A Monte Carlo Approach to Determine Stress Orientations and Differential Stress Ratios from Microseismicity and Earthquake Focal Mechanisms Using Elastic Dislocation Modelling*

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Search and Discovery Article #42138 (2017)**
Posted October 9, 2017

*Adapted from oral presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017

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Abstract

Microseismicity is widely used to monitor hydraulic fracturing stimulations. A new iterative-statistical approach to calculate stress orientations and ratios from microseismic moment tensors, taking into account the fault-auxiliary plane uncertainty, is presented here. The approach uses triangular dislocation modelling to predict the strain and stress associated with microseismic events. The calculated local stress field is then used to resolve the shear and normal stress on focal planes in order to establish an instability criterion. The new technique uses an iterative Monte Carlo approach to randomly select one of the two nodal planes and corresponding slip vector at each focal mechanism. Using elastic dislocation modelling, locally induced stresses are calculated for each nodal plane according to the mechanical properties of the rock volume taking into account the mutual interaction between nodal planes. After each run, a fracture instability criterion is applied to identify unstable nodal planes that are used in a stress inversion. Thus, stress orientations and differential stress ratios can be statistically identified by investigating the result from hundreds of iterative stress inversions. The results are compared to an alternative stress inversion method that does not consider elastic deformation. In this approach, iterative Monte Carlo simulations are run to choose a random subset of microseismic events, of which one of the two nodal planes and the corresponding slip vector are randomly selected. Following a first approximation of the stress field using stress inversion, a fracture instability constraint is used to only select unstable fracture planes for a second, more refined stress inversion. Running a large number of stress inversions results in a range of possible stress orientations and differential stress ratios. These new techniques are tested on earthquake data to evaluate the approach before being applied to microseismic events from hydraulic fracturing of two wells in the Barnett shale in Texas. Comparison with existing stress inversion approaches shows that inversion techniques based on Monte Carlo fracture response modelling provides a more comprehensive assessment of the stress regime responsible for the microseismic events. This leads to a more restricted range of possible stress orientations and differential stress ratios, which can be used to evaluate fracture trends and model discrete fracture networks (DFN).

References Cited

Vavryčuk, V., 2001, Inversion for parameters of tensile earthquakes: J. Geophys. Res., v. 106/16, p. 339-355, doi:10.1029/2001JB000372.

Vavryčuk, V., 2011, Tensile earthquakes: Theory, modeling, and inversion: J. Geophys. Res., v. 116/ B12320, Web Accessed September 30, 2017, https://www.ig.cas.cz/userdata/files/personal-pages/v-vavrycuk/Publications/jgr2011_vavrycuk.pdf

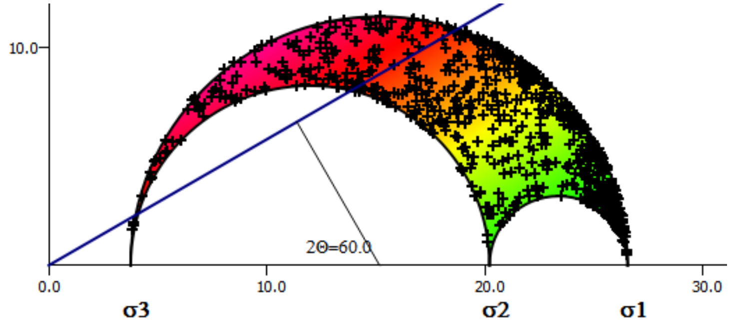
A Monte Carlo approach to determine stress orientations and differential stress ratios from microseismicity and earthquake focal mechanisms using elastic dislocation modelling

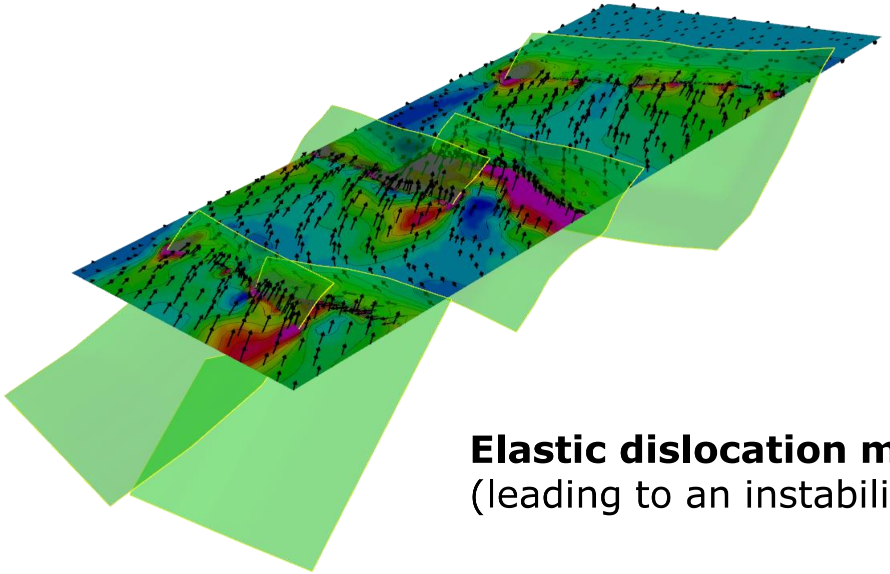
H. Broichhausen, C. Seiler, E. Macaulay

3 April 2017

New stress inversion techniques for focal mechanisms

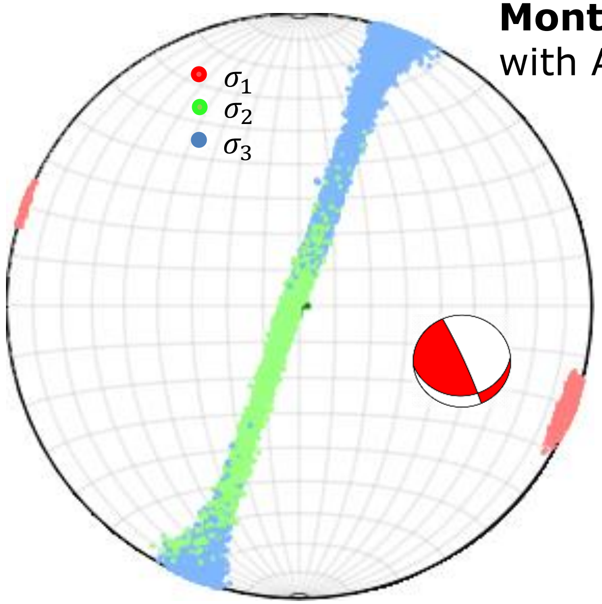
Iterative stress inversions
using an instability criterion



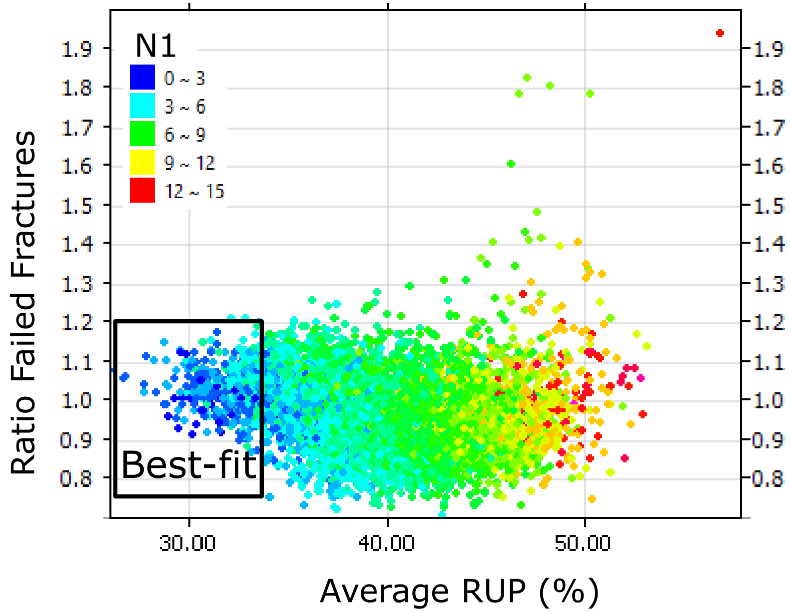


Elastic dislocation modelling
(leading to an instability criterion)

Monte Carlo simulation in combination
with Angelier's direct stress inversion



Confidence estimators cross plot



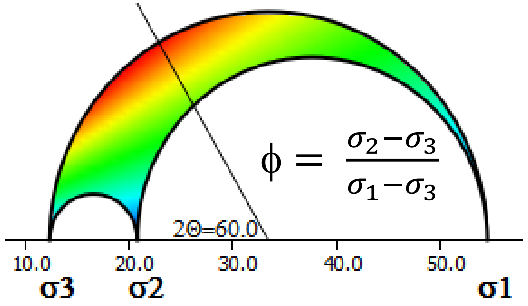
Introduction

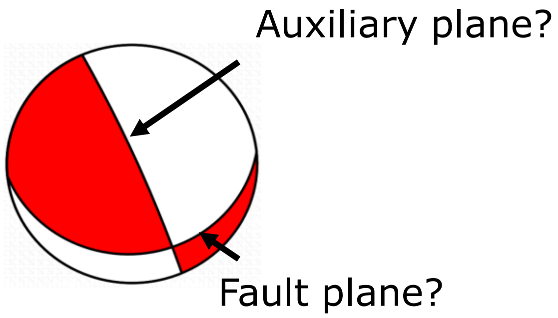
- Quantifying stress regimes in hydrofracturing fields is fundamental for:
  - Understanding fracturing mechanisms
  - Mechanical heterogeneity
  - Well planning and production strategies

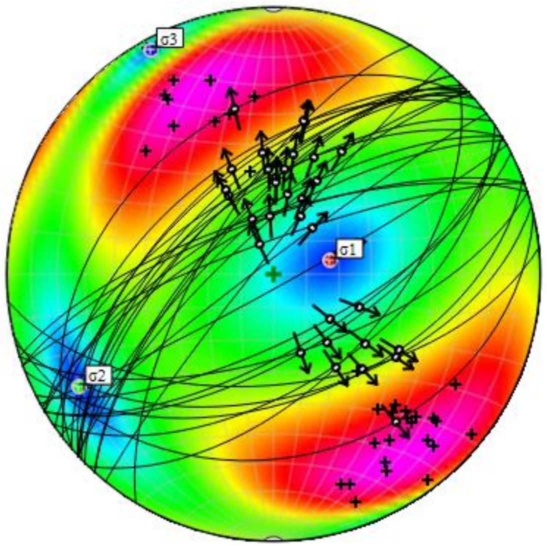
- Most stress inversion approaches require:
  - **Homogenous** (single stress regime)
  - **Shear** failure (Wallace-Bott hypothesis)

- In hydraulic fracturing we are facing:
  - **Heterogeneous** (multiple stress regimes)
  - **Shear and tensile** failures (tensile earthquakes)
  - **Two** nodal planes (fault/auxiliary plane)

→ This can lead to incorrect stress regimes.







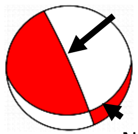
Stability inversion

Statistical Assumption:

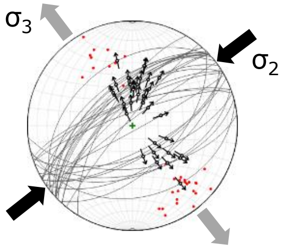
50% of the planes are statistically auxiliary planes and as such shouldn't fail the instability criterion.

Repeat thousands of times

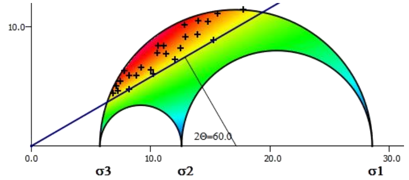
- **Randomly** choose **one of the nodal planes** at each event location



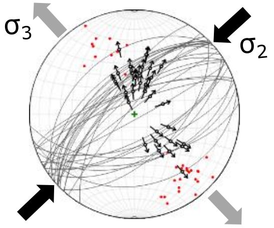
- **I. Stress inversion** on ALL shear planes

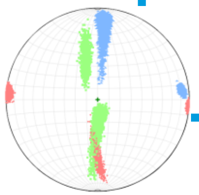


- Filter fracture planes on stability criterion



- **II. Stress inversion** on instable shear planes

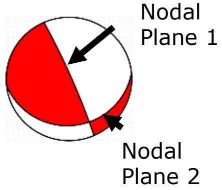




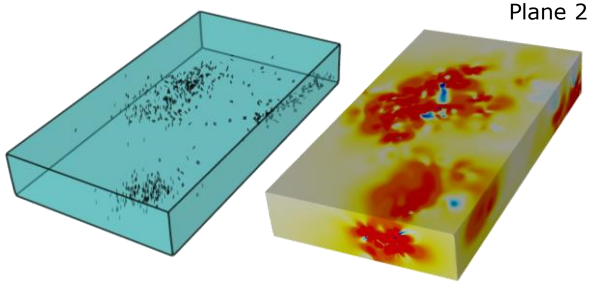
Fracture Response Stability Inversion (FRS inversion)

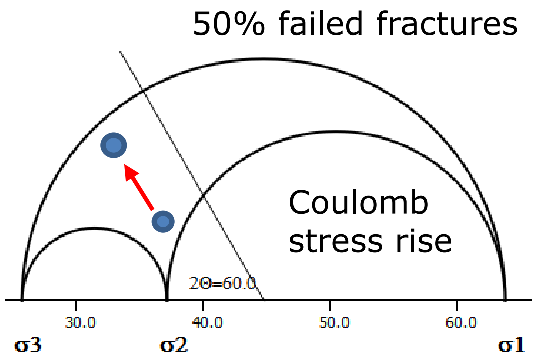
Repeat thousands of times

- **Randomly** choose **one of the nodal planes** at each event location

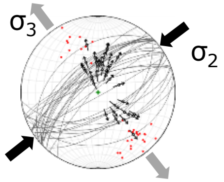


- **Elastic Dislocation Modelling**

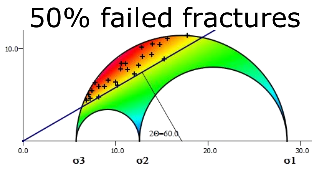




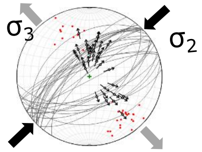
- **I. Stress inversion** on planes where Coulomb stress rises

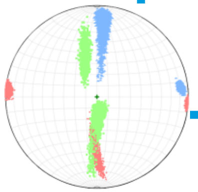


- Filter fracture planes on stability criterion



- **II. Stress inversion** on instable shear planes





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Stress inversion: Confidence estimators – the estimator cross plot

Angelier's confidence estimators

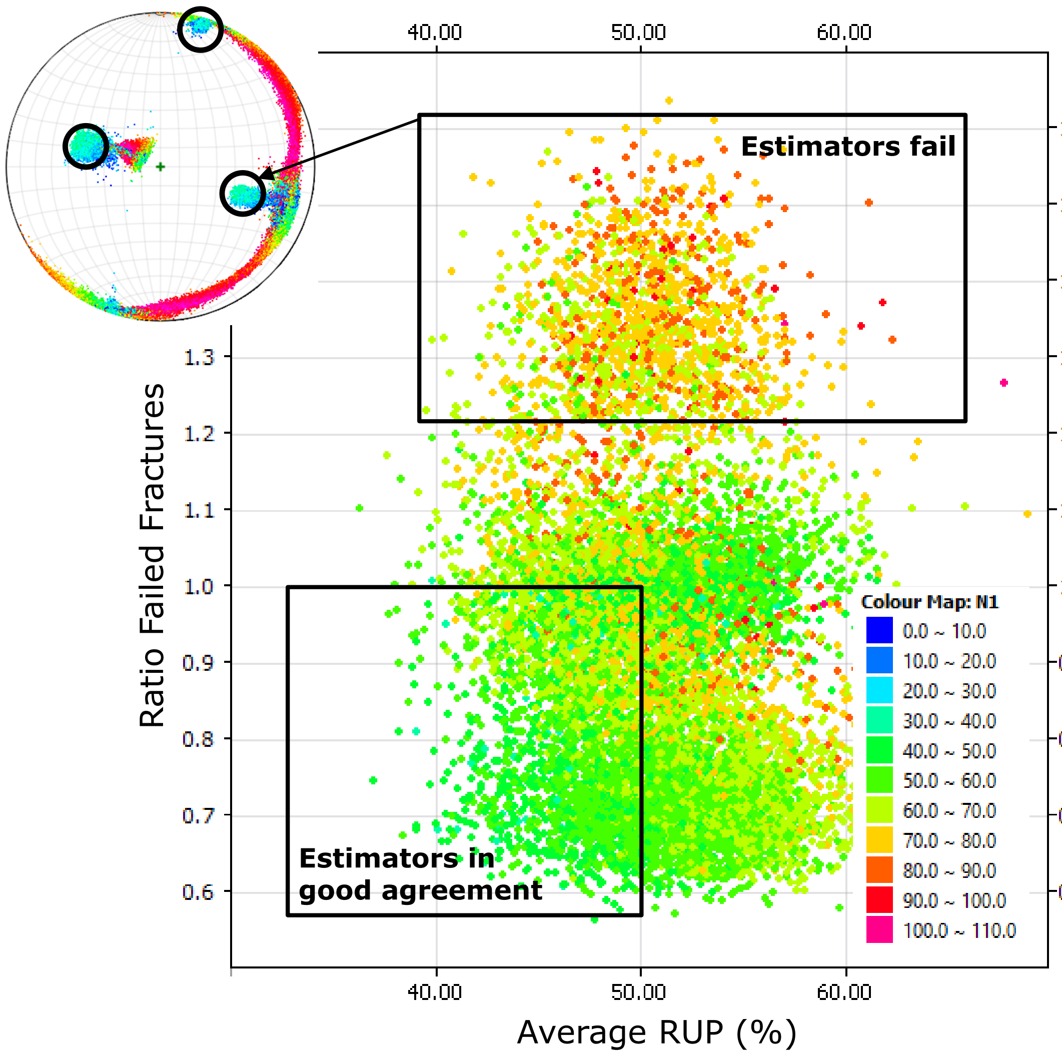
Average RUP value: RUP values range 0-200%
0 % shear stress parallel to slip with same sense,
200 % shear stress maximum parallel to slip with opposite sense

RUP values below 50% correspond to a good fit between actual fault slip data and the calculated maximum shear stress

New confidence estimator

Ratio of failed fractures

0	failed fractures after second inversion **higher**	1	failed fractures after second inversion **lower**	>10
	good agreement		not in good agreement	



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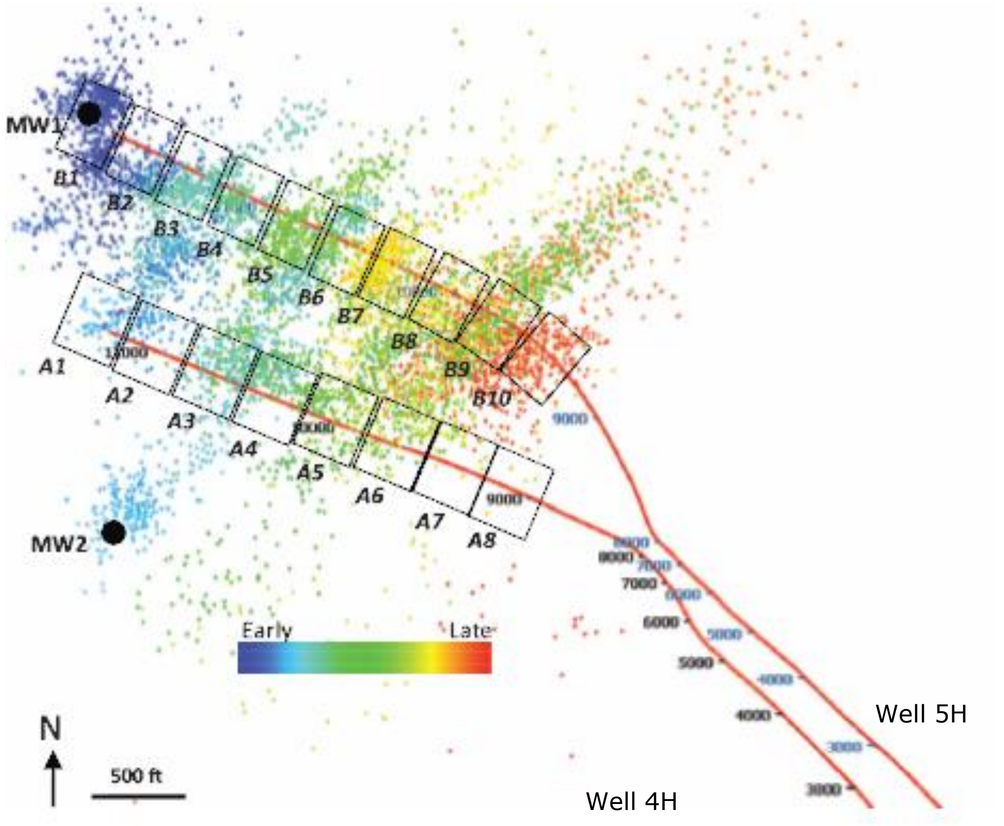
Study area located in NE Texas

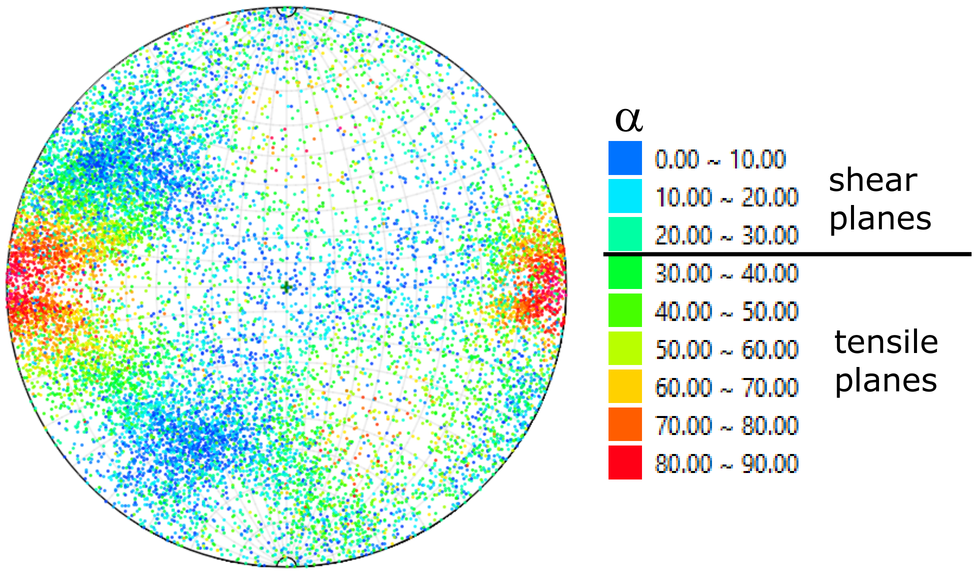
Two wells in the Barnett shale play. Microseismic events from hydraulic fracturing are shown as dots and colour coded for event stages.



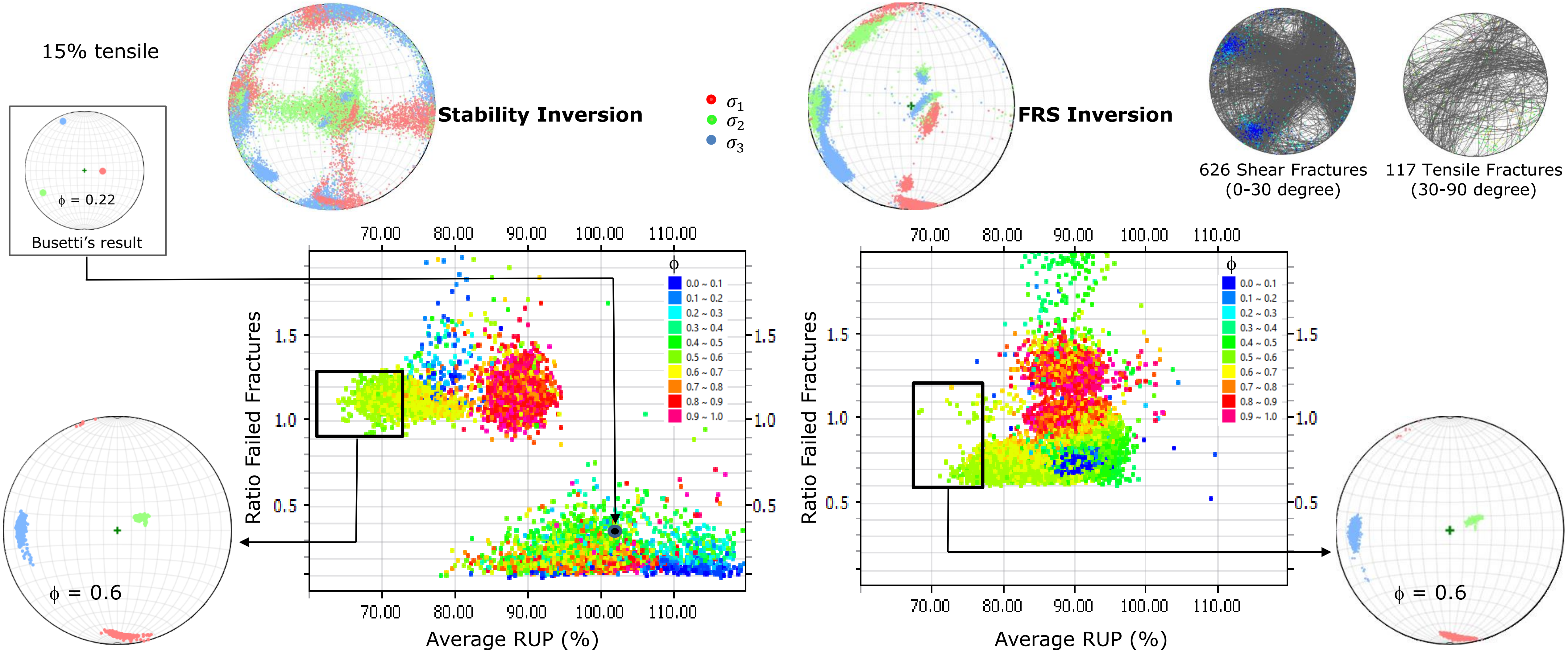
Busetti *et. al* 2014

Source parameters derived from Moment tensor:

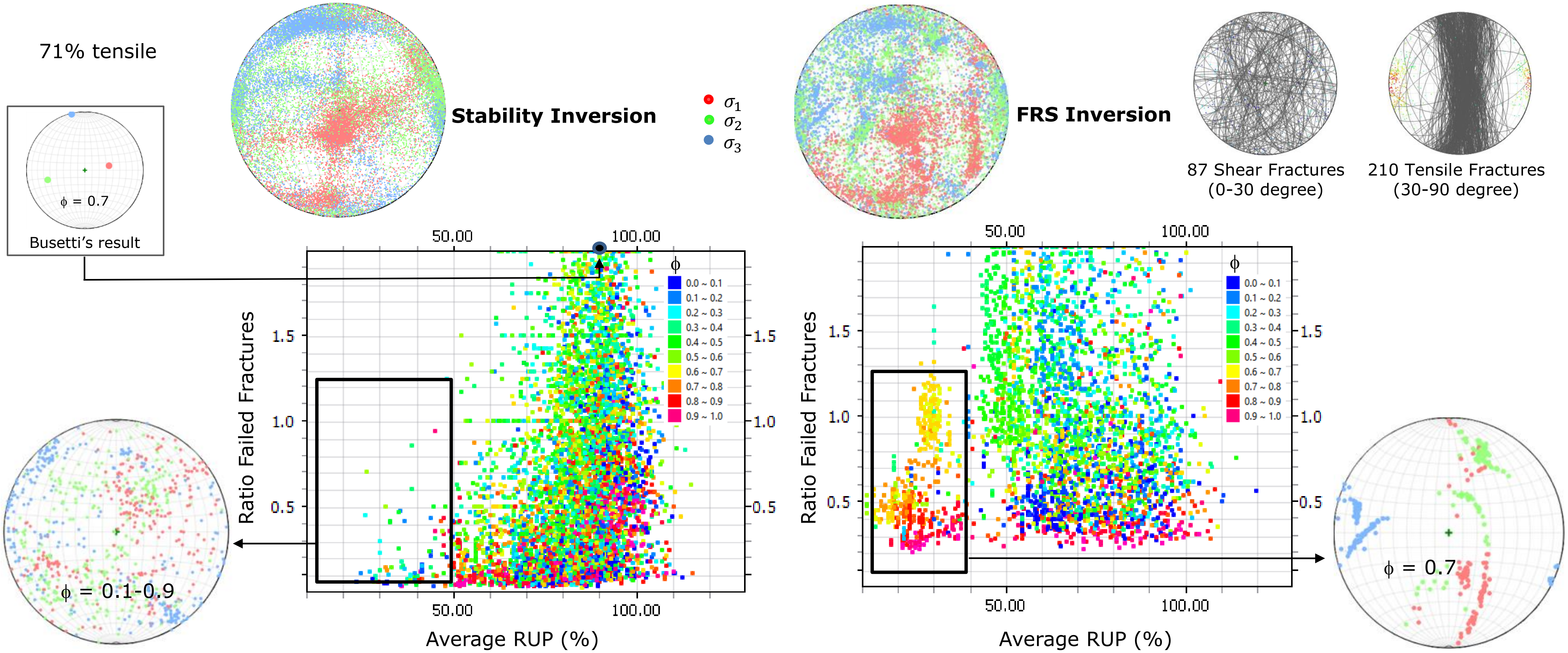
- **Focal plane orientation**
- **Slip vector**
- **Deviation angle** α (Vavrycuk V. 2001, 2011)



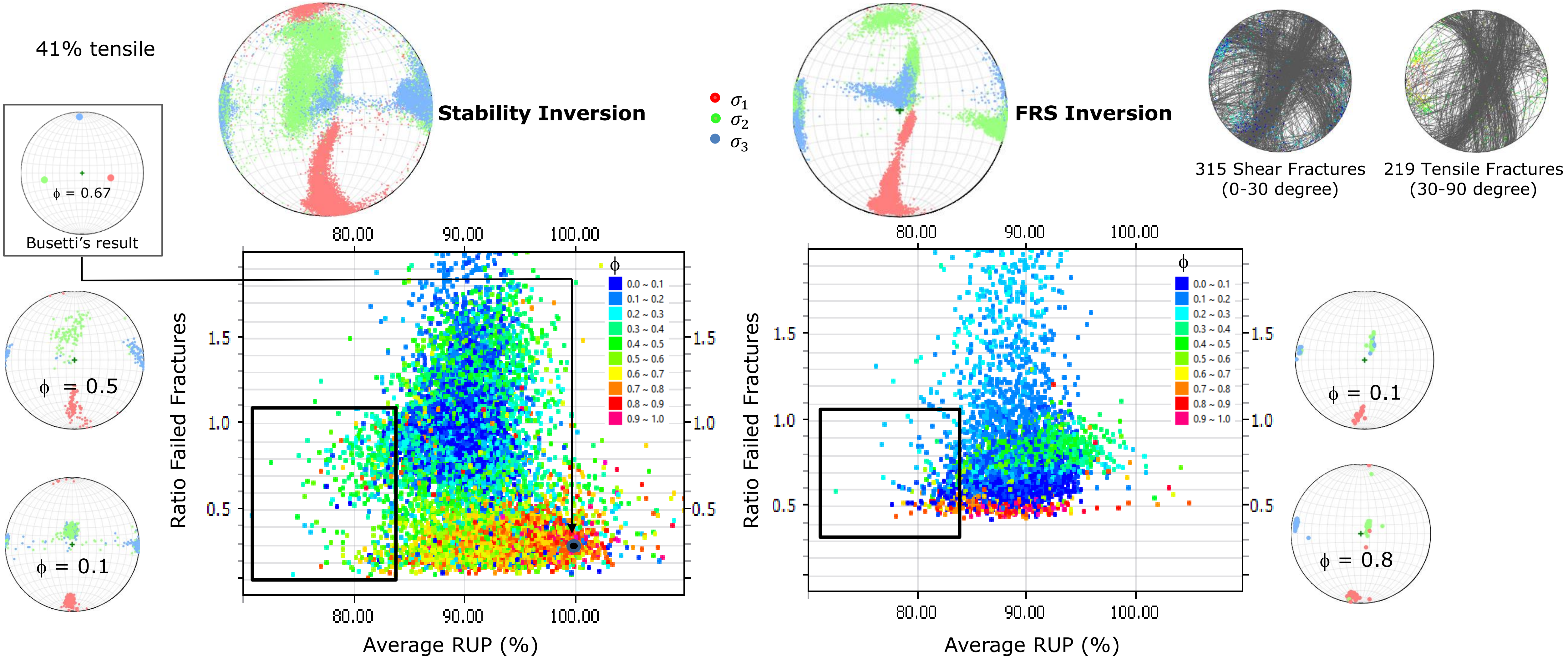
Shear dominated - Well 5H Stage 7



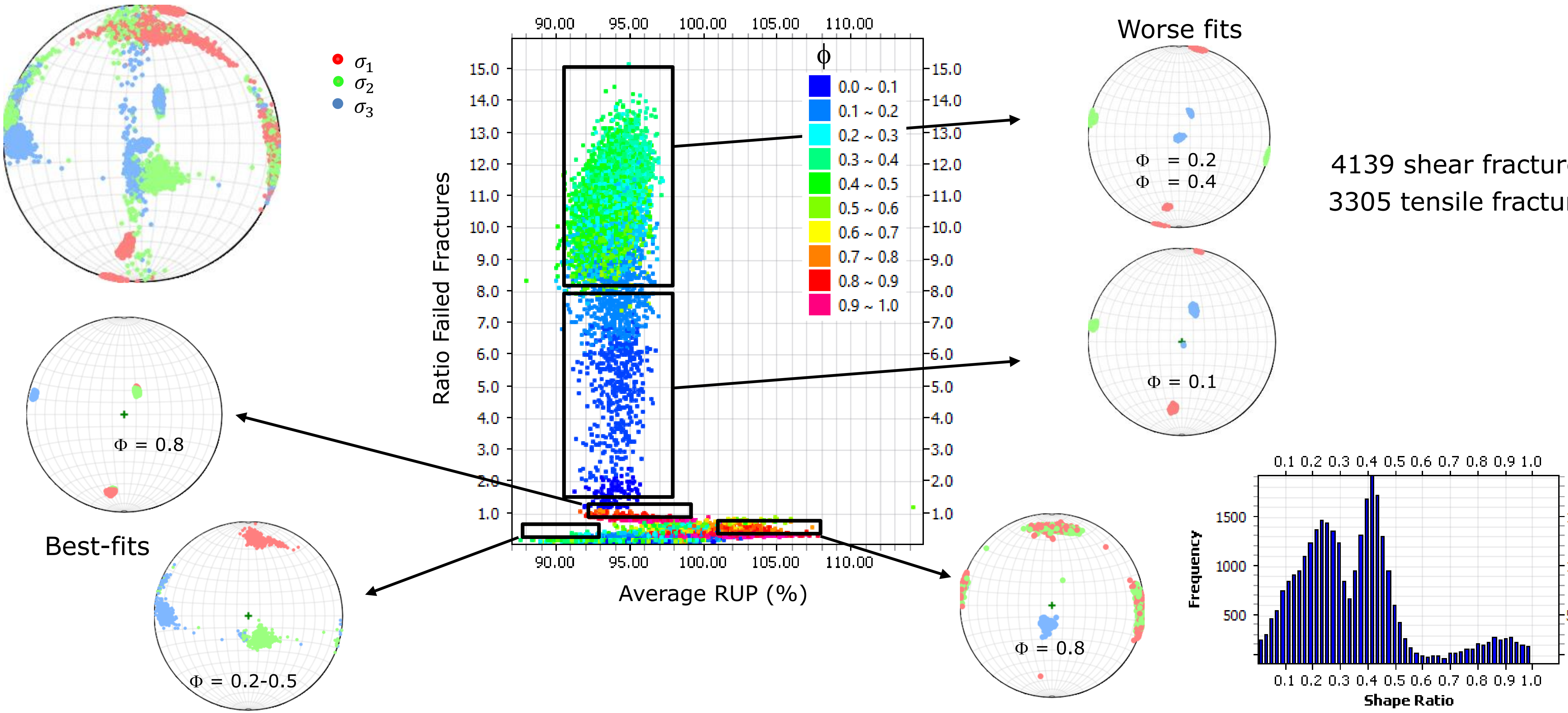
Tensile dominated - Well 5H Stage 2



Well 5H Stage 5: no unique solution



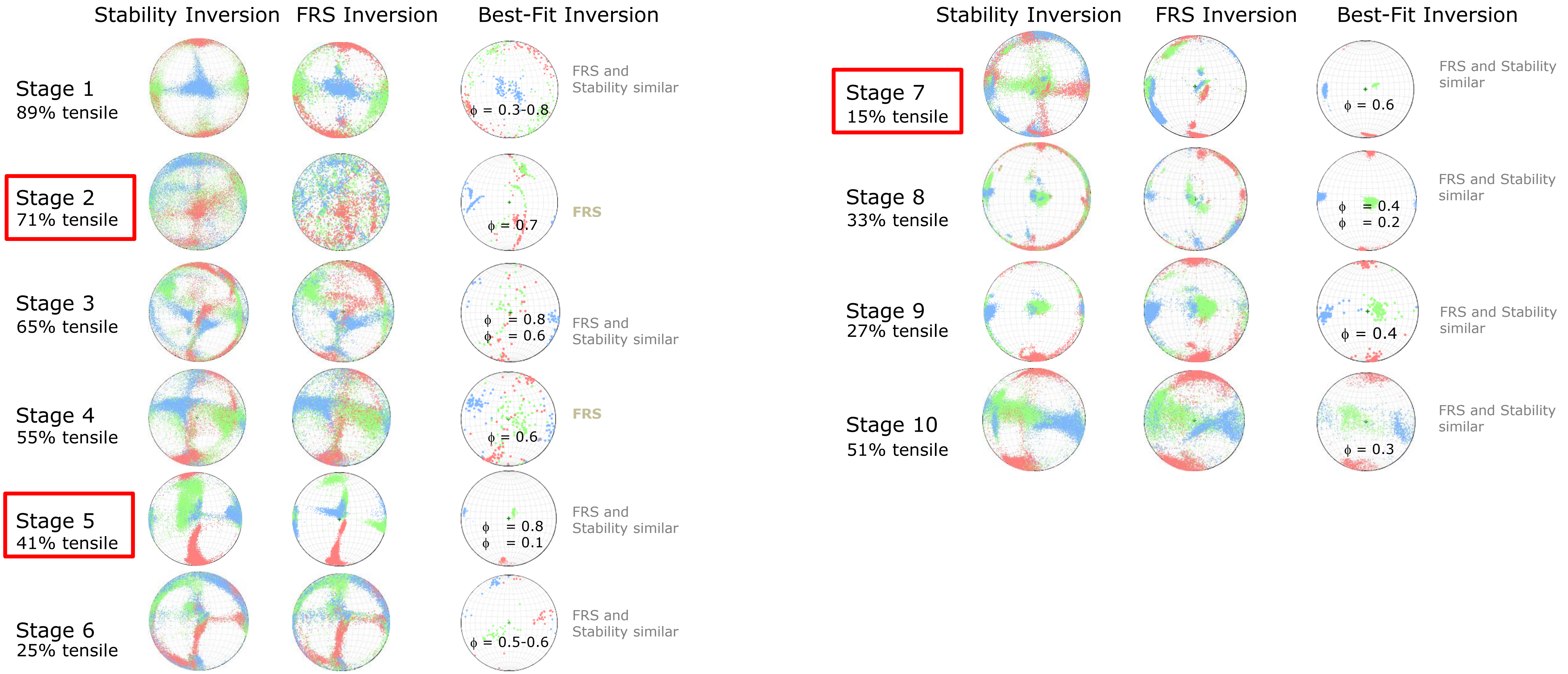
Stability inversion for all stages together: all 7444 events



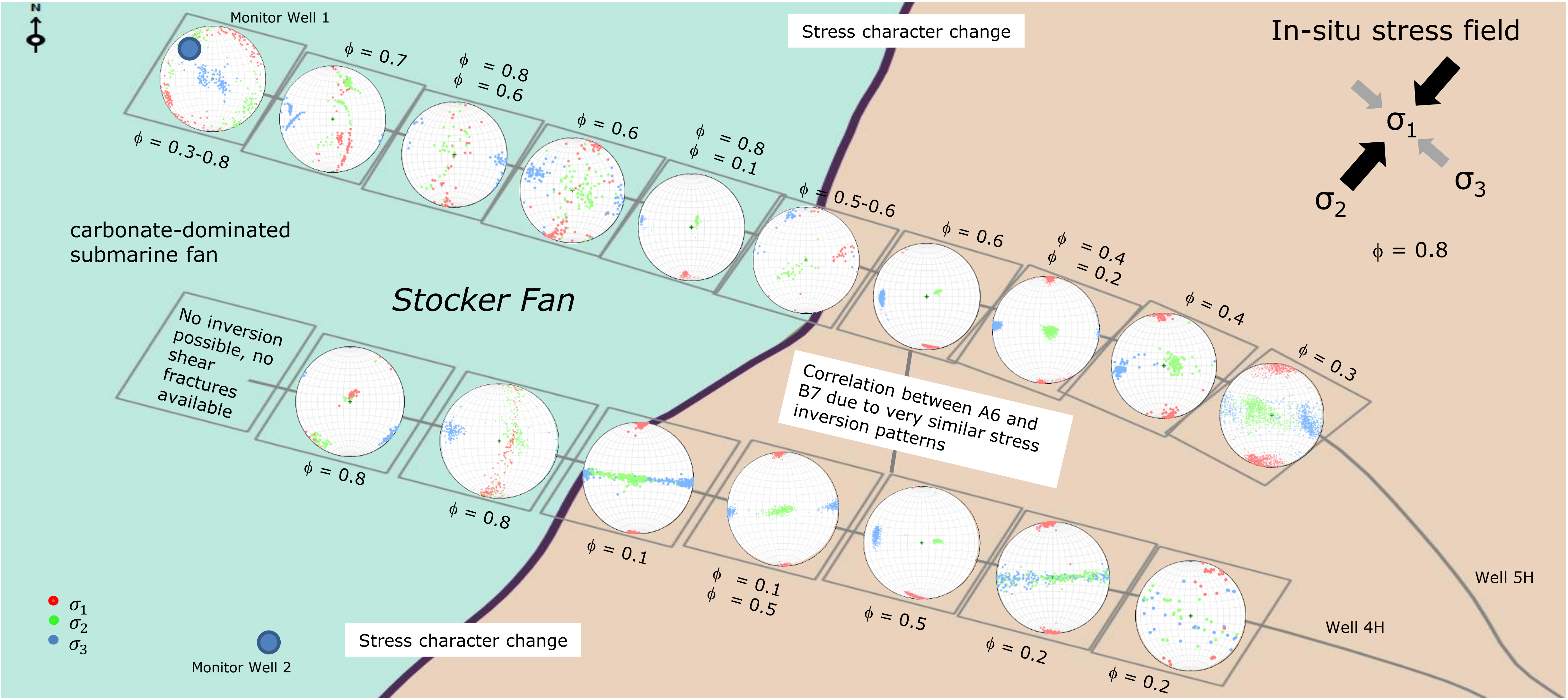
4139 shear fractures

3305 tensile fractures

Well 5H: Stress inversion results



Summary of all Stress Inversion Results



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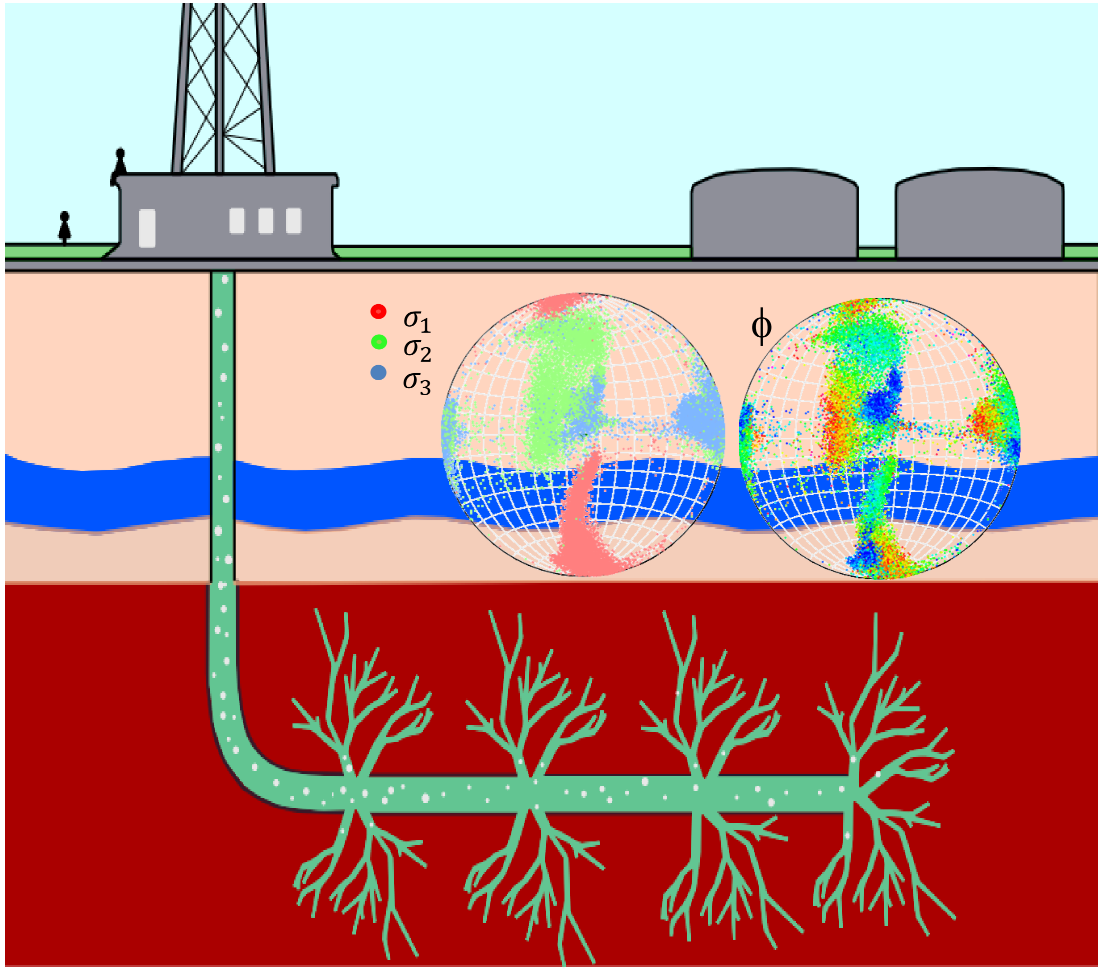
Conclusions

- Monte Carlo simulation using elastic dislocation theory provides a more comprehensive representation of the stress field, and allows both tensile and shear fractures to be considered.

- This approach also allows the uncertainty in stress regimes to be quantified and allows heterogeneity related to differences in rock mechanics to be determined.

- Understanding the stress field, which will inform well planning.



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Acknowledgements

We thank ConocoPhillips Company for supporting our work through the donation of this field data set.

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