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Sustainable enhancement of coal seam gas production in Queensland

Development of new technologies for upgrading the return on what is currently uneconomic or marginally economic

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Presentation Agenda

- Some commercial aspects of the CSG industry
- Production challenges in Surat and Bowen Basins
- The effect of stress and material heterogeneity
- Current practice in the prediction of hydraulic fractures and permeability increase in CSG wells
- Development of advanced predictive capabilities:
  - Near-wellbore stress and fracture initiation
  - Complex, three-dimensional fracture propagation
  - Propagation of proppant into natural fractures
- Future research, including the incorporation of production forecasting and uncertainty analysis

Queensland Government

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Centre for Natural Gas

AUSTRALIA PACIFIC LNG

Santos

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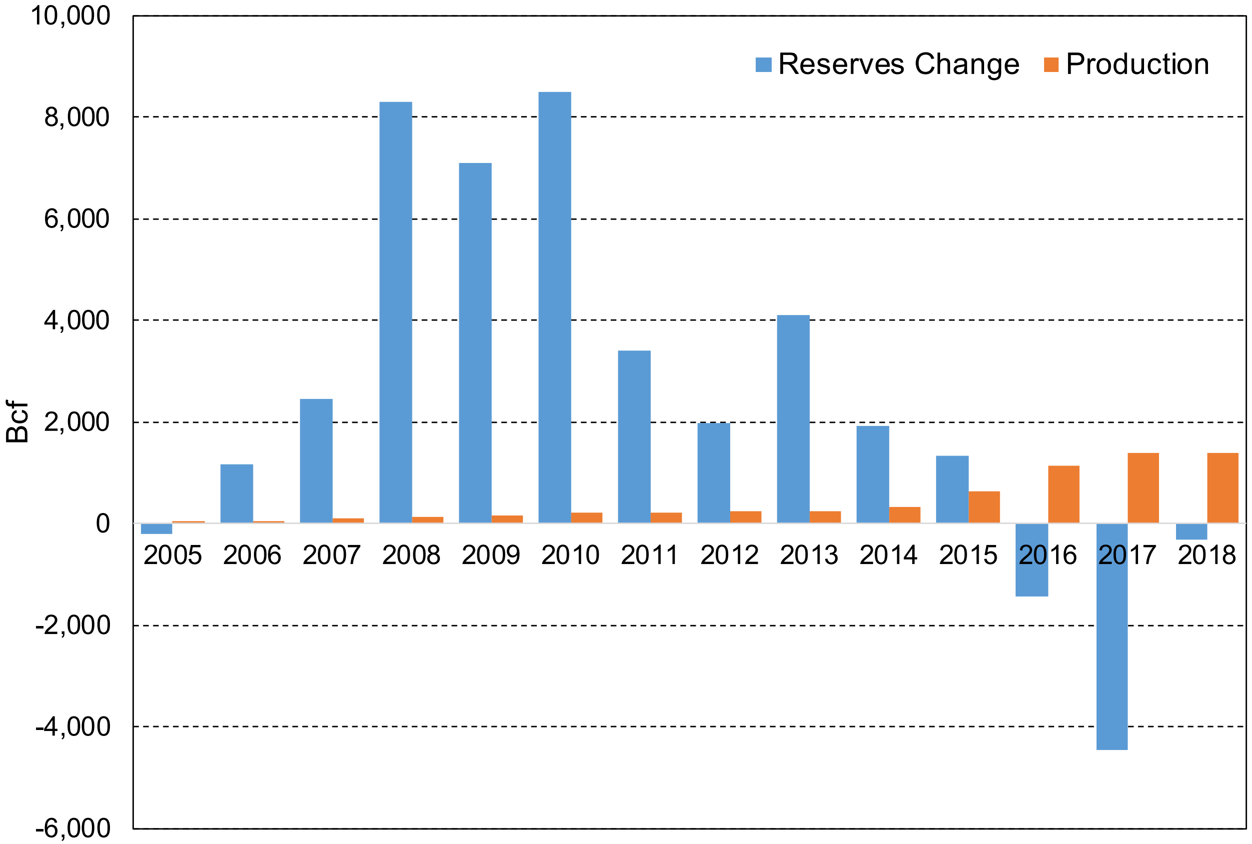
CSG and LNG in Eastern Australia

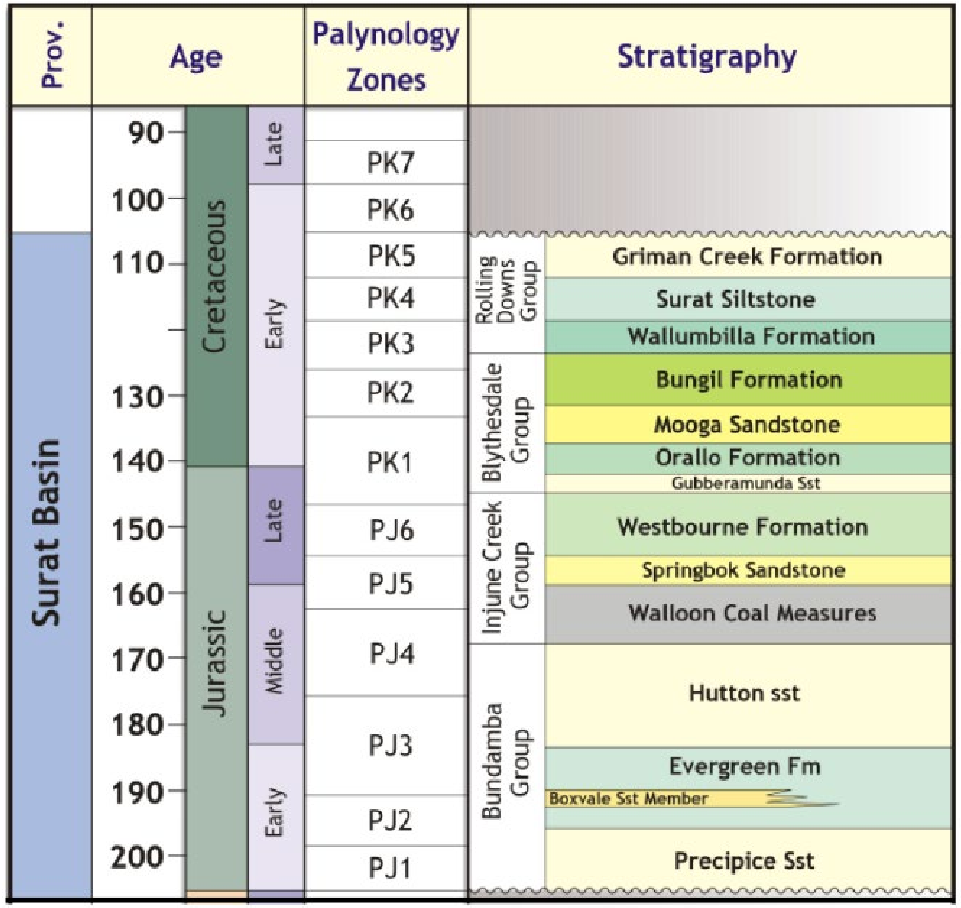
- East-coast, on-shore gas market in Australia well positioned to produce CSG-LNG for at least the next thirty years
- Approximately $9 billion in LNG exports in 2016-17, when only at 75% capacity
- Environmental, economic and political drivers to increase production from assets
  - Less CO2 intensive source of energy
  - Demand for electricity/manufacturing
  - State and federal policies to promote increased production and exploration
- However, significant volumes of gas remain classified as 3C resources
- Production challenges contributing to the write-down of some reserves



https://www.data.qld.gov.au/dataset/petroleum-gas-production-and-reserve-statistics

Production Challenges in the Surat and Bowen Basins

- Production outcomes from hydraulic fracture stimulations not universally repeatable
- Bowen Basin coals thick and continuous, can be drilled and produced from horizontal wells without hydraulic fracturing
- Surat Basin coals occur in multiple thin seams (0.1~0.5m thickness) with clastic interburden
- Complex rock mechanical properties
  - Low Young's modulus, high Poisson's ratio
  - Varying connectivity of fractures and cleats
- Stress regime varies between reverse faulting, strike-slip, and normal faulting with depth
  - Can manifest as stress barrier to fractures
  - Evidence of non-planar fracture growth



The geology of the Surat Basin, Australia (reproduced from Pandey and Flottmann, SPE-173378-MS)

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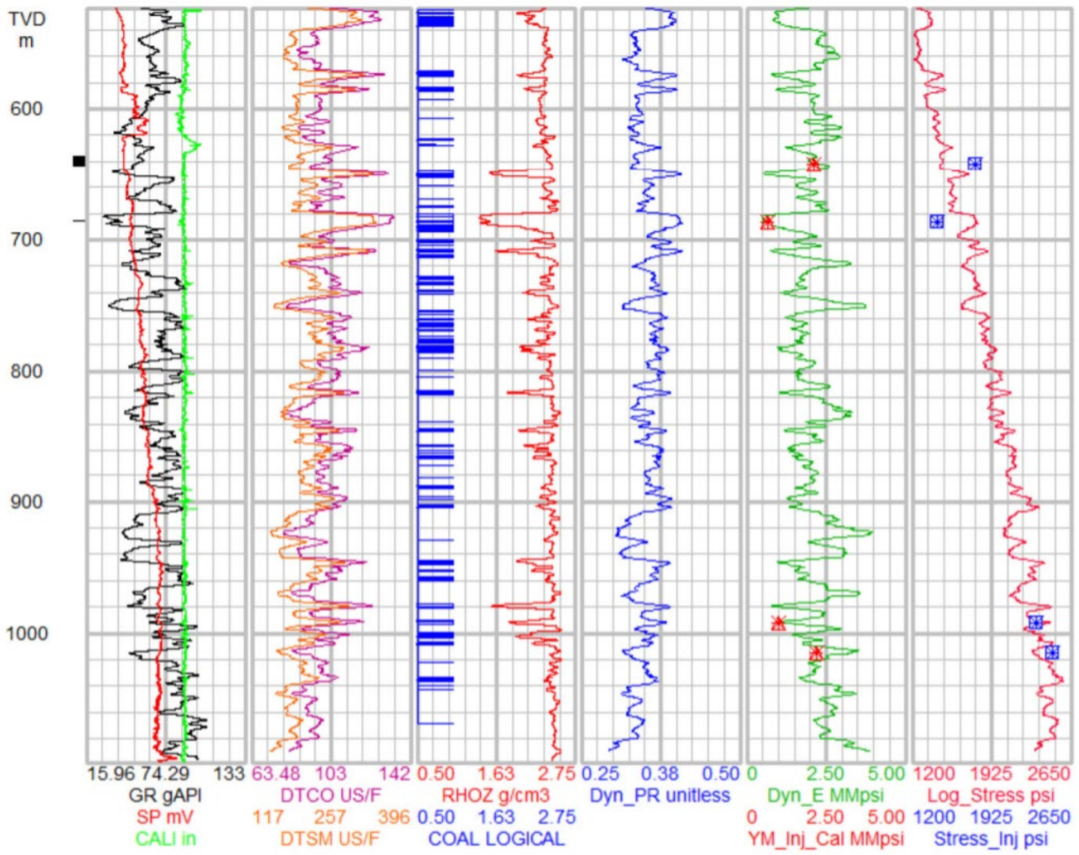
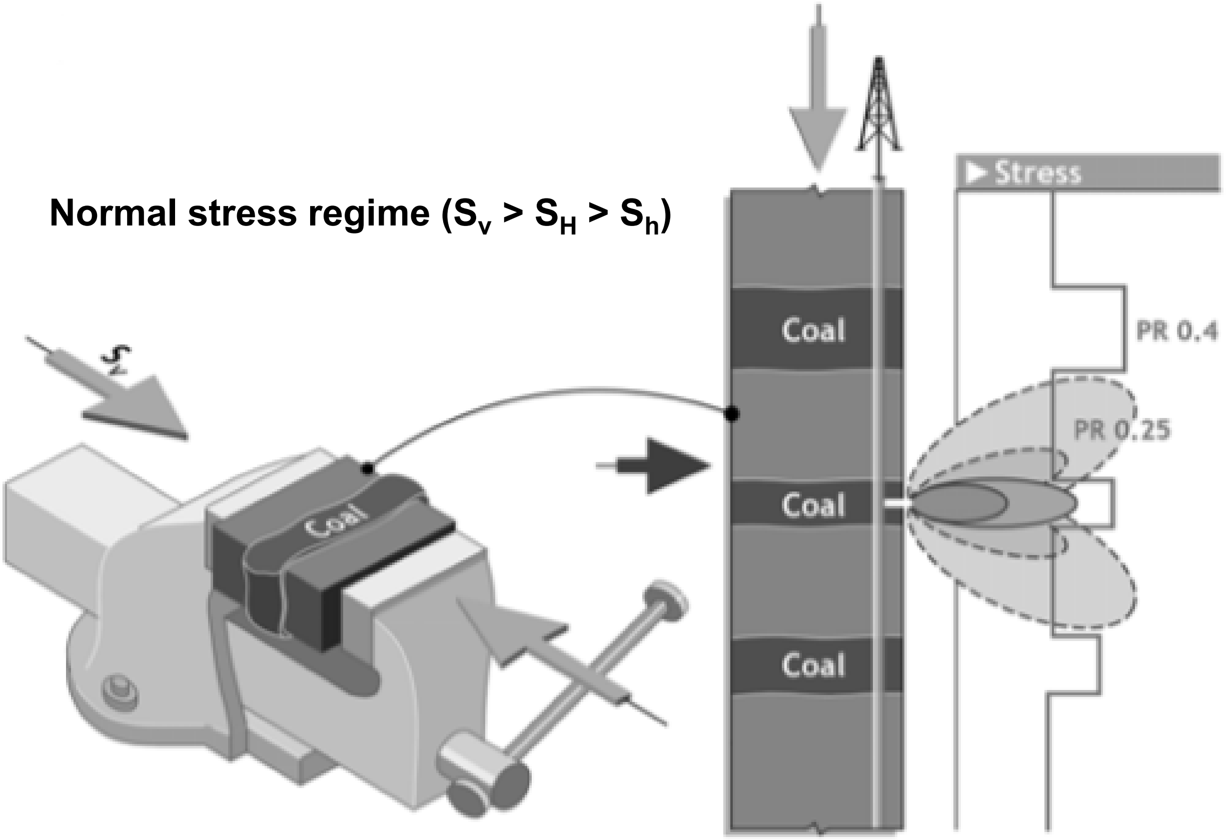


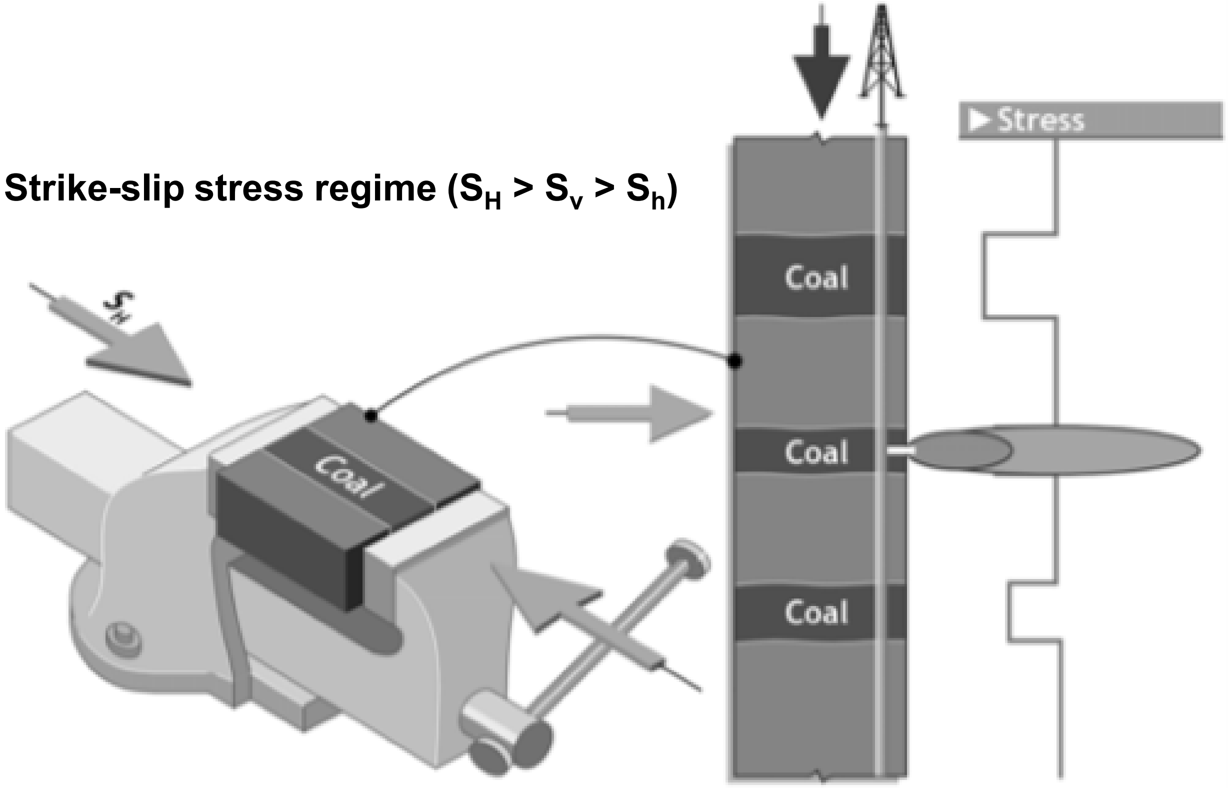
Calculated log properties from a well in the Surat Basin, Australia (reproduced from Pandey and Flottmann, SPE-173378-MS)

Production Challenges in the Surat and Bowen Basins

Normal stress regime ($S_v > S_H > S_h$)



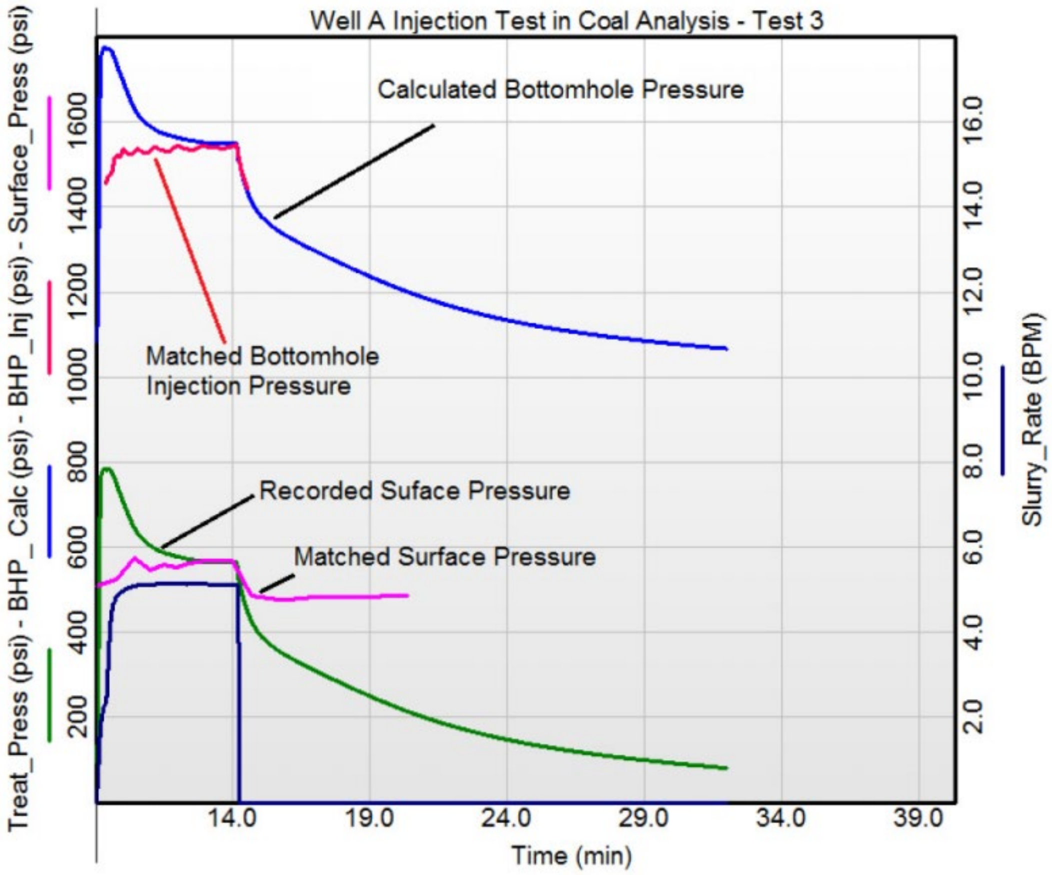
Strike-slip stress regime ($S_H > S_v > S_h$)



The combination of contrasting stress regime and mechanical properties manifesting as stress barriers to fractures (adapted from Tavener, Flottmann and Brooke-Barnett, 2017)

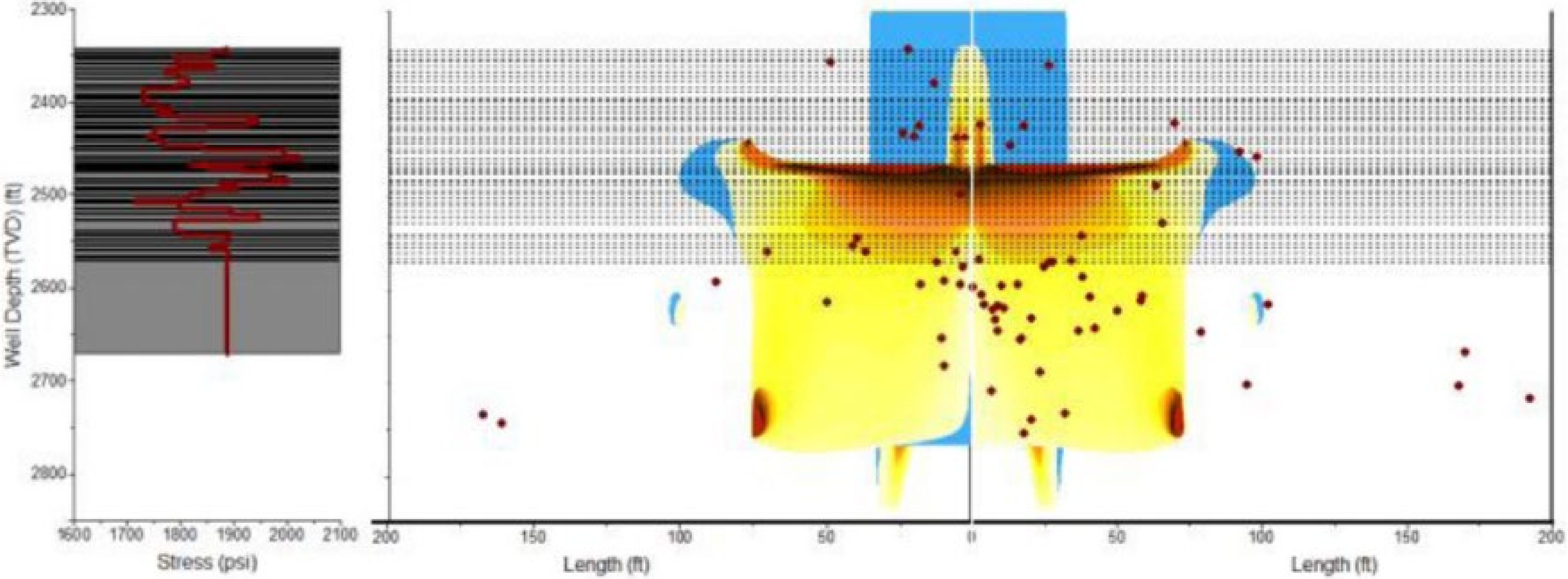
Predicting Fracture Growth during Well Completions

- The use of 2D models in 1D stress state driven by their robustness and expediency
  - Stability facilitates wide parameter studies
  - Short run times helpful in history matching
- The 1D stress model constrains planar-3D and pseudo-3D simulators when the stress regime deviates from normal ($S_v > S_H > S_h$)
- Non-planar fractures observed in minebacks
- Field diagnostics (e.g. microseismic, tiltmeters) has highlighted horizontal fracture growth
- A comparison of 2D simulators by Pandey and Flottmann (SPE-173378-MS) highlighted
  - Overestimation of simulated fracture height
  - Absence of observed horizontal fractures
  - Difficulty pressure-matching water treatments



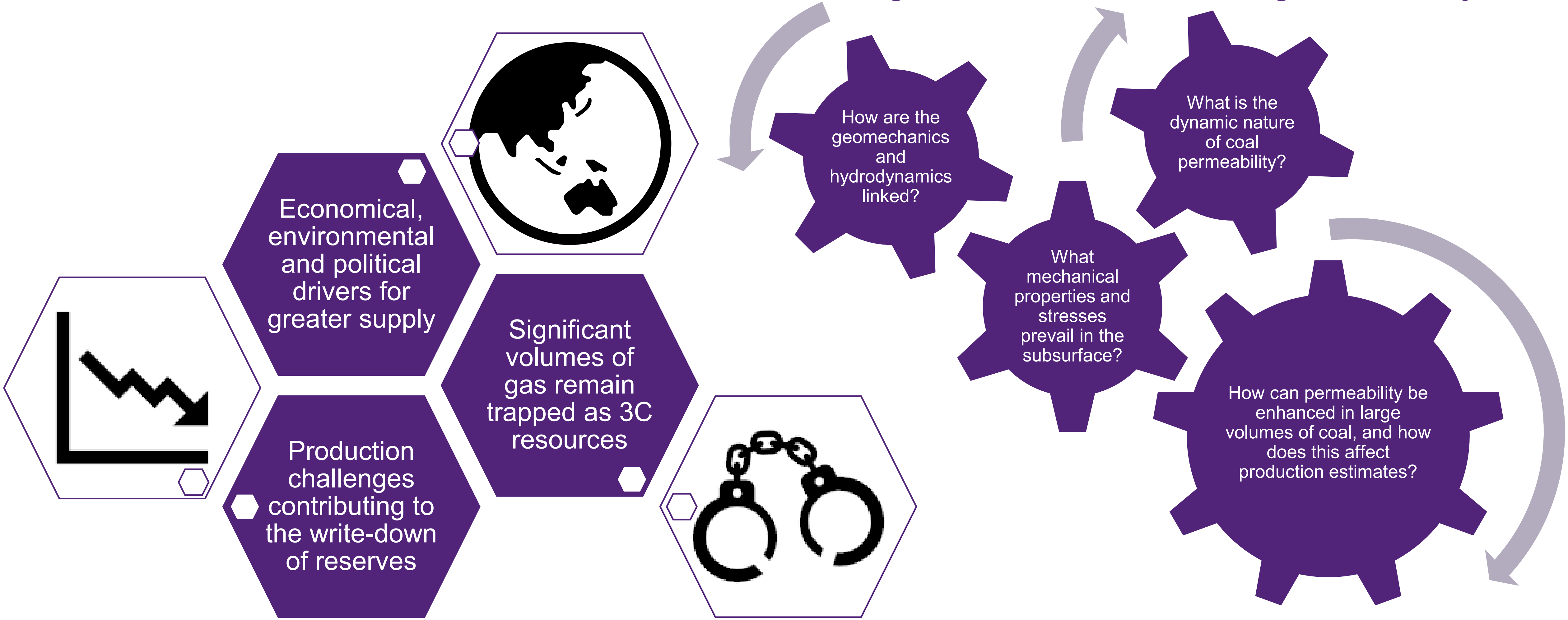
Successful pressure match for a well in the Surat Basin, Australia (reproduced from Pandey and Flottmann, SPE-173378-MS)

Predicting Fracture Growth during Well Completions



Discrepancy between simulated and observed fracture geometry for a single well stage in the Surat Basin (adapted from Pandey and Flottmann, SPE-173378-MS)

Resources to Reserves: Sustaining and Increasing Supply



Research Questions

- What is the near-wellbore stress state in coals, and how does it influence fracture initiation?
- How do hydraulic fractures propagate in coal and clastic rocks and interact with natural fractures?
- What is the injectivity of standard and novel proppant particles in CSG reservoirs?
- What is the long term retained permeability of induced and natural fractures, and the stimulated reservoir volume?
- What is the influence of greater understanding on production predictions, along with the associated uncertainty?

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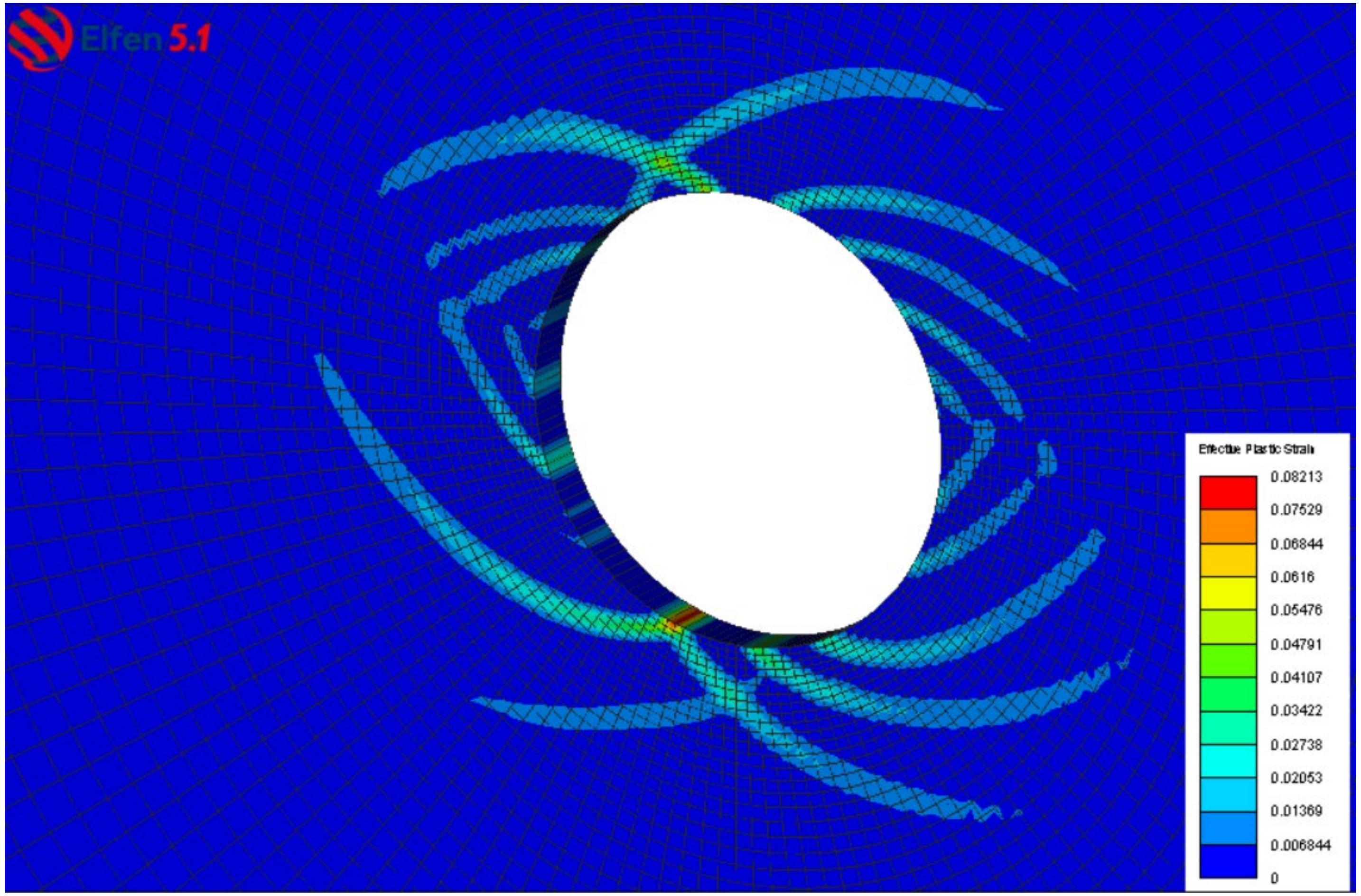
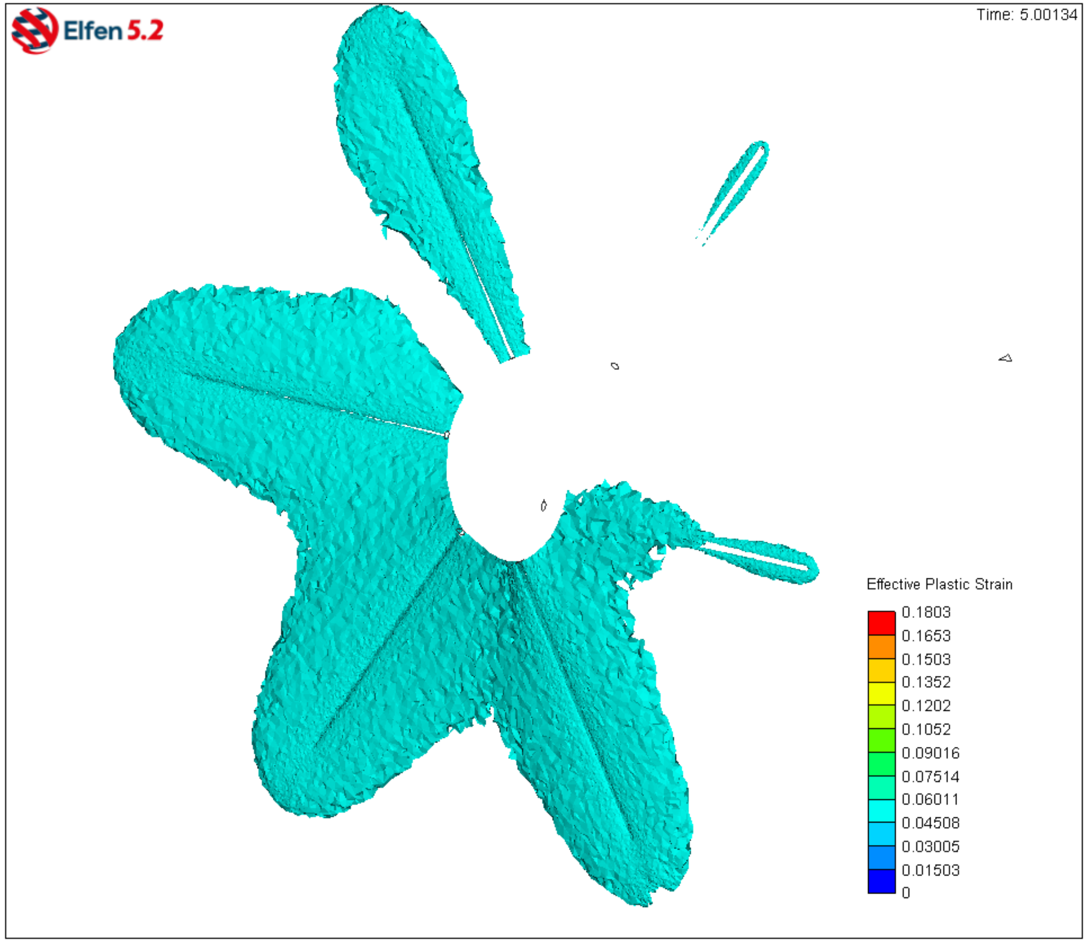
The Influence of Near-Wellbore Stress on Fracture Initiation





Prediction of near-wellbore damage following drilling.

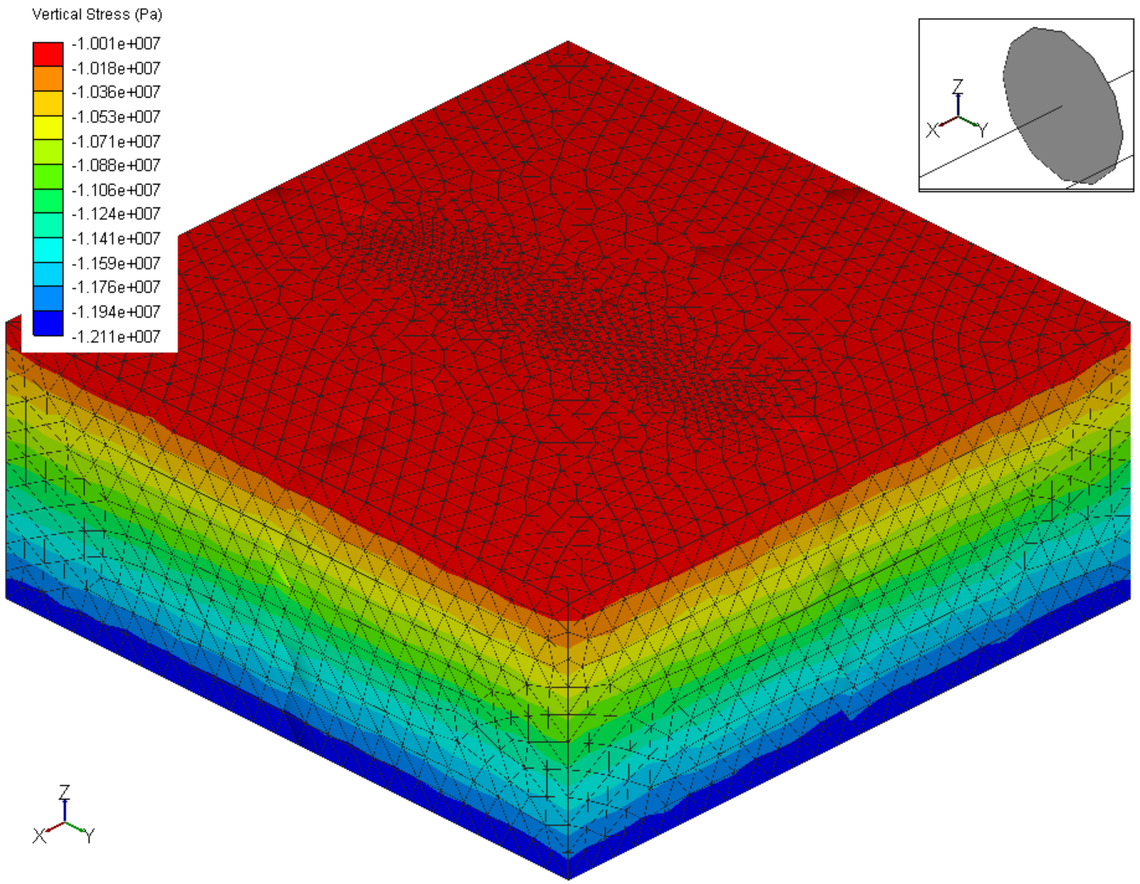
Coalescence of fractures around stage perforations.

3D FEM-DEM Modelling of a Synthetic CSG Well Stage

- Systematically vary the stress regime
  - NF = normal, SS = strike-slip, RF = reverse
- Sensitivity analysis on Young's Modulus
- Sensitivity analysis on pumping rate
- Influence of perforation orientation to stress

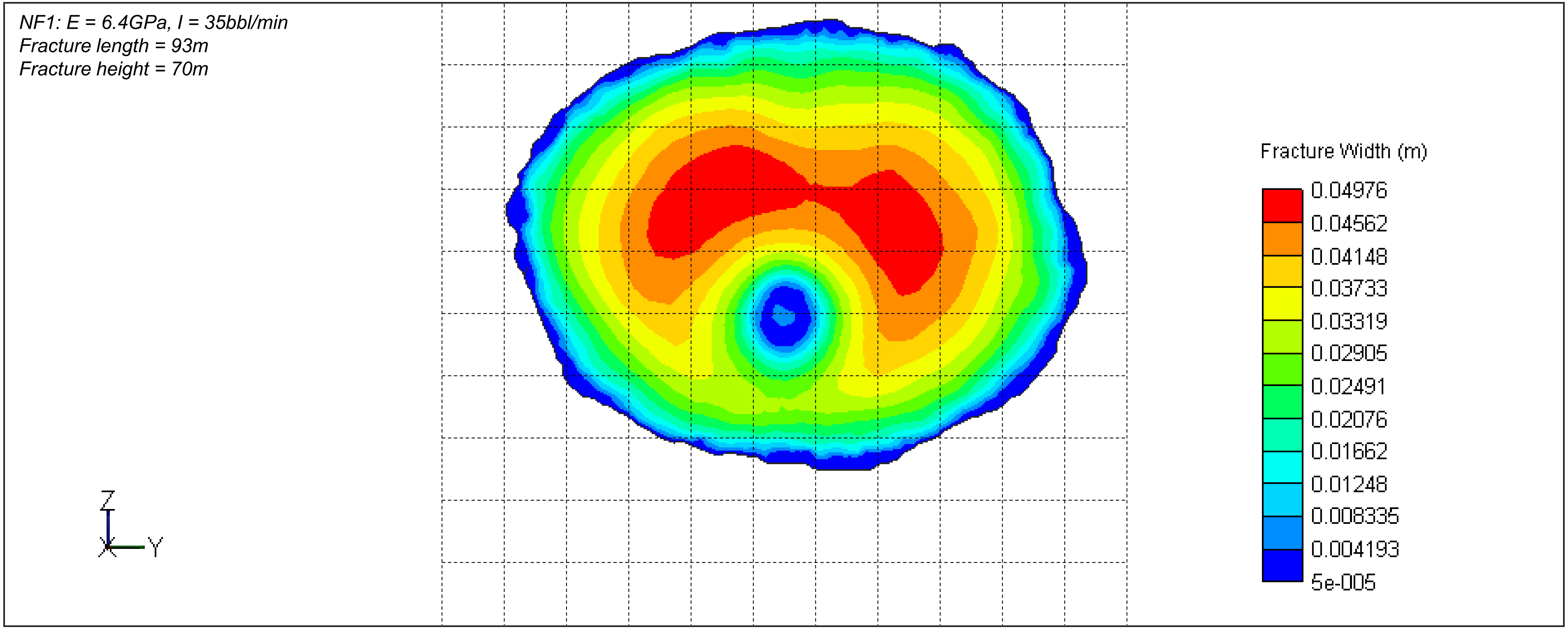
Model Name	K_h (-)	K_H (-)	θ (deg)	E (GPa;MMpsi)	I (bbl/min;m^3/s)
NF1	0.6	0.8	0	6.4; 0.928	35; 0.093
SS1	0.8	1.2	0	6.4; 0.928	35; 0.093
SS1B	0.8	1.2	45	6.4; 0.928	35; 0.093
RF1	1.2	1.4	0	6.4; 0.928	35; 0.093
NF2	0.6	0.8	0	6.4; 0.928	15; 0.040
SS2	0.8	1.2	0	6.4; 0.928	15; 0.040
SS2B	0.8	1.2	45	6.4; 0.928	15; 0.040
RF2	1.2	1.4	0	6.4; 0.928	15; 0.040
NF3	0.6	0.8	0	3.2; 0.464	35; 0.093
SS3	0.8	1.2	0	3.2; 0.464	35; 0.093
SS3B	0.8	1.2	45	3.2; 0.464	35; 0.093
RF3	1.2	1.4	0	3.2; 0.464	35; 0.093

Summary of the modelling campaign performed in this study (θ=45° indicates misalignment of S_H and starter fracture)

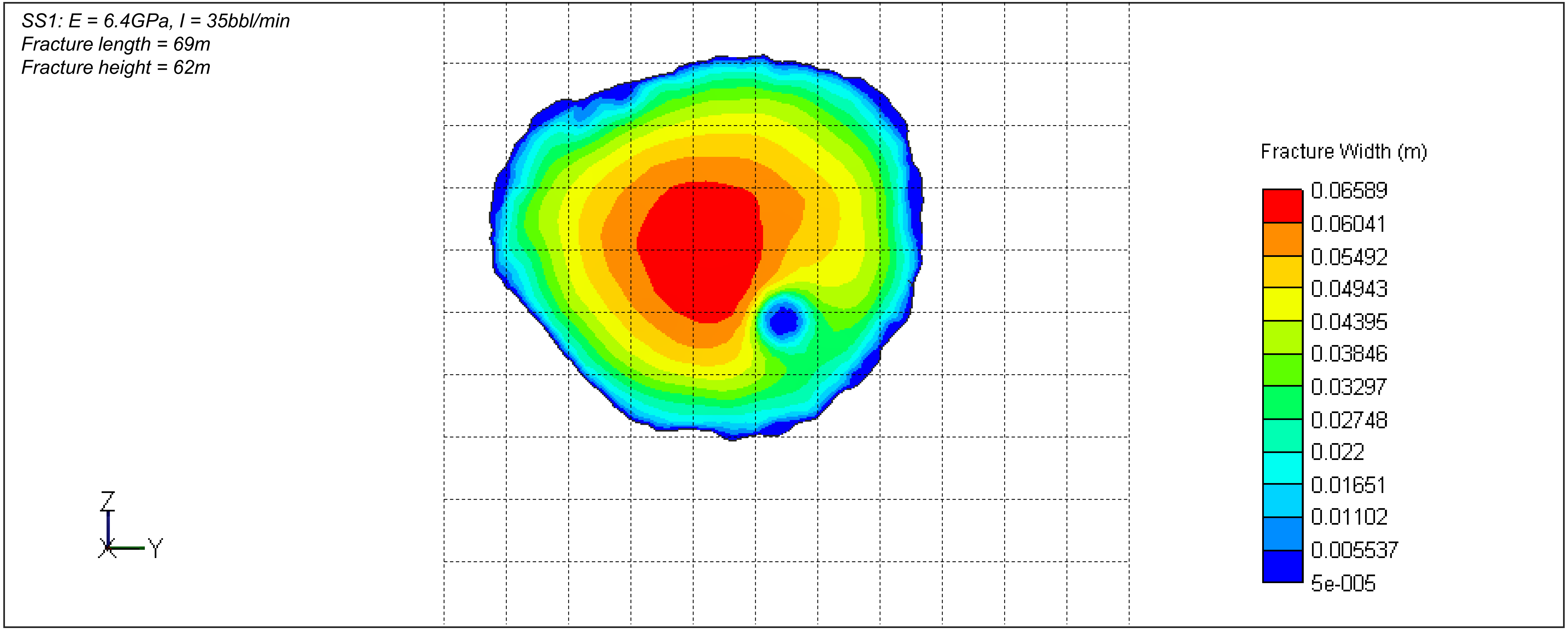


Contour plot of the vertical stress distribution in the model domain, including (inset) the orientation of the starter fracture with the y- (i.e. S_H) and z- (i.e. S_v) directions

Normal Faulting: S'_v=10MPa; S'_H=8MPa; S'_h=6MPa; P_p=7MPa

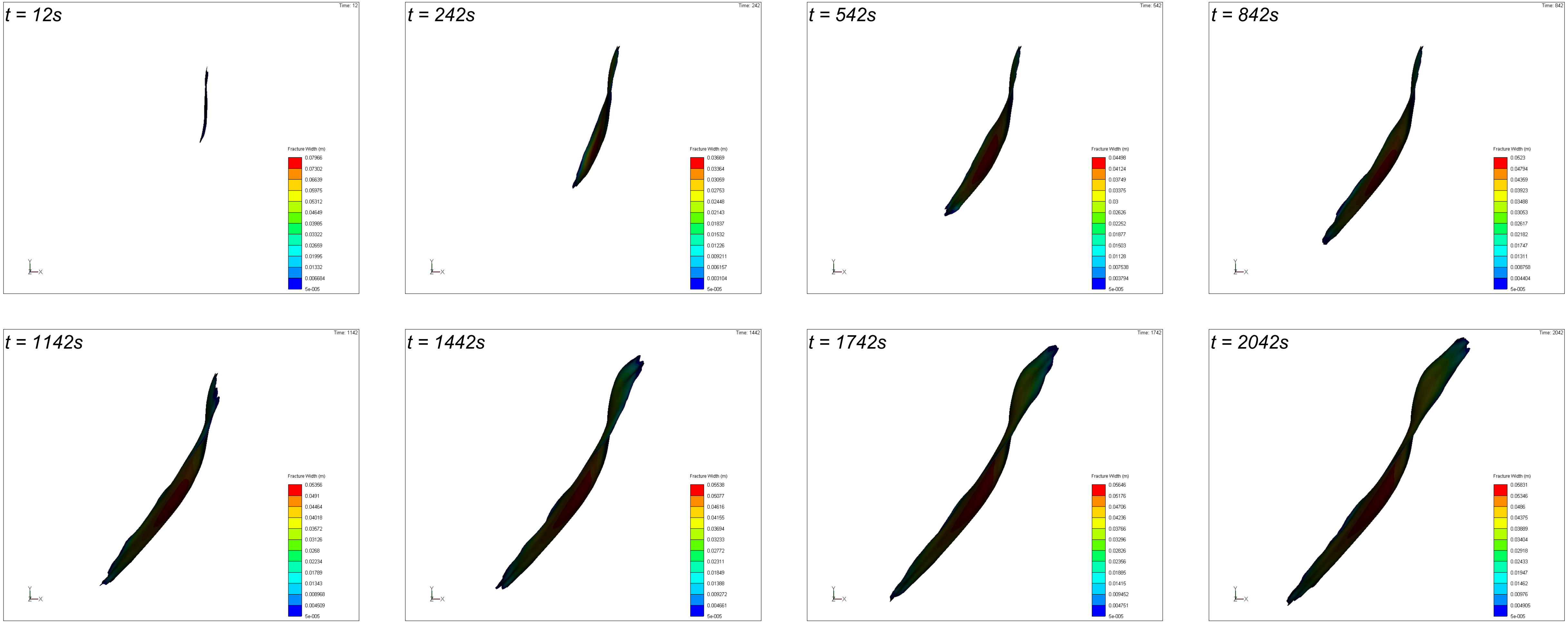


Strike-Slip: S'_H=12MPa; S'_v=10MPa; S'_h=8MPa; P_p=7MPa

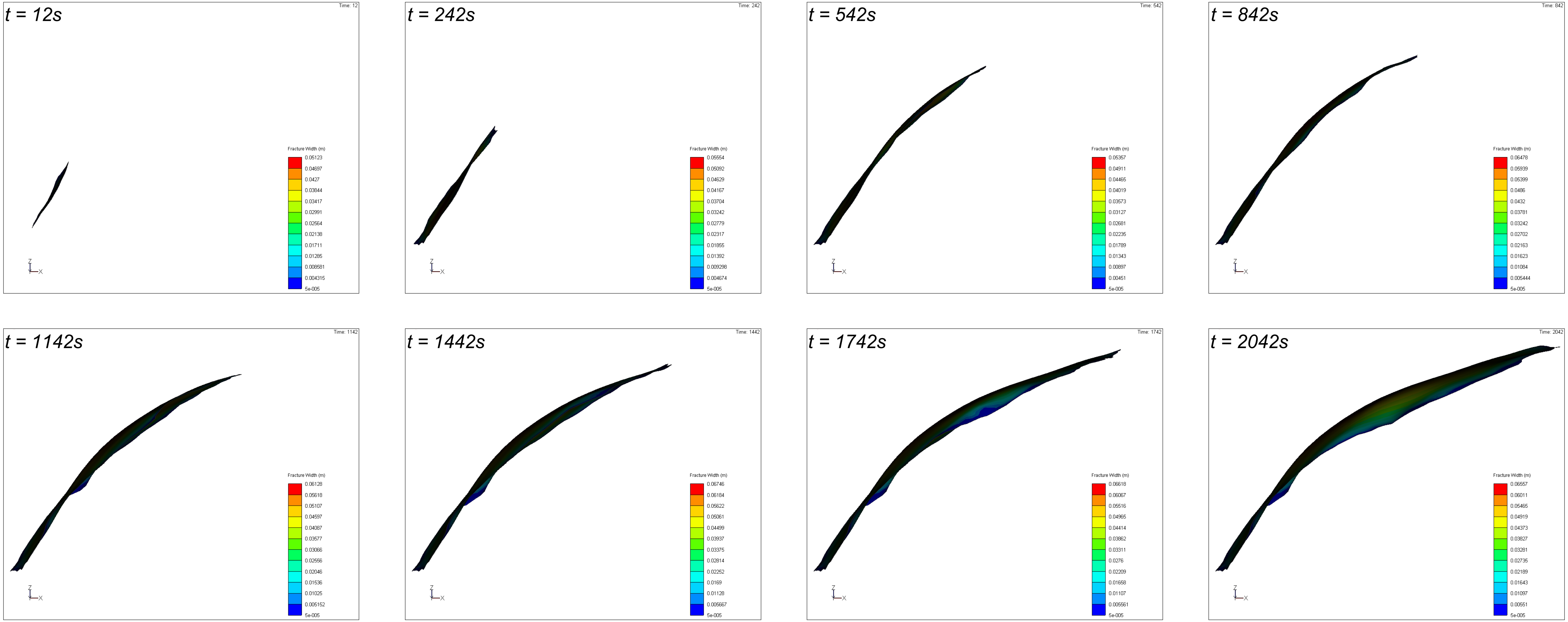


Transient Propagation: Normal Faulting and Strike-Slip

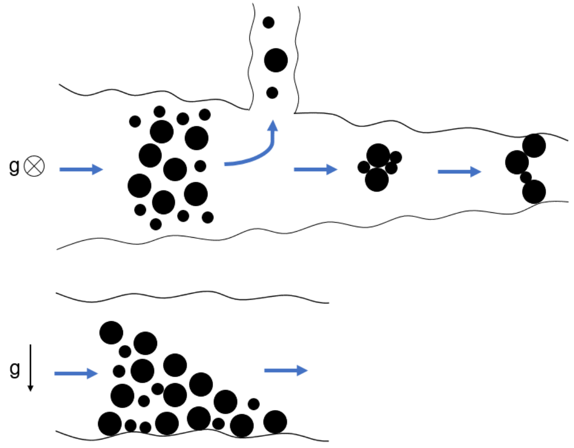
Strike Slip (Θ=45): S'_H=12MPa; S'_v=10MPa; S'_h=8MPa; P_p=7MPa

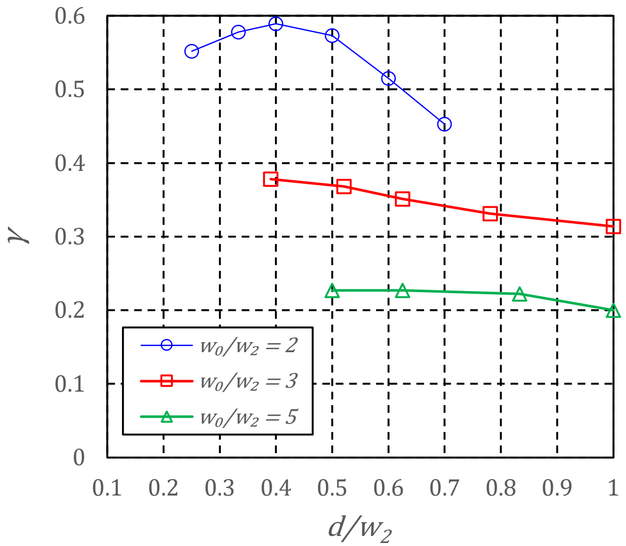


Reverse Faulting: S'_H=14MPa; S'_h=12MPa; S'_v=10MPa; P_p=7MPa

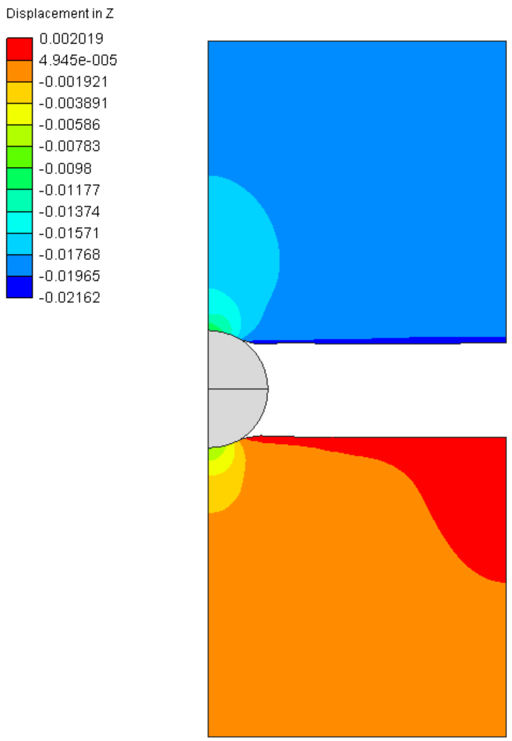


Injectivity and Straining of Proppant in Fractures

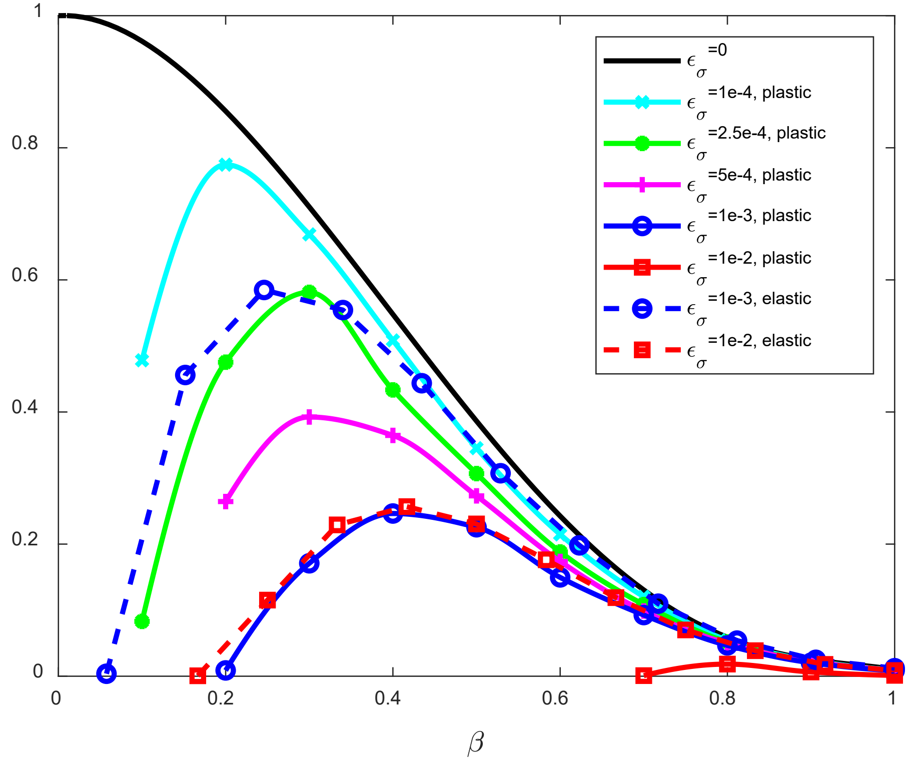




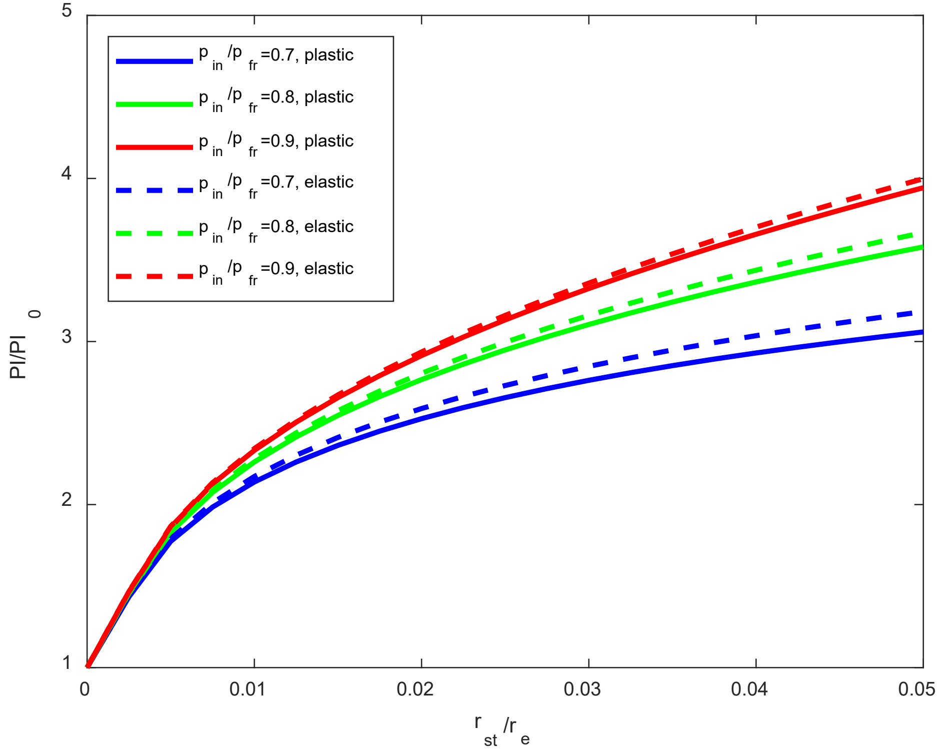
Closure of Propped Fractures under Closure Stress



Finite element model



Fracture permeability as a function of packing and stress



Change in productivity index as a function of embedment

Concluding Remarks

- Advanced computational modelling can provide new insight on the mechanics of CSG well stimulation
- The continuation of this work will incorporate productivity predictions based on enhanced stimulation
- Uncertainty must be quantified, and this is an area of ongoing research
- Repeatable, reliable and cost effective stimulation strategies will convert resources to reserves

- I would like to acknowledge:
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