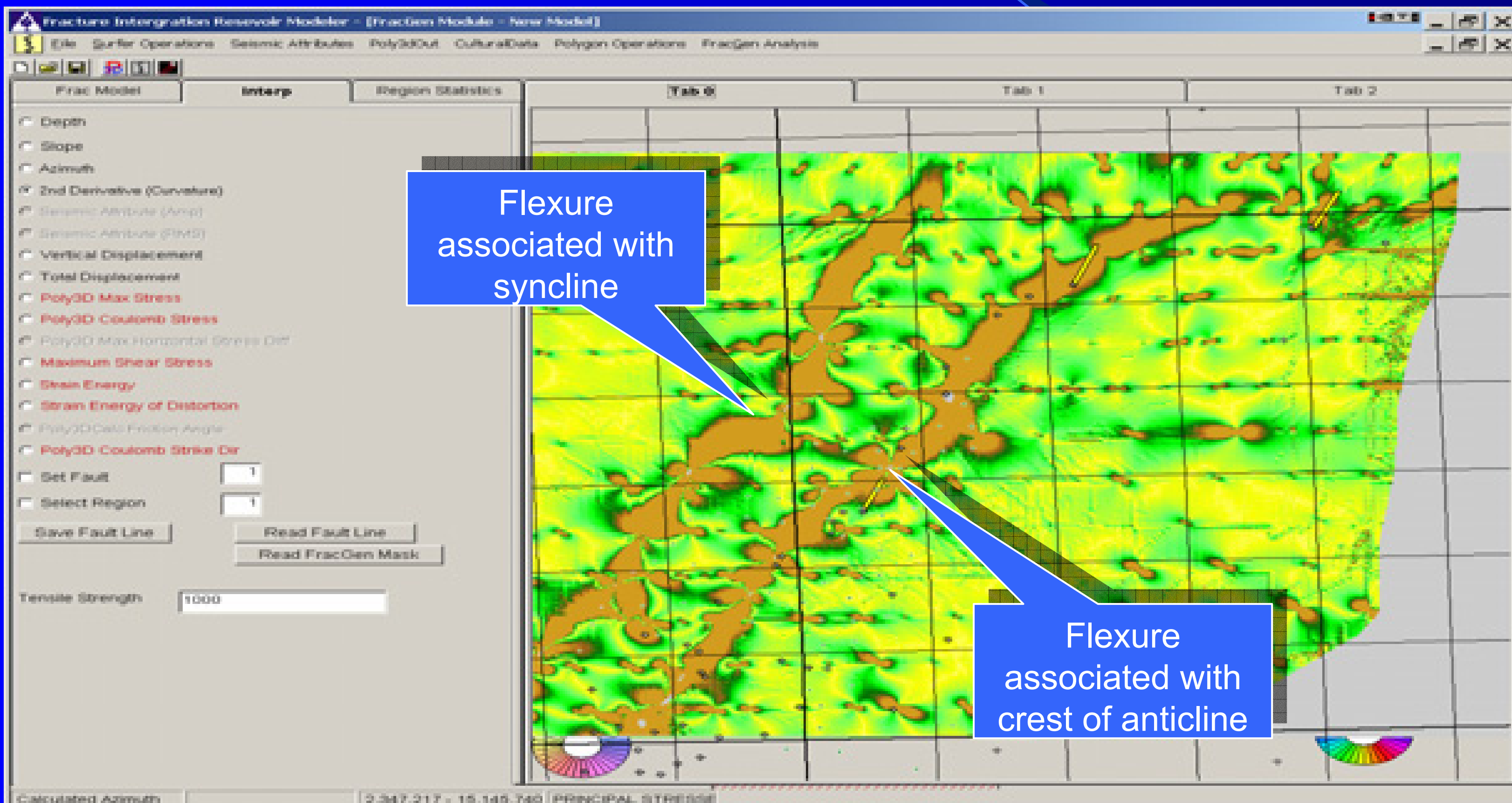
Poly 3D Calculated Vertical Displacement



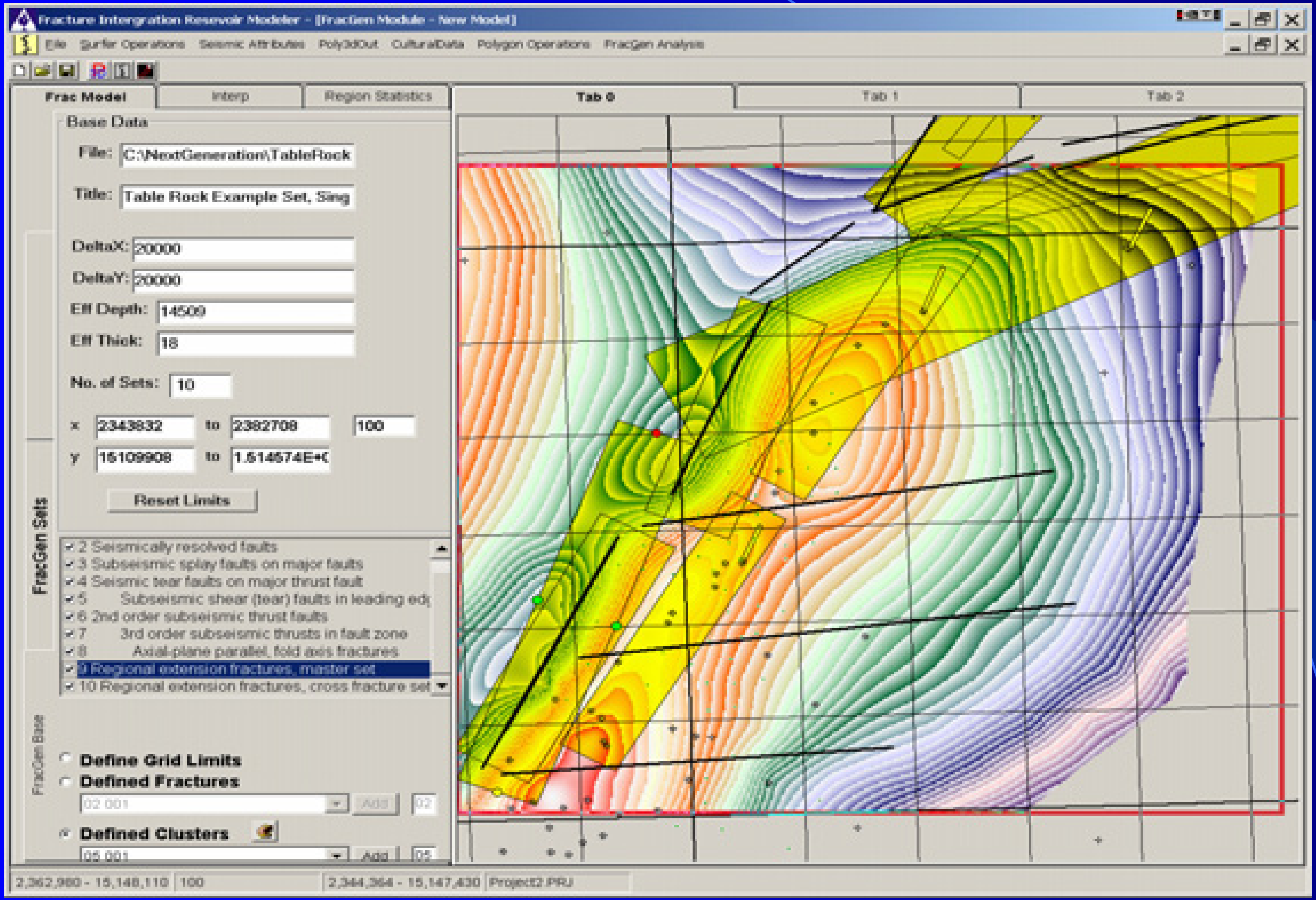
Poly3D Calculated Coulomb Stress Fields



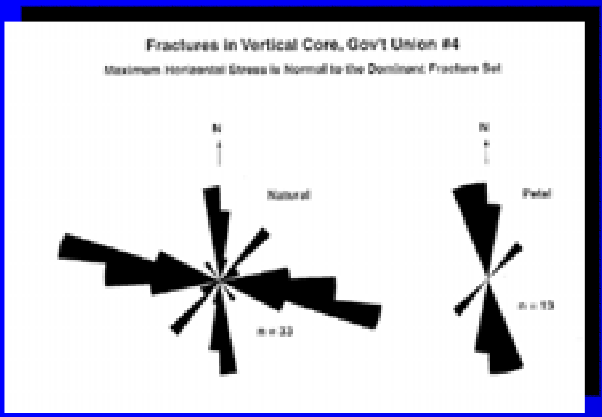
Frontier Formation – Structural 2nd Derivative

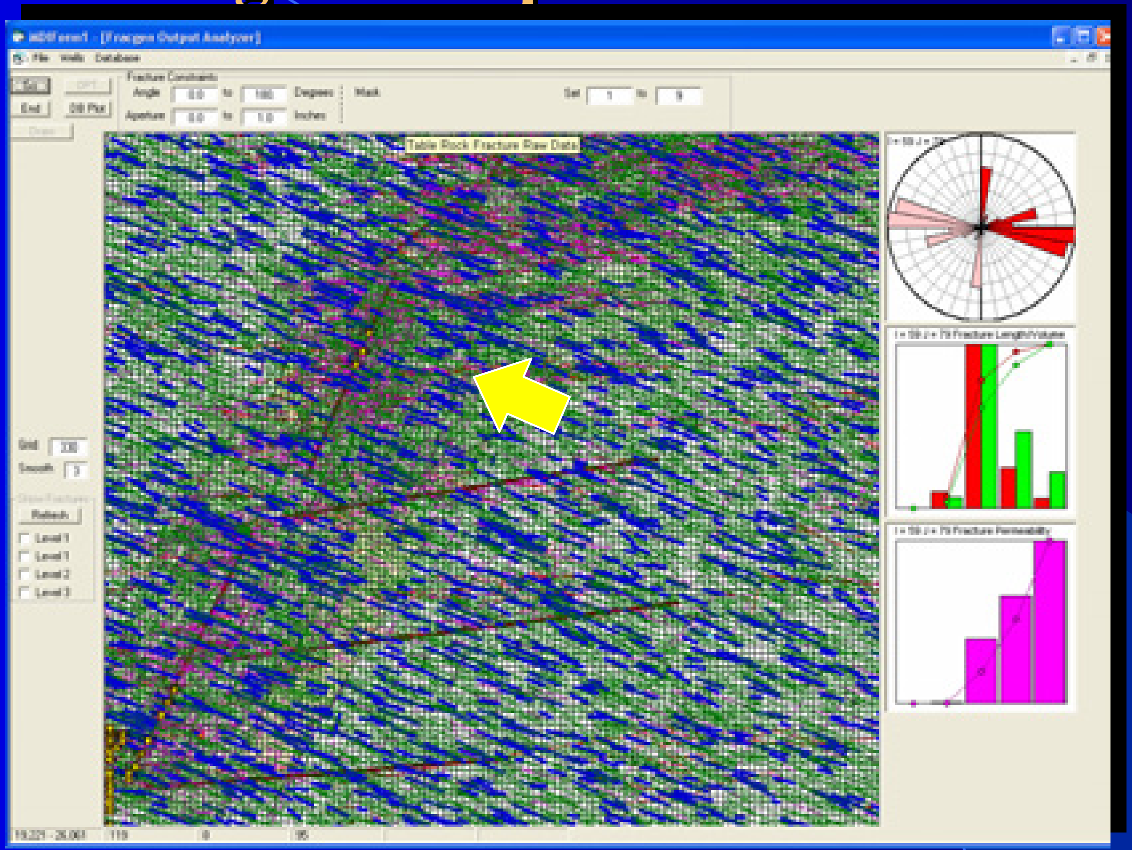


FracGen Data Sets



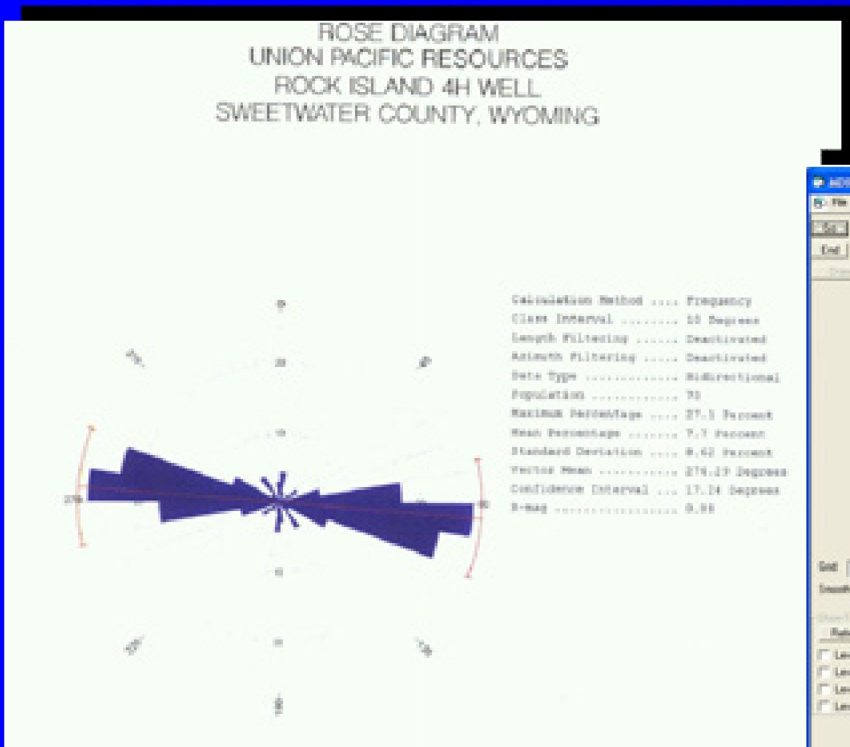
Pre- and post Fracgen Comparison

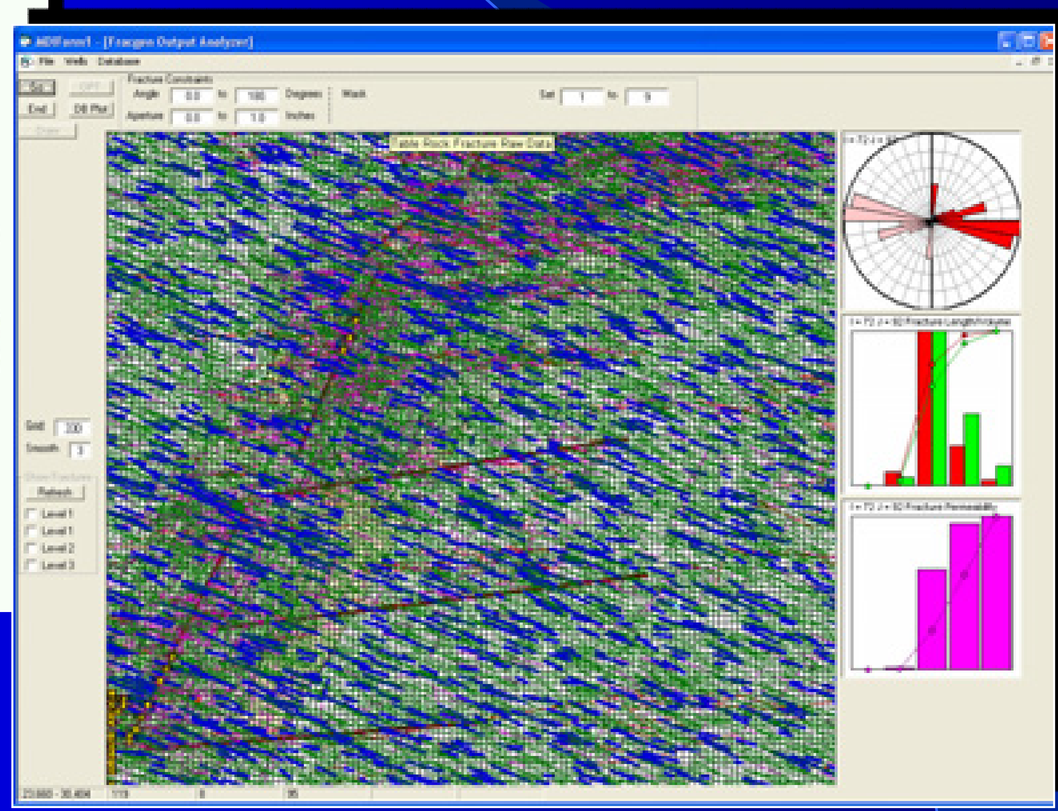




Comparison of fracture orientation rose information from GU-4 well and FracGen simulation from same area.

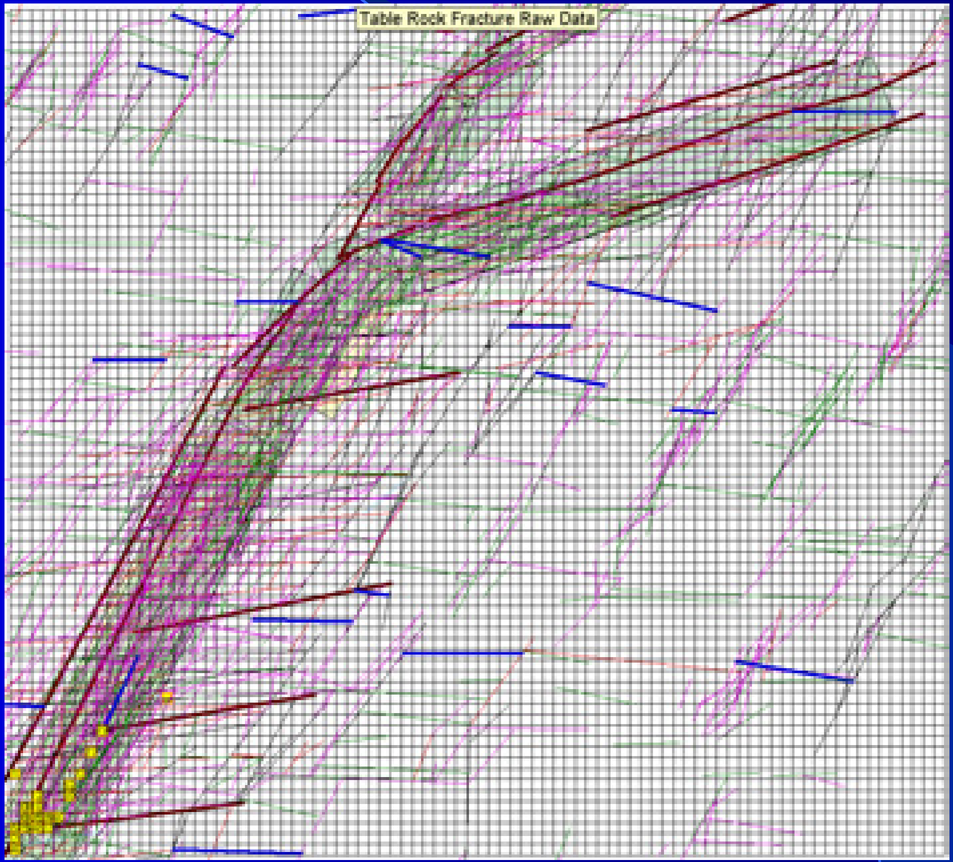
RI 4H Real and Simulated



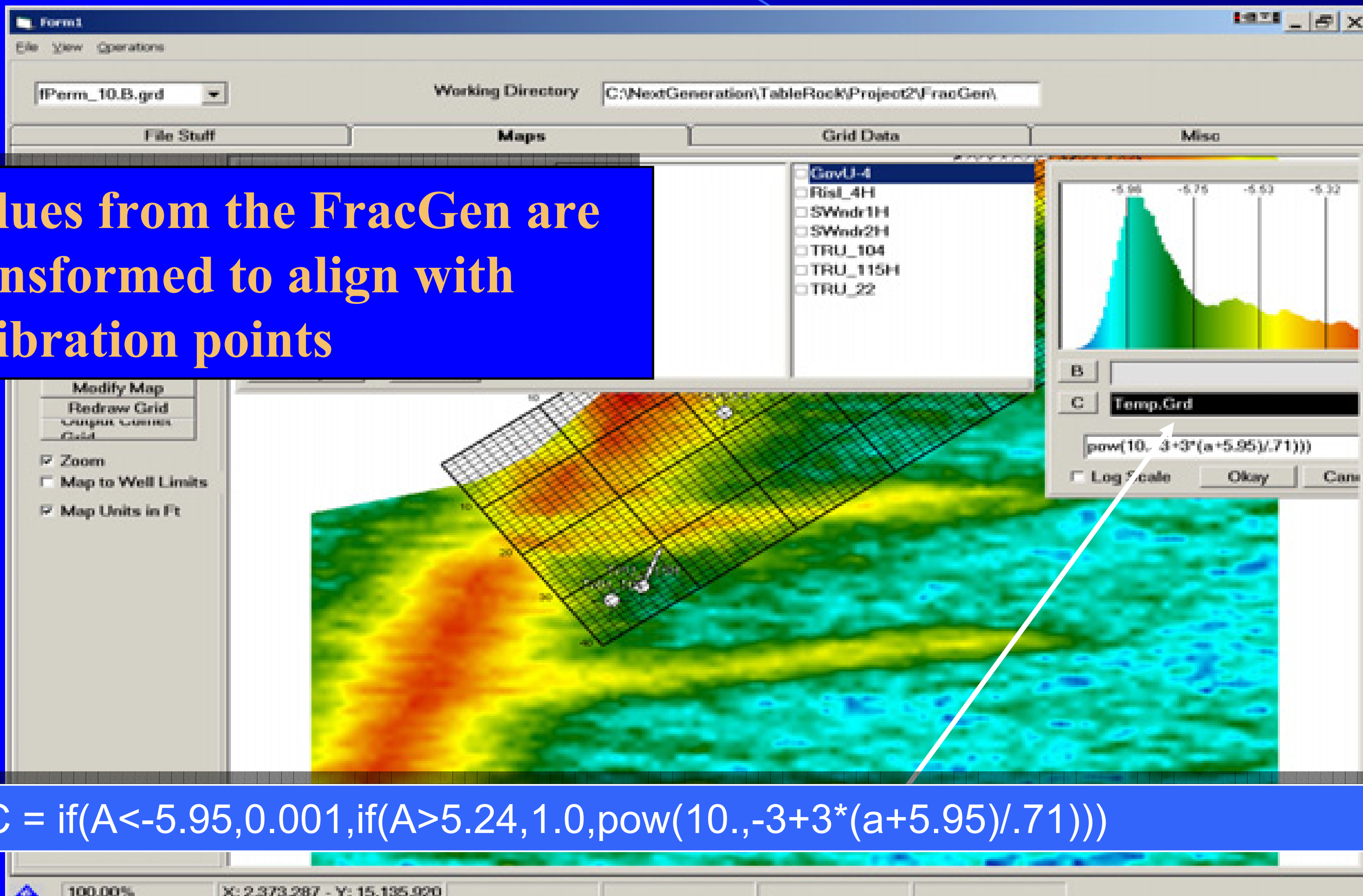


FracGen Fracture Processing

- Measure the following fracture properties for each grid cell:
  - Number of intersections
  - Length of fracture within the grid cell
  - Permeability of fracture (as a function of aperture width) within each grid cell.
  - Volume (aperture × length) of fracture within each grid cell.
  - Volume weight permeability function.
  - Number of fracture terminations within a grid cell.



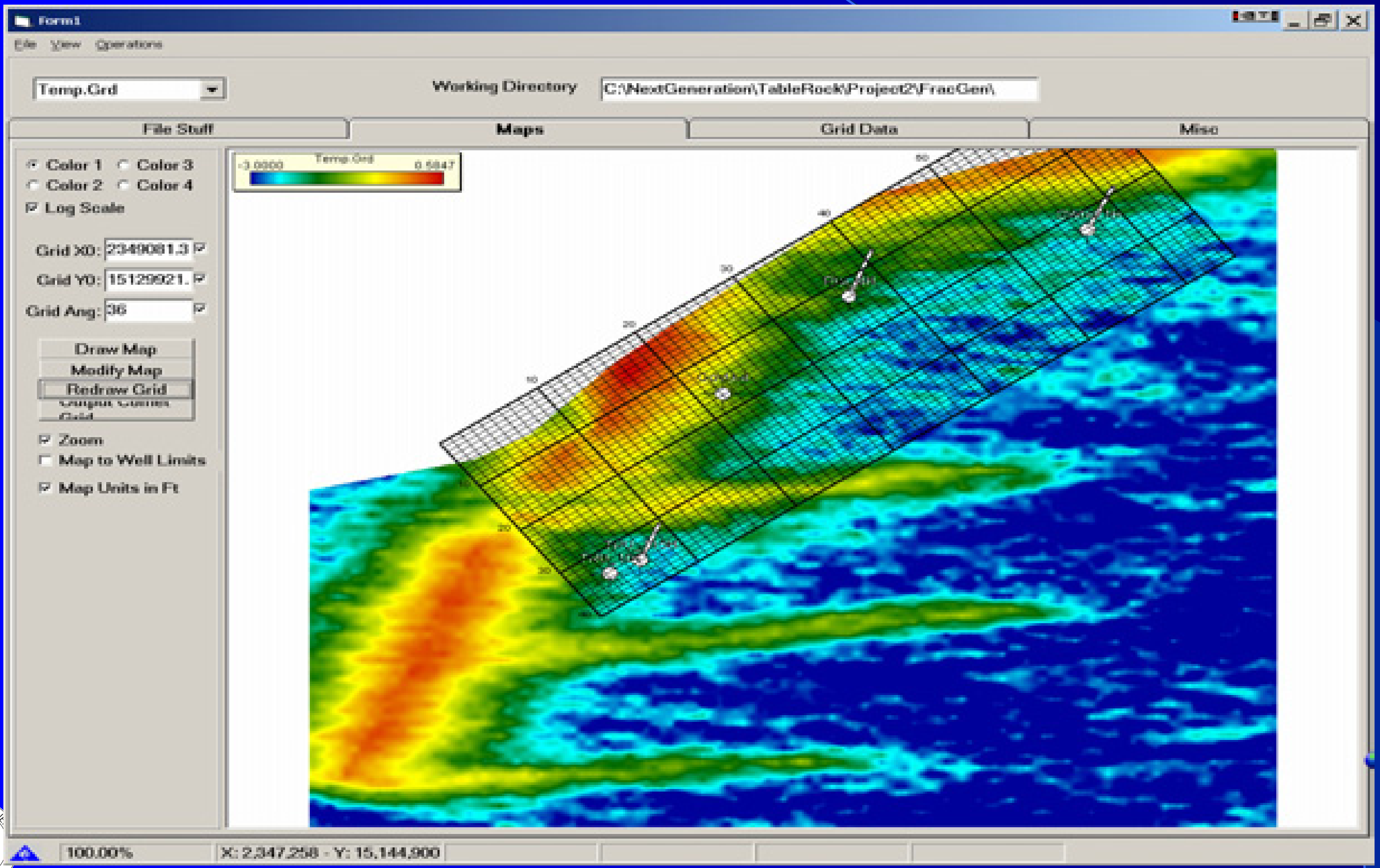
FracGen Transformation



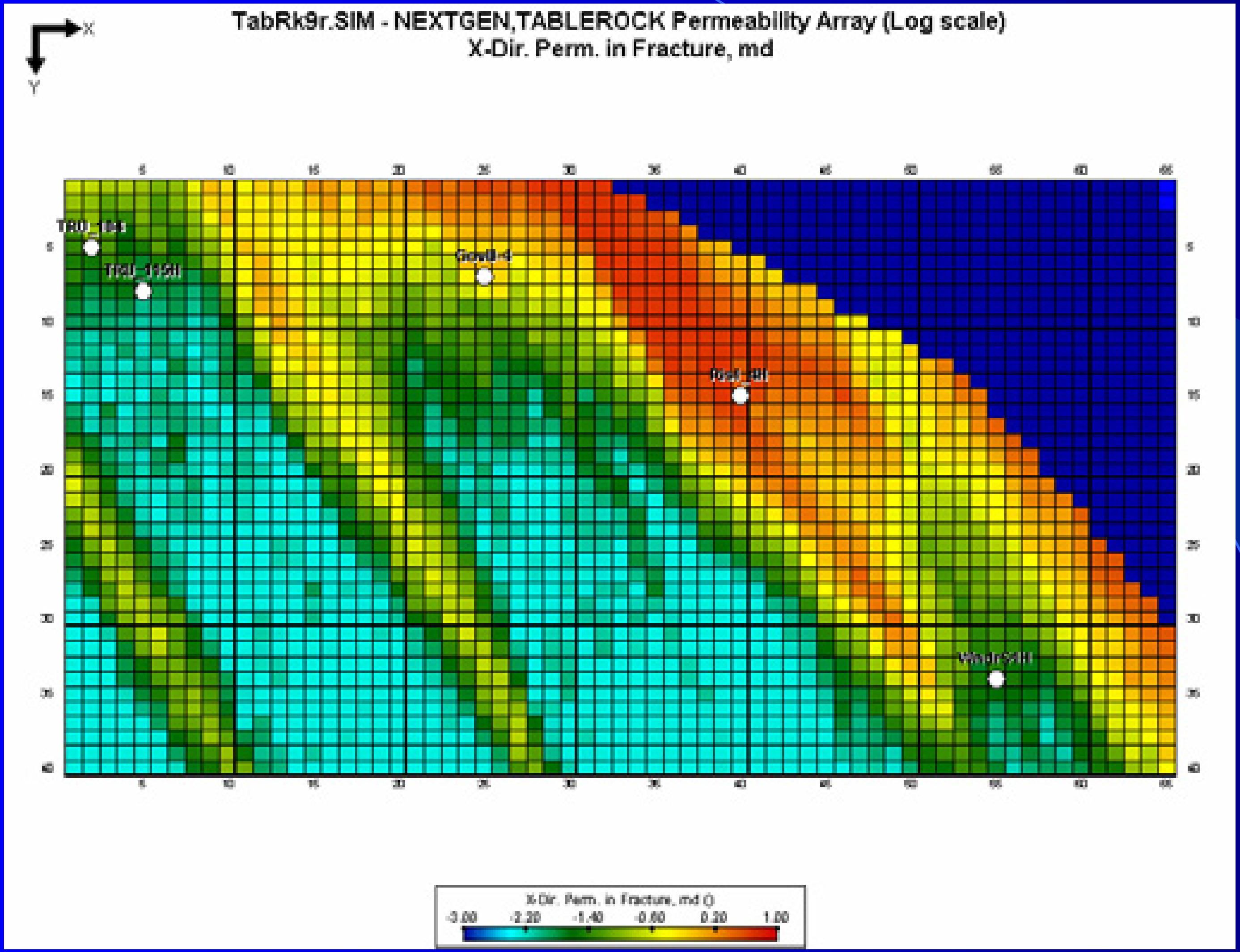
Values from the FracGen are transformed to align with calibration points

C = if(A<-5.95,0.001,if(A>5.24,1.0,pow(10.,-3+3*(a+5.95)/.71)))

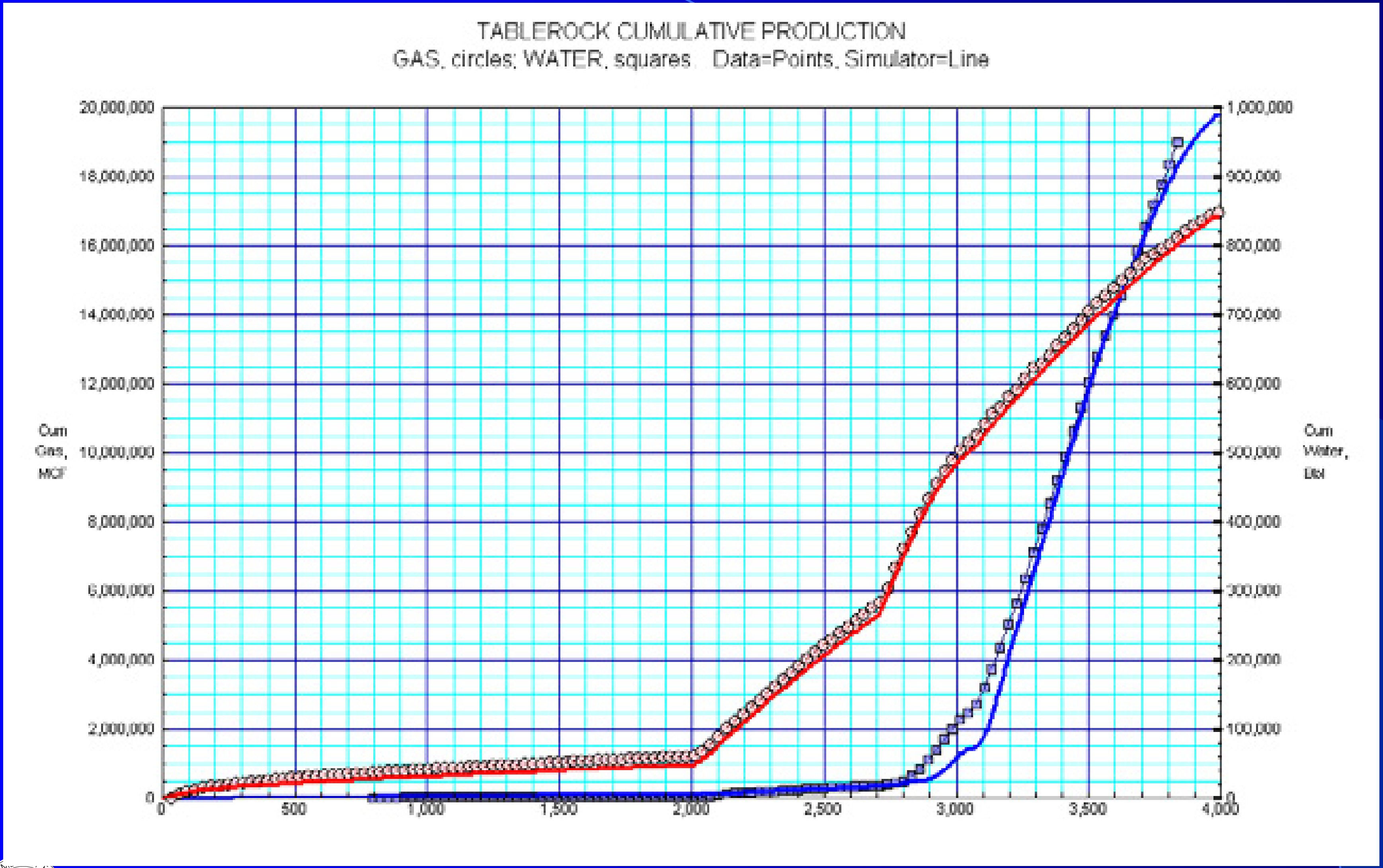
Grid Map in Permeability Units



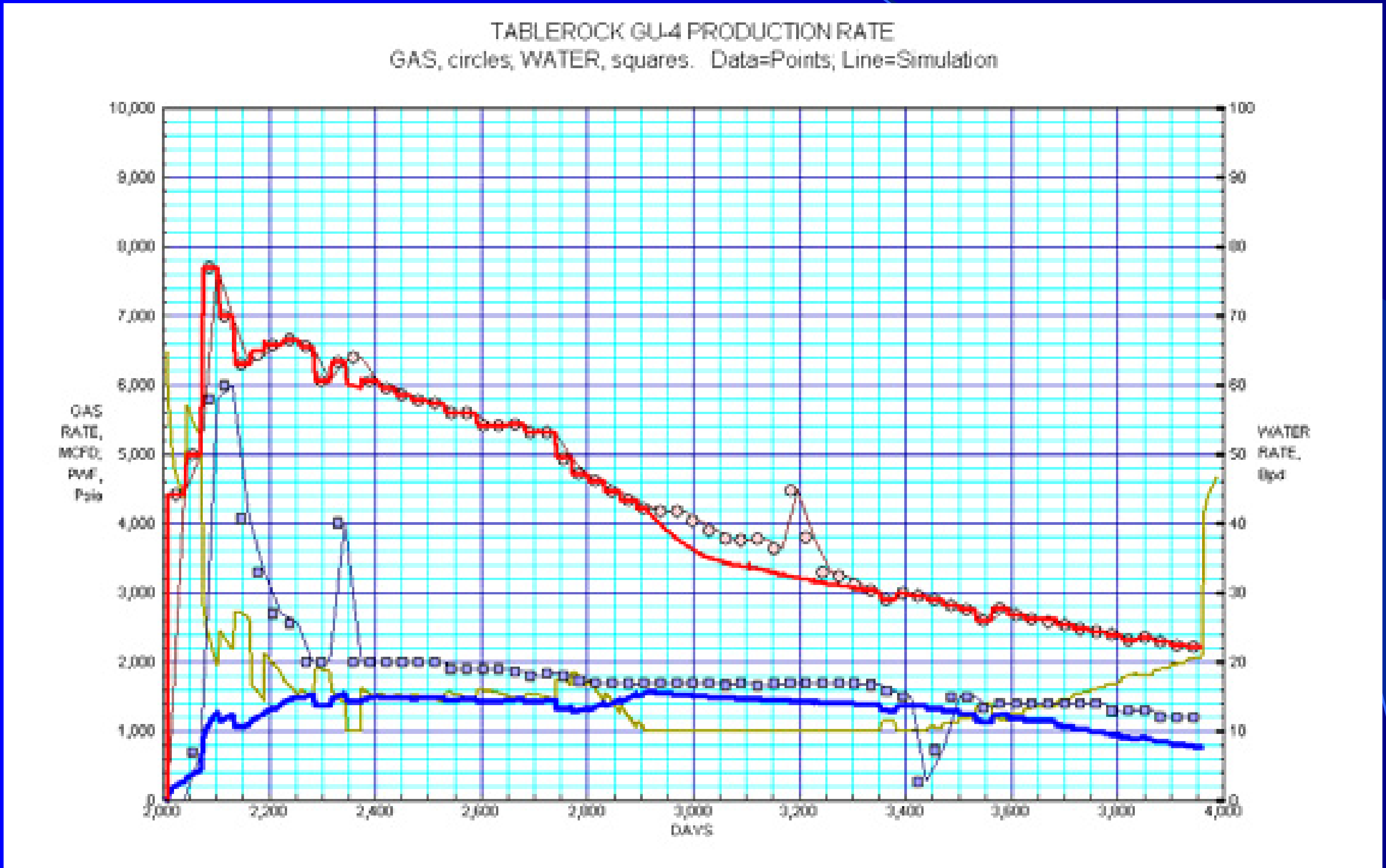
Output grid for Simulator



Field Level History Match



GU-4 Production Match



RI-4H History Match

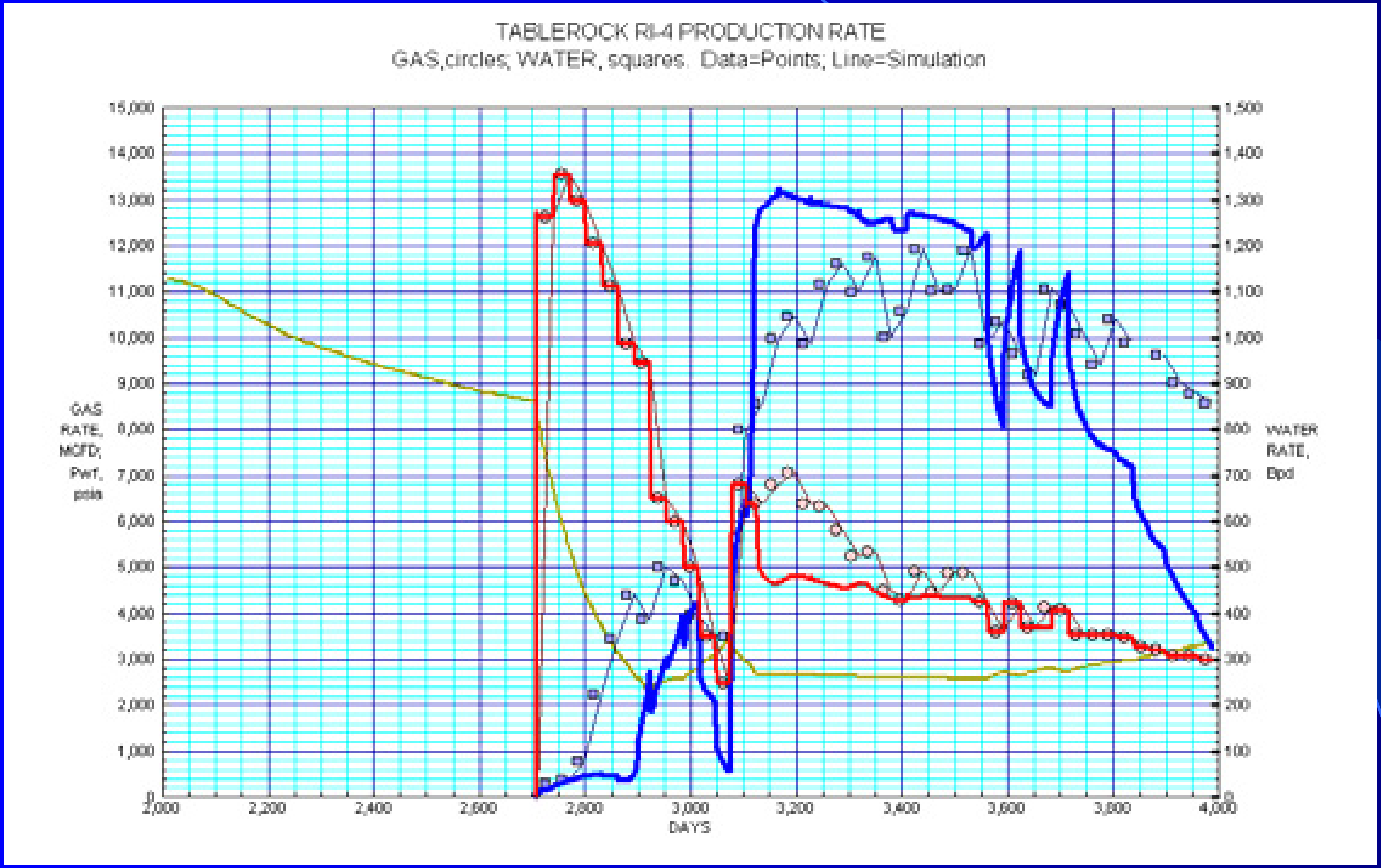


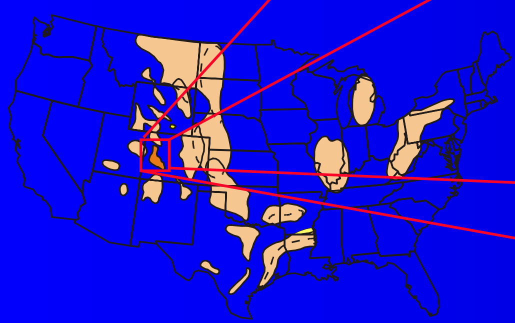
Table Rock Validation

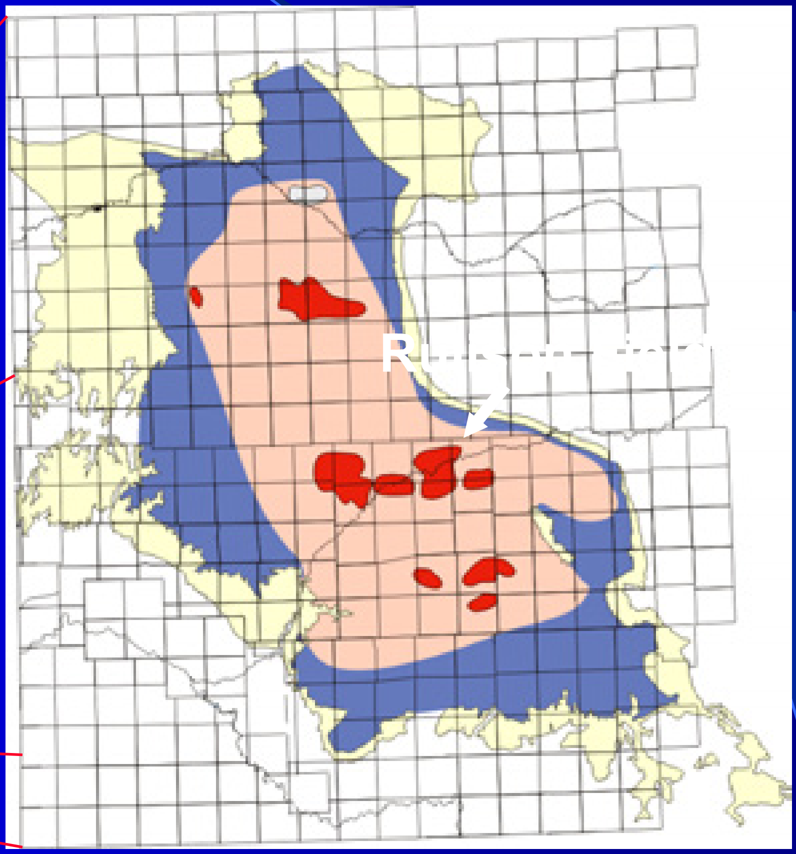
- Data Used
  - Core/FMI
  - Seismic structure
  - Seismic coherency
  - Production streams
- Interpretation Methods
  - Mechanical modeling
  - Curvature
  - Discrete fracture network generation
  - Permeability transform generation
  - Reservoir modeling
- Results
  - Cohesive fractured reservoir model that fits known data
  - Useful tool for future reservoir management

RULISON FIELD, PICEANCE BASIN, COLORADO

The southern Piceance Basin contains a basin-centered gas deposit housing 300 Tcf of gas.

The Rulison Field is located in the southeastern portion of the basin

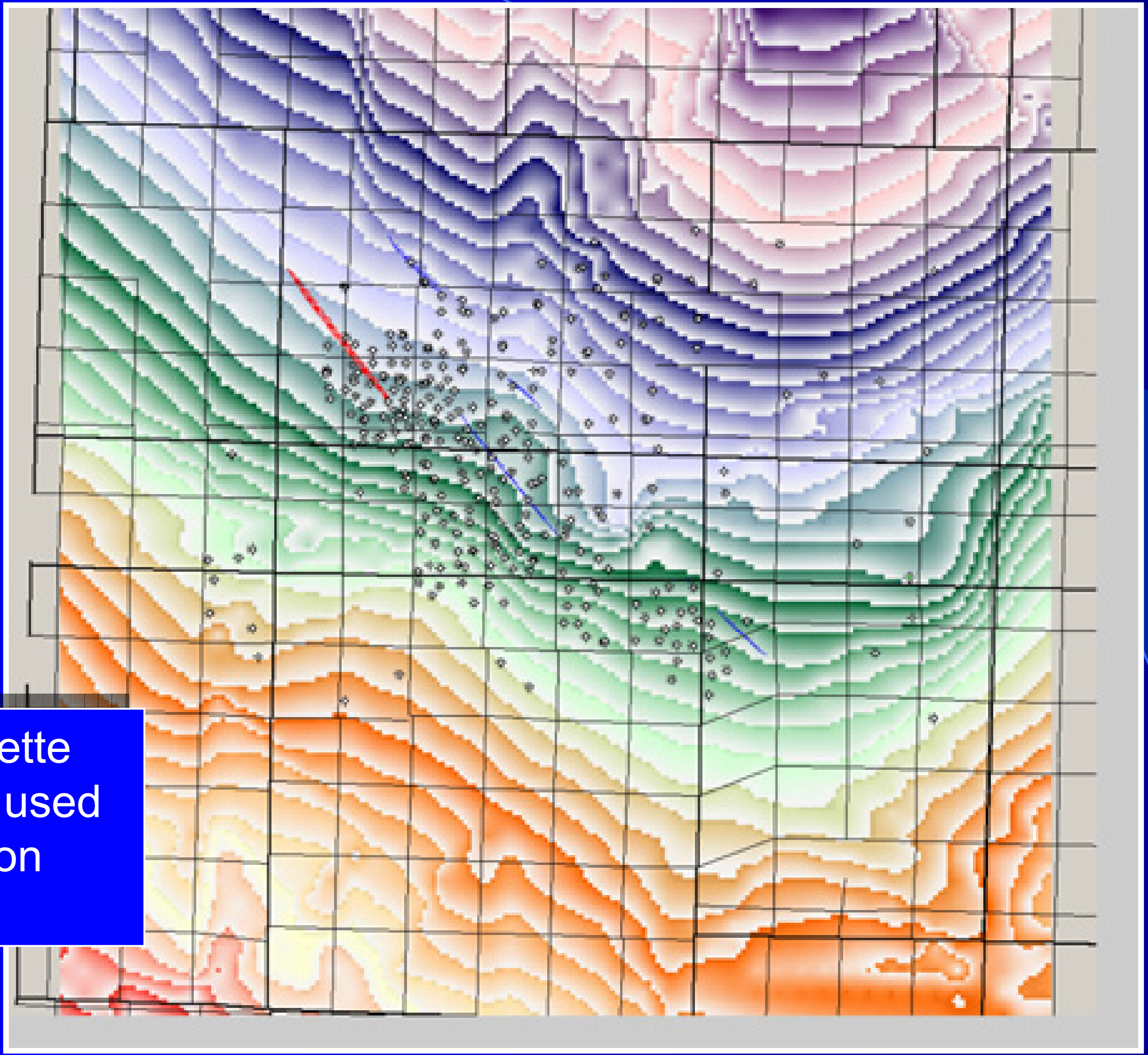




Rulison Field Validation

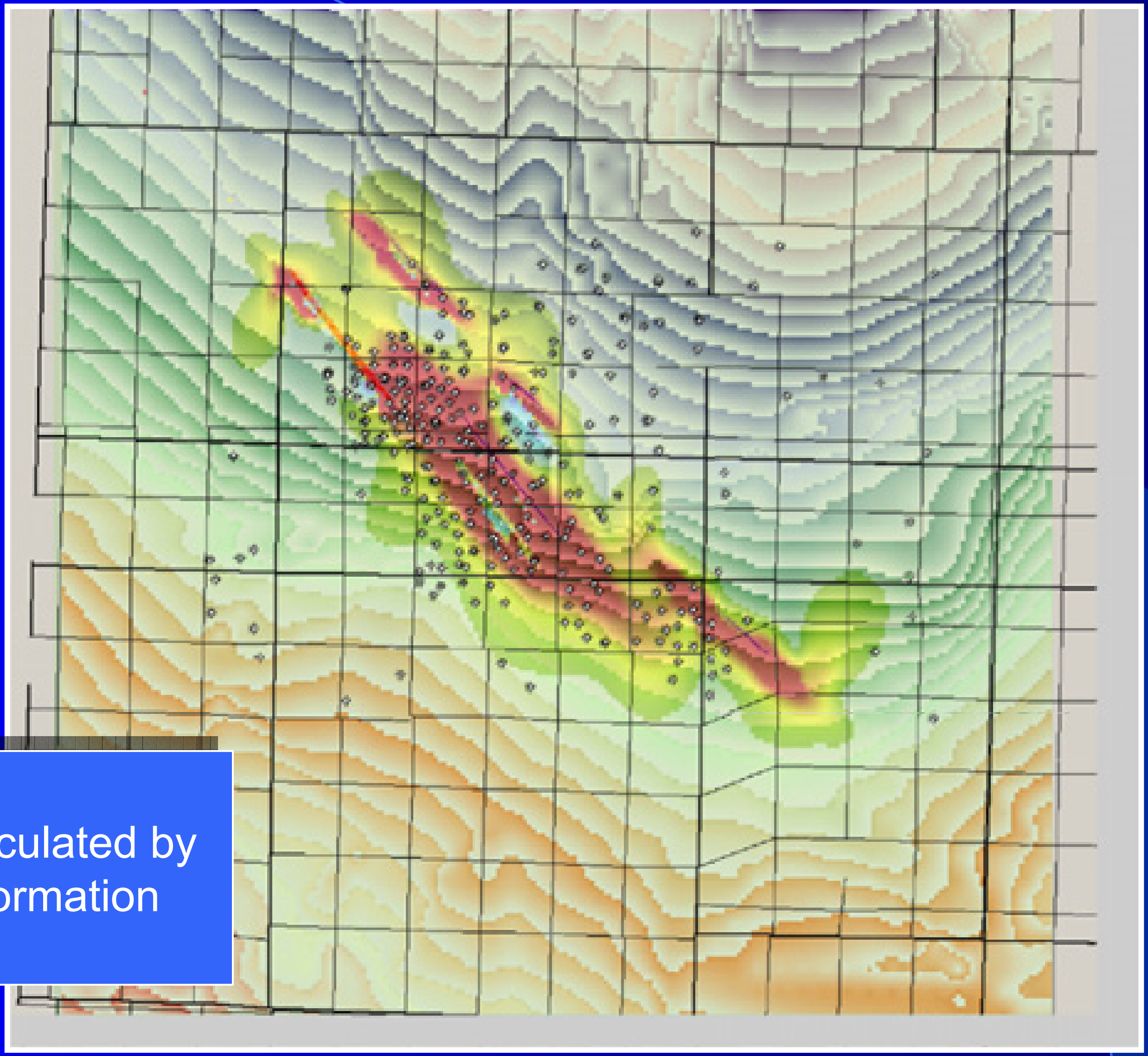
- Rulison area known to contain subtle structure, stress sensitive reservoirs from MWX project
  - Used Cretaceous Cozzette Fm. scout tops, updated early mechanical model
  - Modeled burial stress history with DOE visco-elastic model
  - Well productivity from historical ARI basin analysis data
- Generated a simple boundary element mechanical model of the subtle faults (tectonic stress) and combined it with modeled burial/uplift stresses, cross correlated to normalized bulk wellbore permeability

Rulison Faults and Depth



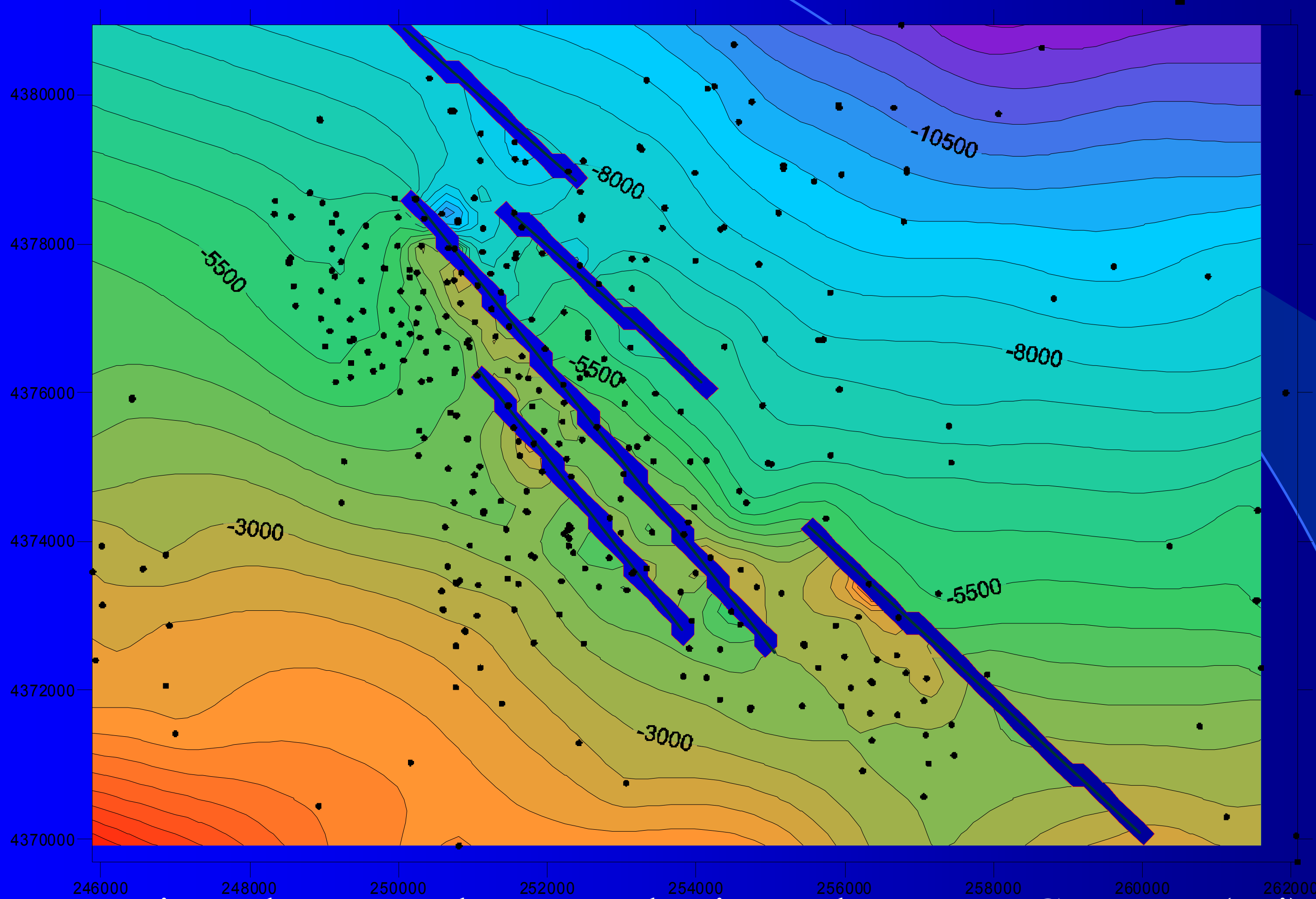
Gridded Cozzette depth structure used as observation horizon.

Max Extensional Stress/Structure



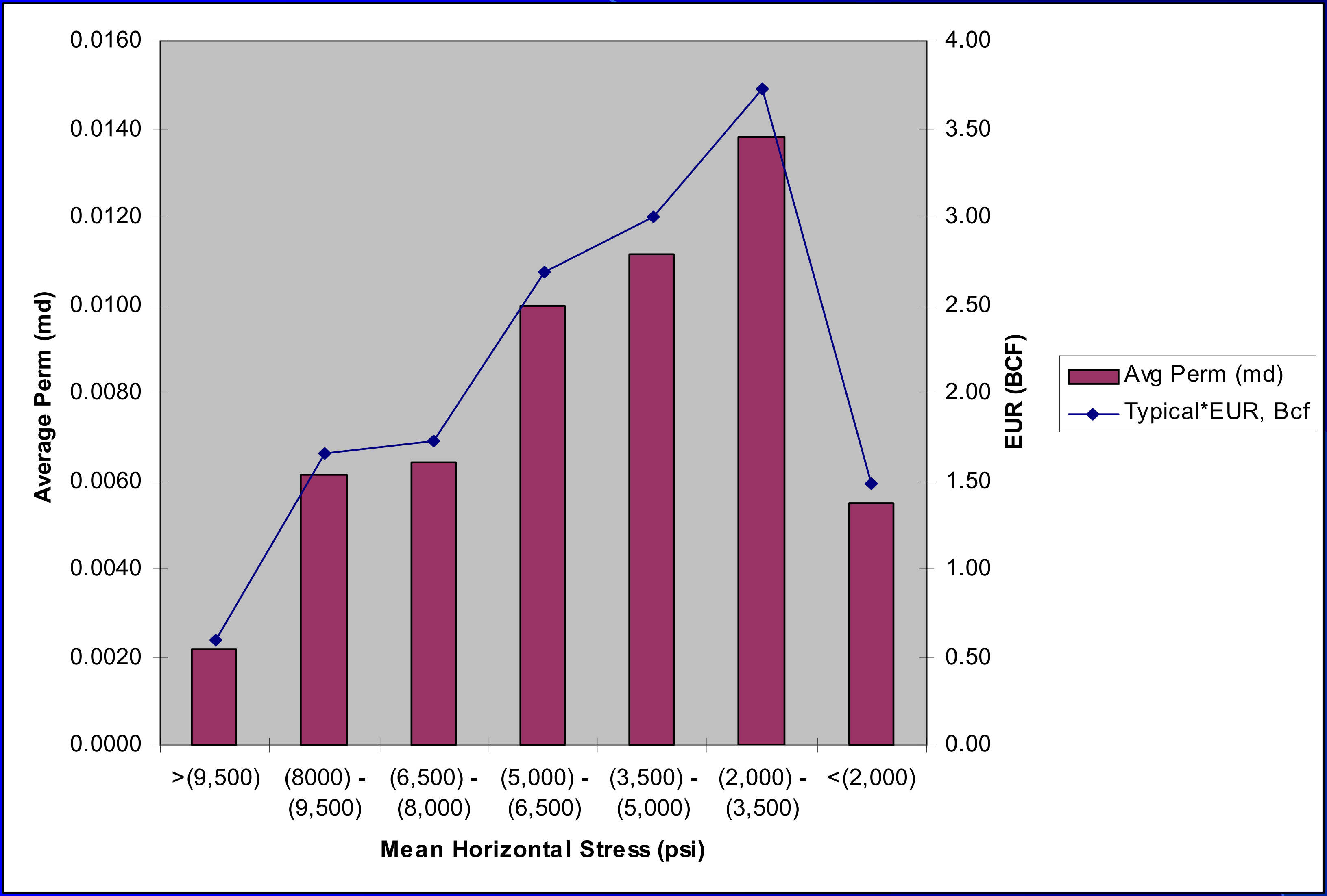
Overlay of maximum extensional stress calculated by Poly3D on Cozzette formation structure map

Rulison Stress Calibration Map



Projected present day mean horizontal stress at Cozzette (psi)
Blue shades, high stress, Orange shades, low

Rulison Results All Wells (chart)



Rulison Conclusions

- Data used
  - Scout tops
  - Artificially constructed faults located from rudimentary seismic and well control
  - Existing basin history and fracture work from MWX
  - Existing bulk wellbore permeability database
- Interpretation techniques
  - Mechanical modeling
  - Basin level viscoelastic stress history modeling
  - Basic log analysis and decline curve techniques
- Results
  - Strong correlation between modeled stresses and productivity
  - Good working model for regional acreage evaluation
  - Good exploitation tool within the modeled areas

Conclusions

- Fractured reservoirs contain many features of diverse origins and scales that require integration of diverse data to build an effective reservoir model
  - Fracture scale varies from micro to macro
  - Accept multiple origins for fractures and apply appropriate projection method(s)
    - Fault related (mechanical)
    - Bending (curvature, finite element)
    - Burial Uplift (basin stress modeling)
- Reliability improves by integrating multiple interpretive methods and incorporating cross validation techniques
    - Mechanical modeling
    - Stress history modeling
    - Structure and/or seismic attributes
    - Geologic/seismically constrained DNF methods
    - Basic petrophysical and reservoir engineering tools
- NextGen is an emerging tool to build verifiable reservoir models in complex settings by integrating diverse data and interpretations