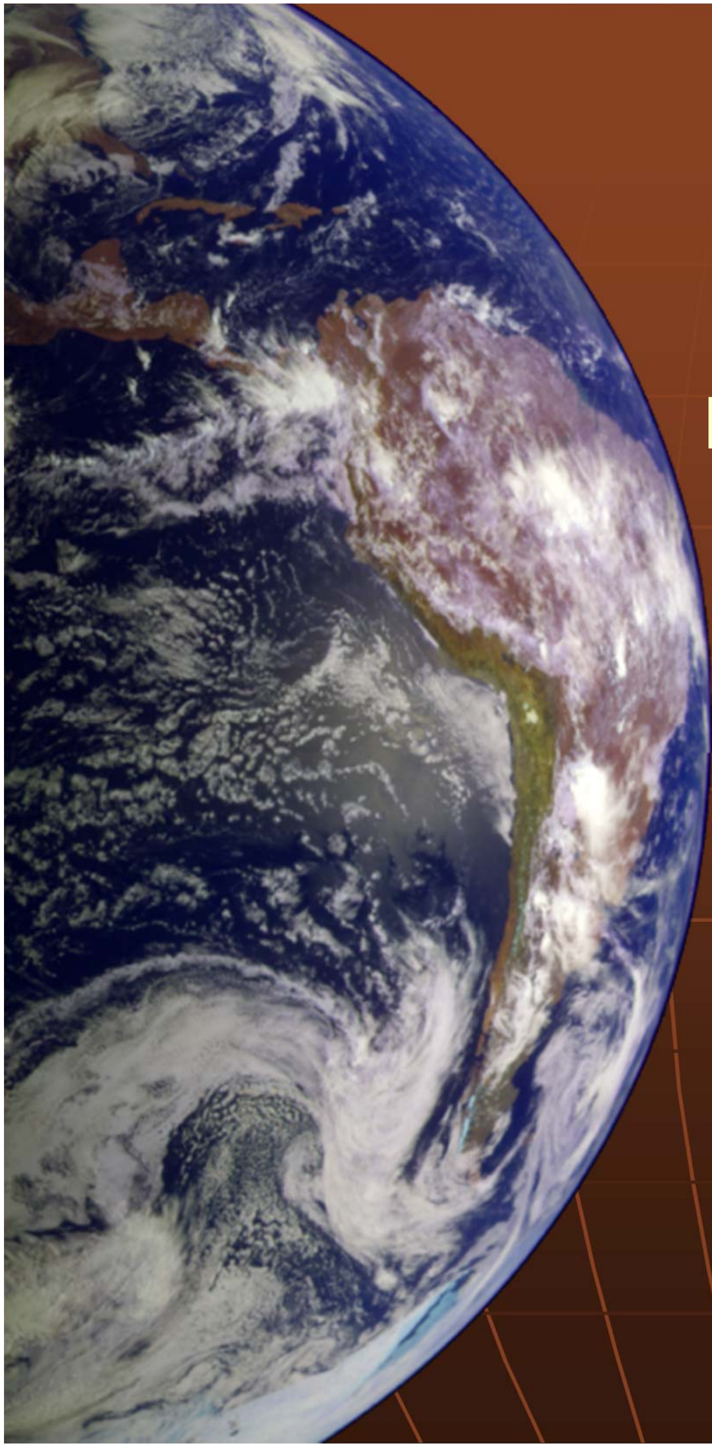
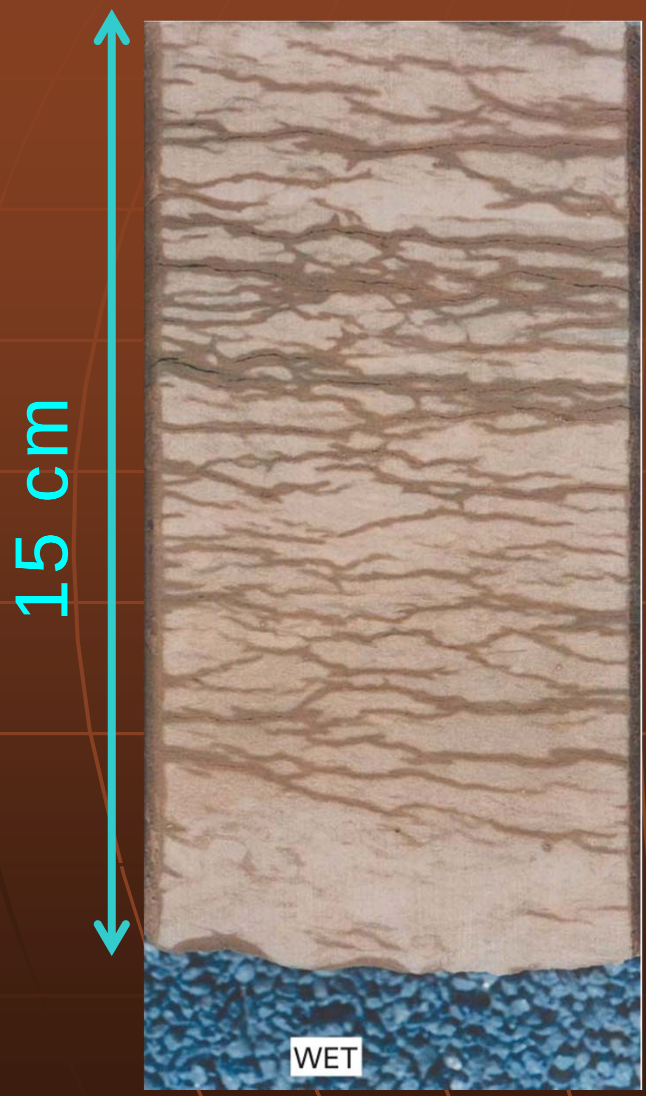


Fracture density characterization in tight rocks

Kyle Spikes
UT-Austin

Motivation



From Pitman et al., 2001, USGS Professional Paper

Fracture density $$\varepsilon_{cd} = \frac{Na^3}{V} = \frac{3\phi^{crack}}{4\pi\alpha}$$

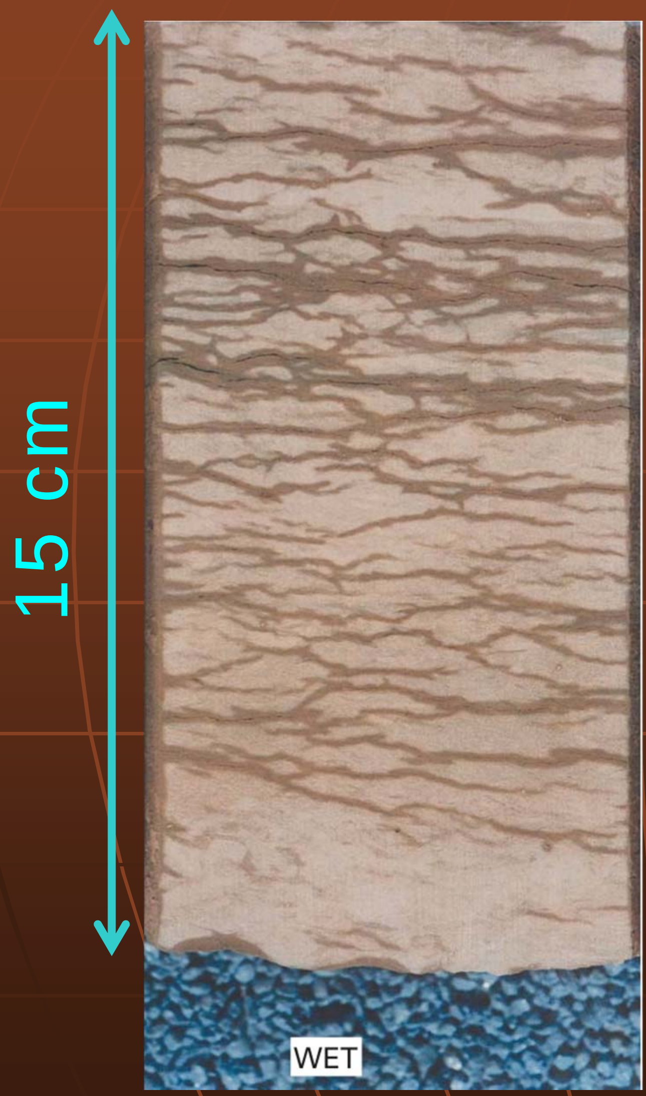
Product of number of fractures and average radius per volume

Varies as a function of fracture orientation and composition

An indicator of increased permeability

To relate to elastic properties, must account for composition, fracture orientation and shape, fluid content, and fracture volume

Motivation



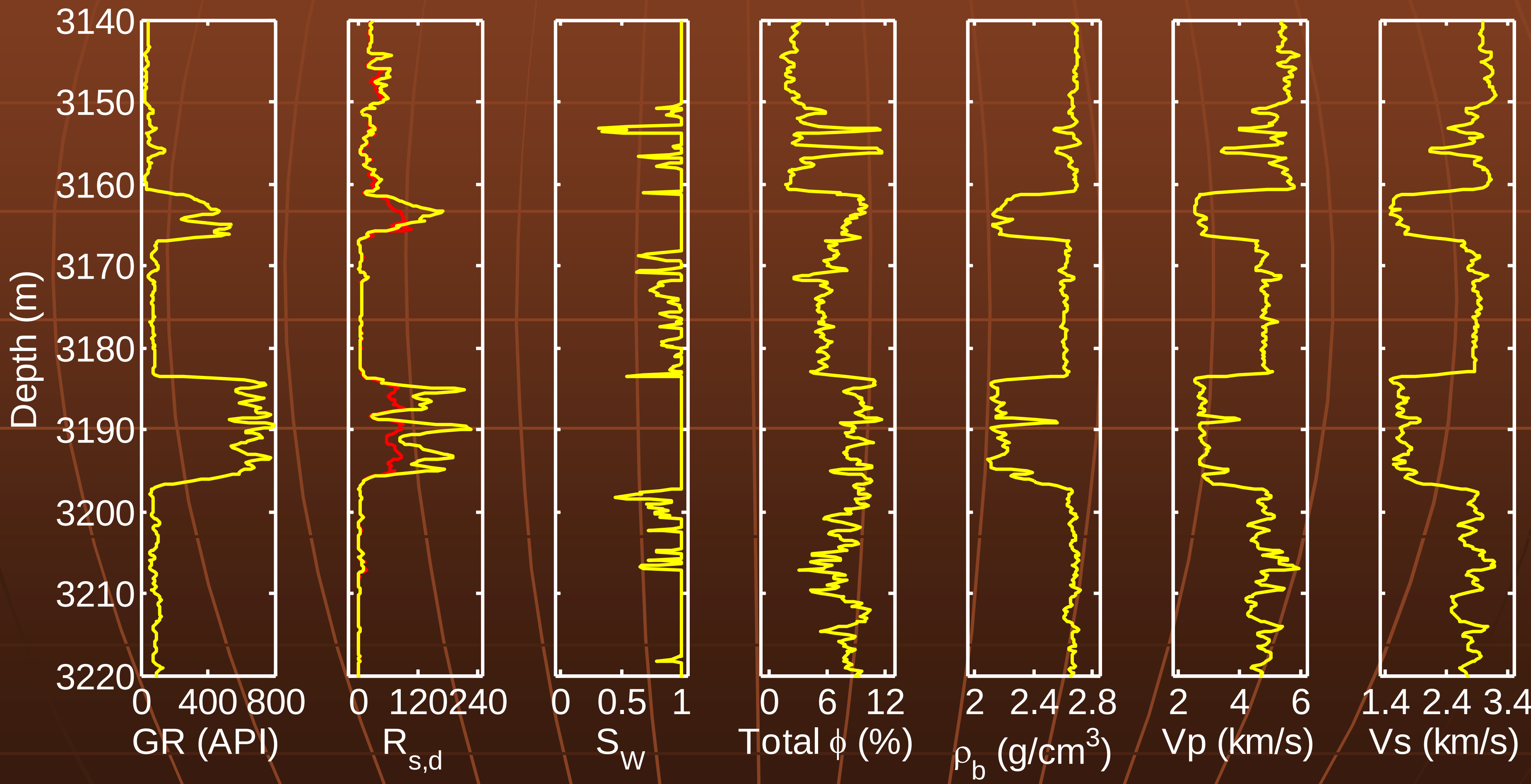
From Pitman et al., 2001, USGS Professional Paper

Middle Bakken Siltstone

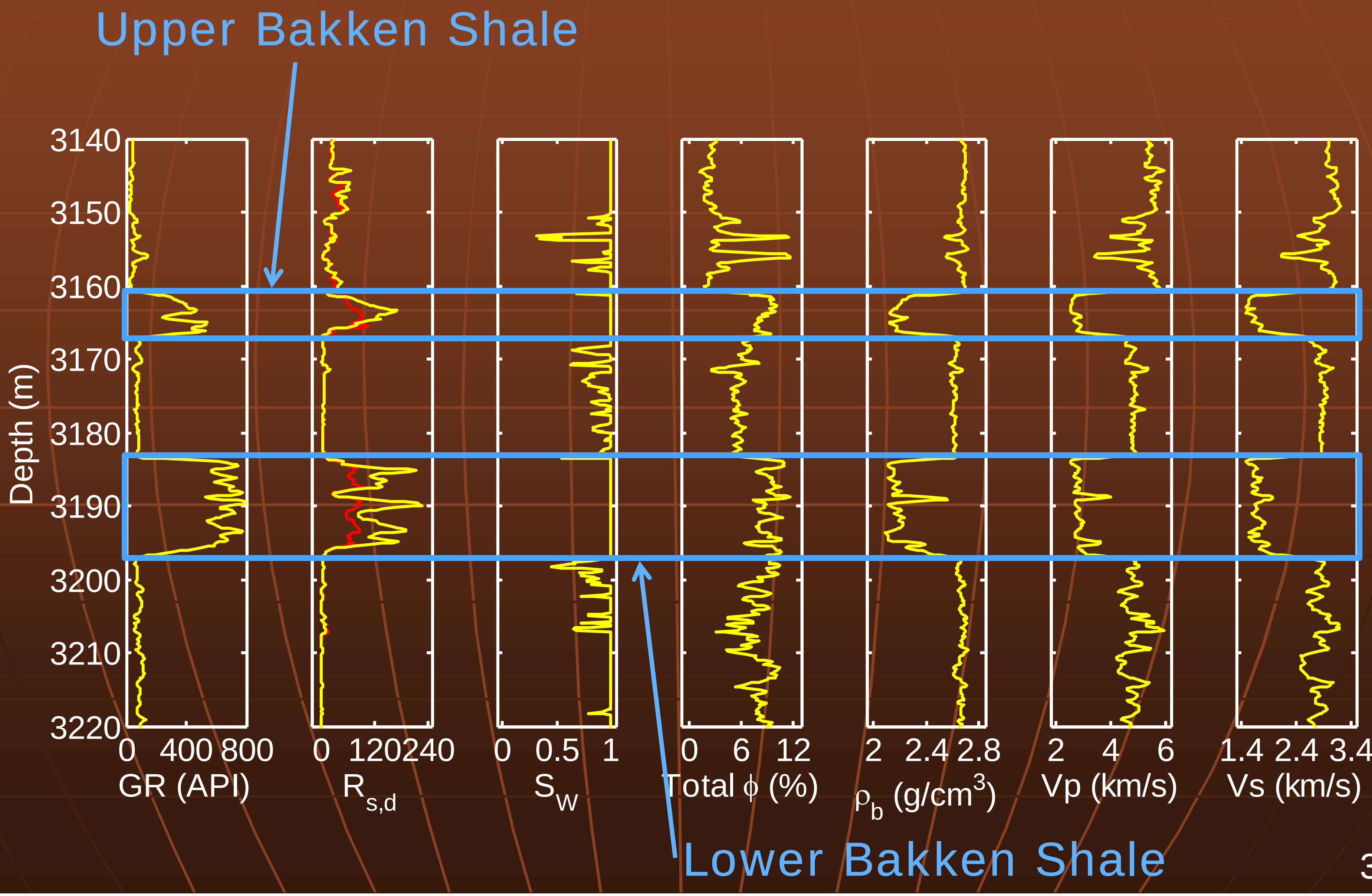
Rock physics characterization of a hetero-geneous solid with an isotropic distribution of inclusions with different shapes and volumes (i.e., aspect ratios and fracture porosity)

Introduction

Annala 11-36H, Sanish Field
Work based on well data

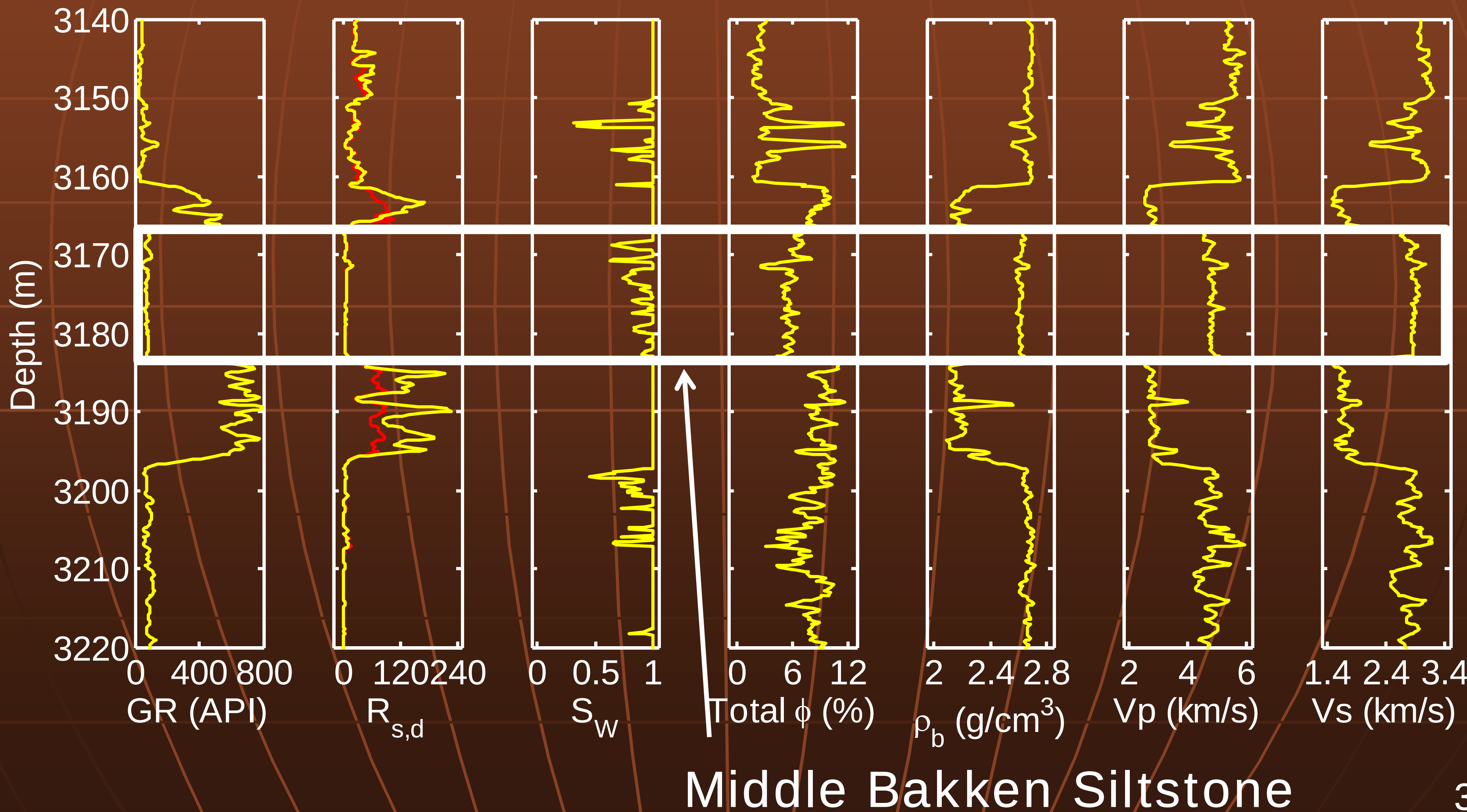


Introduction

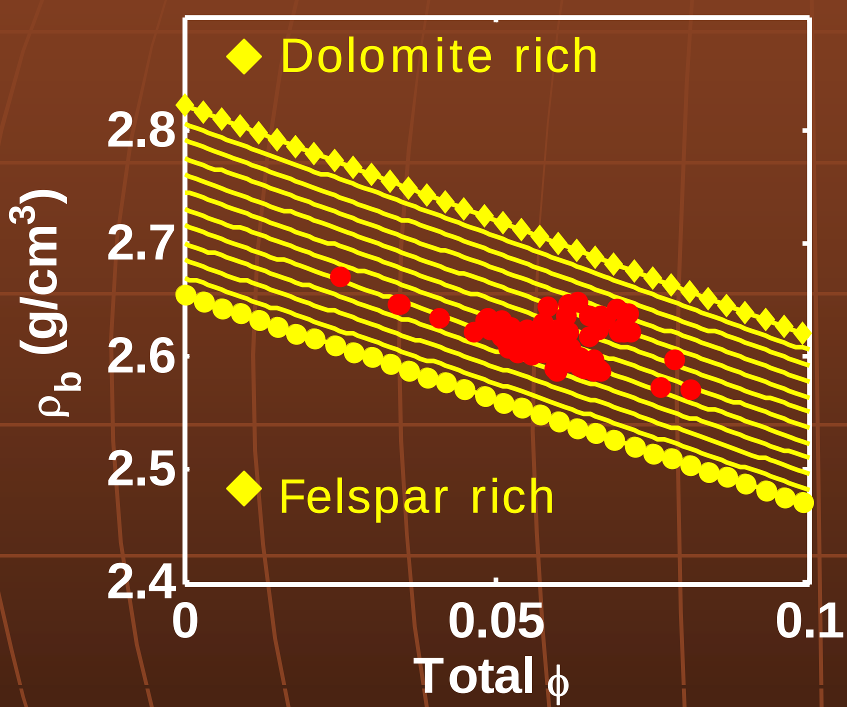


Introduction

High density with relatively low accompanying P- and S- velocity in the Middle Bakken



Rock properties – Density



Composition

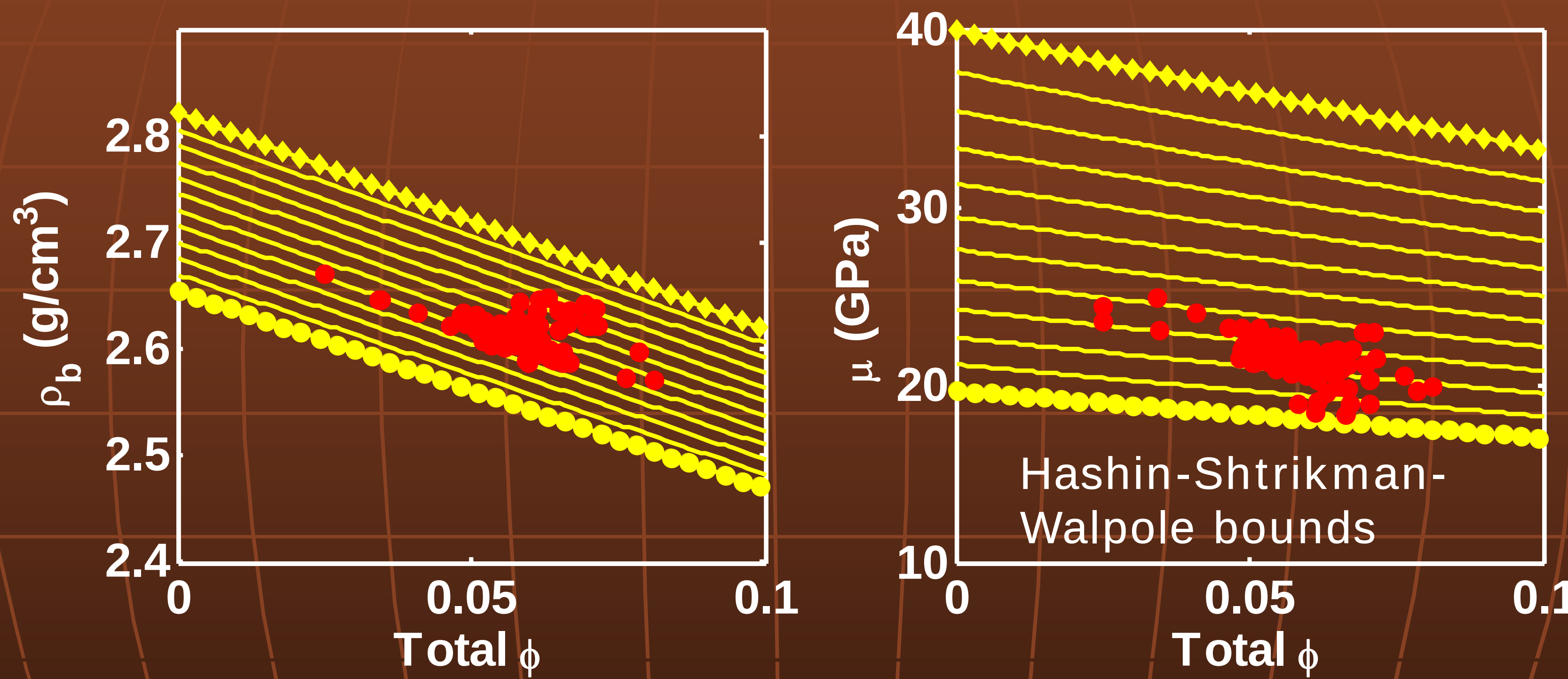
Quartz content: 20%

Clay content: 10%

Feldspar content: 5 to 75%

Dolomite: 80 to 10%

Rock properties – Density and shear modulus



Composition

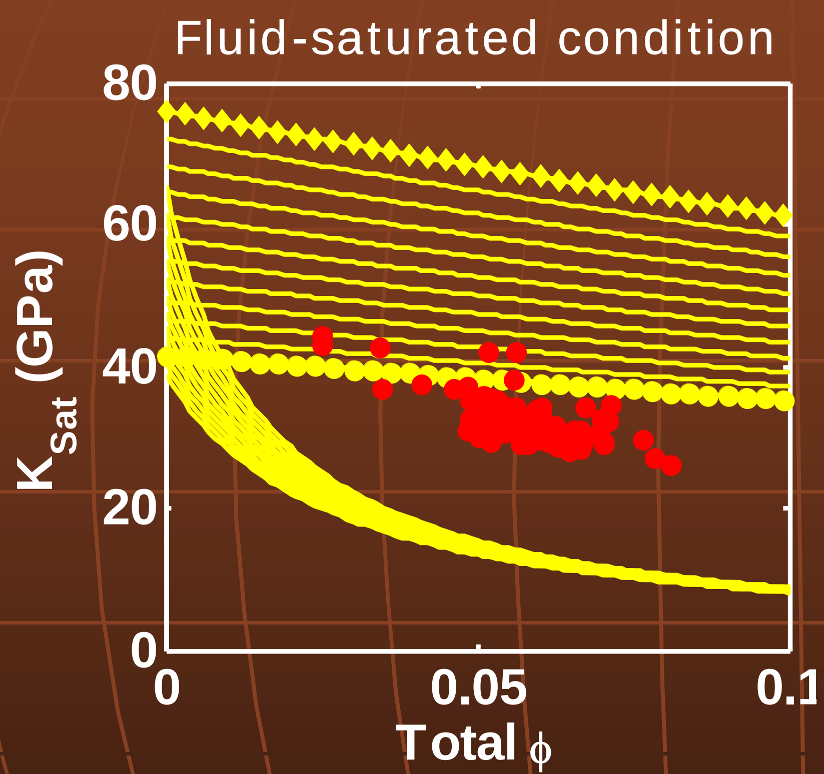
Quartz content: 20%

Clay content: 10%

Feldspar content: 5 to 75%

Dolomite: 80 to 10%

Rock properties – Bulk modulus



Hashin-Shtrikman-Walpole bounds

Composition

Quartz content: 20%

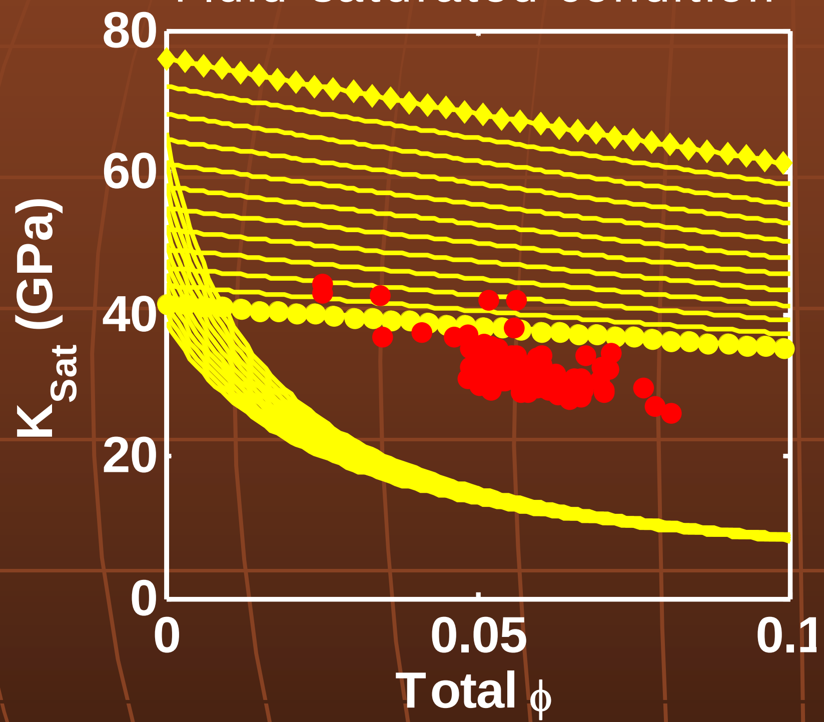
Clay content: 10%

Feldspar content: 5 to 75%

Dolomite: 80 to 10%

Rock properties – Bulk modulus

Fluid-saturated condition



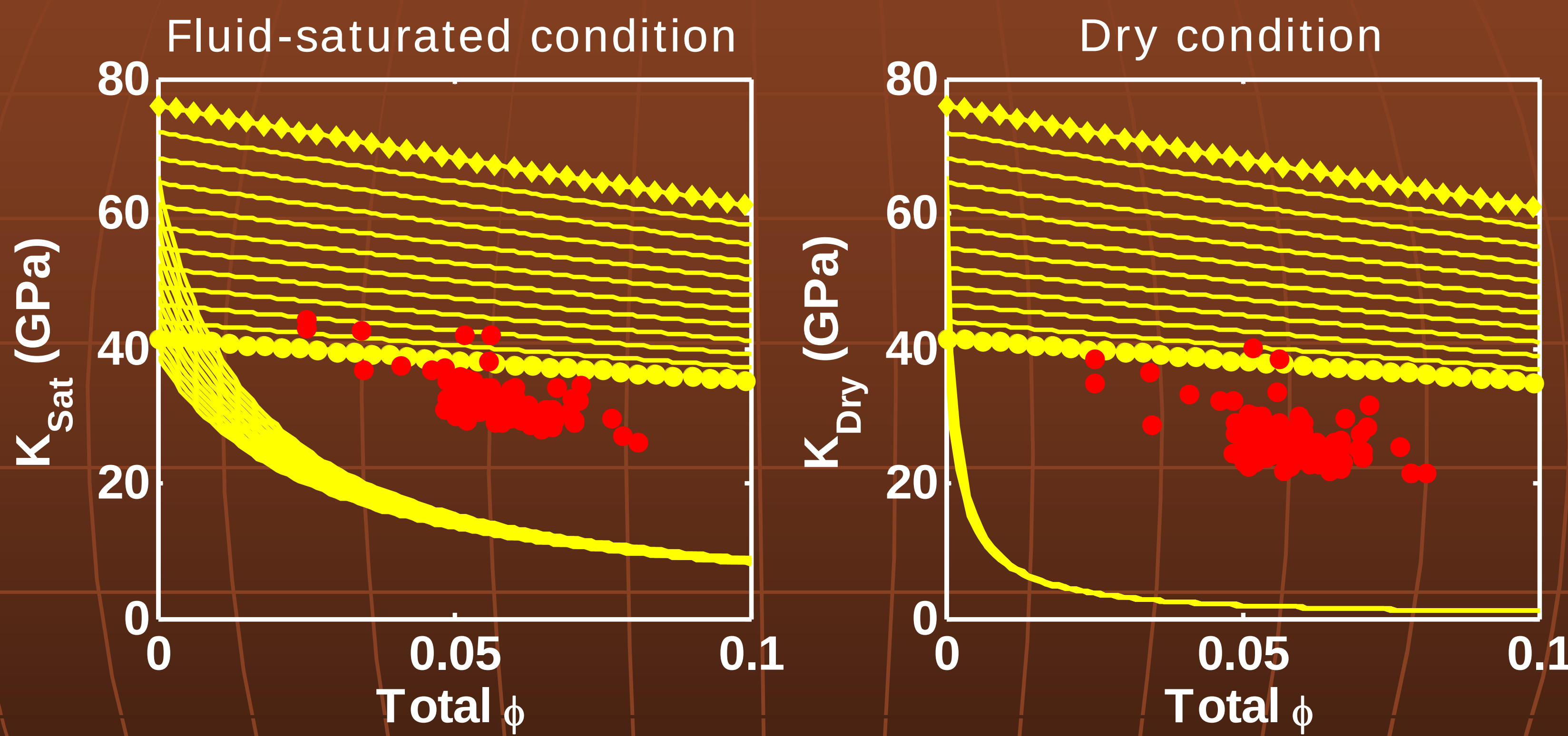
Dry condition from Gassmann

$$\frac{1}{K_{Dry}} = \frac{\phi}{K_{\phi}} + \frac{1}{K_{Solid}}$$

$$K_{\phi} = \frac{\phi}{\frac{1}{K_{Sat}} - \frac{1}{K_{Solid}}} - \frac{K_{Solid} K_{fluid}}{K_{Solid} - K_{fluid}}$$

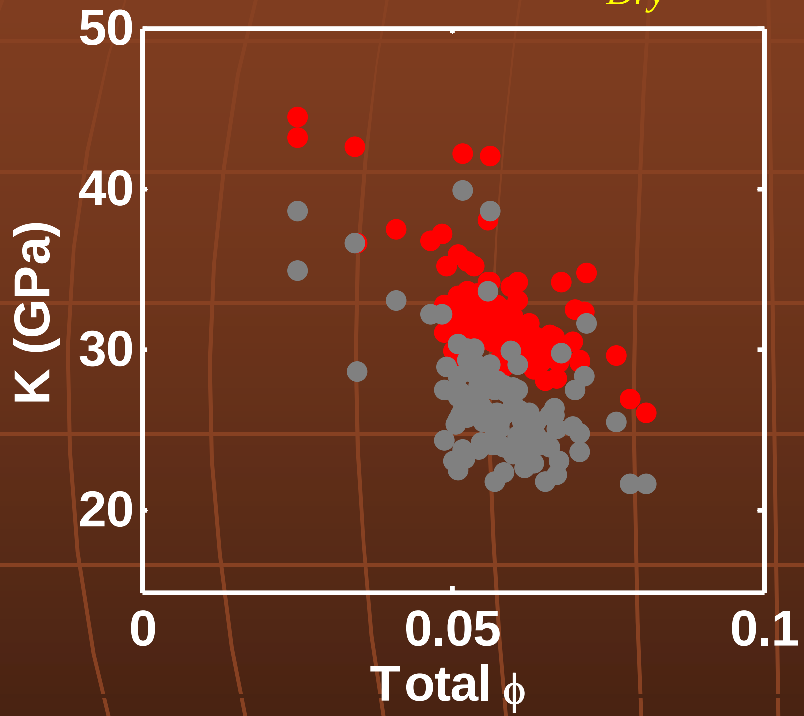
$$\frac{1}{K_{Sat}} = \frac{1}{K_{Solid}} + \frac{\phi}{K_{\phi} + \frac{K_{solid} K_{fluid}}{K_{solid} - K_{fluid}}}$$

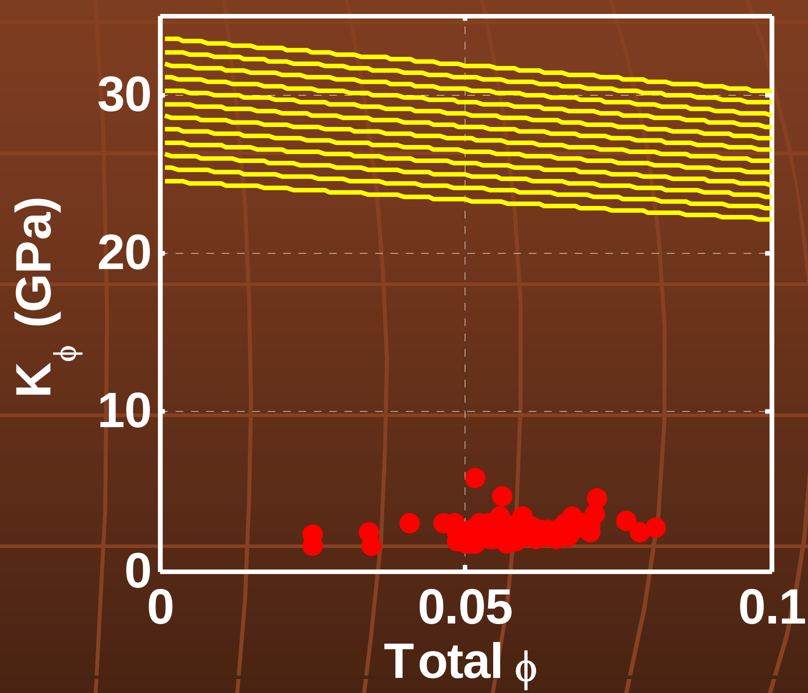
Rock properties – Bulk modulus



Rock properties – Bulk modulus

$$\frac{1}{K_{Dry}} = \frac{\phi}{K_\phi} + \frac{1}{K_{Solid}}$$



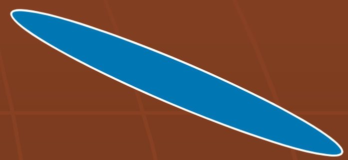


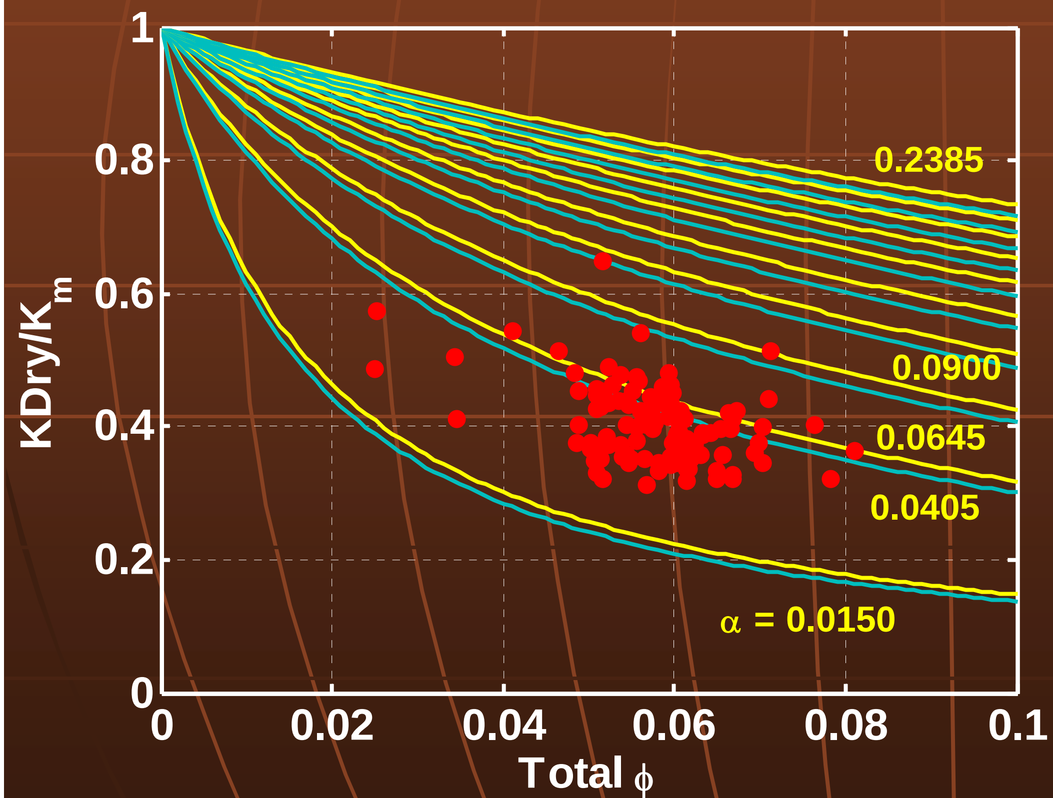
K_ϕ non-negligible

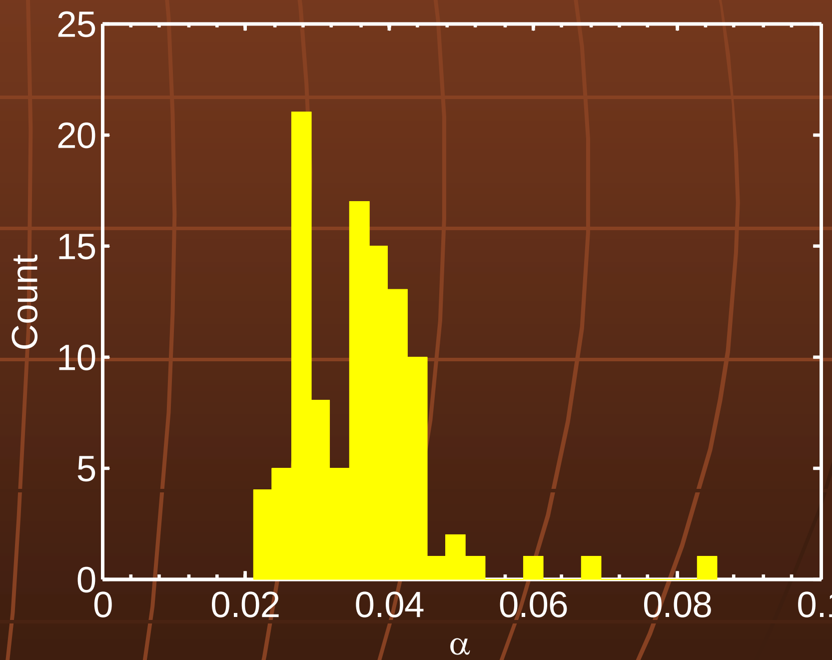
Pore-space stiffness effects must be included

Pore-stiffness modeling with variable composition

$$\frac{1}{K_\phi} = \frac{4}{3\alpha\pi K_{Solid}} \frac{(1-\nu^2)}{(1-2\nu)} \qquad \frac{1}{K_{Dry}} = \frac{\phi}{K_\phi} + \frac{1}{K_{Solid}}$$







Use distribution of aspect ratios in N-phase self-consistent model

$$\sum_{j=1}^{N} f_j (K_j - K_{SC}^*) B^{*j} = 0$$

$$\sum_{j=1}^{N} f_j (\mu_j - \mu_{SC}^*) \zeta^{*j} = 0$$

Required definitions:

1) Volumetric quantities of solids and inclusions
2) Aspect ratios of solids and inclusions

Estimate:

a) Quantities of solids from composition estimates
b) Quantities of inclusions as the sum of pore and crack porosity
c) α of solids = 1
d) α of pores = 0.1
e) α of cracks from distribution

N-phase Self-consistent model

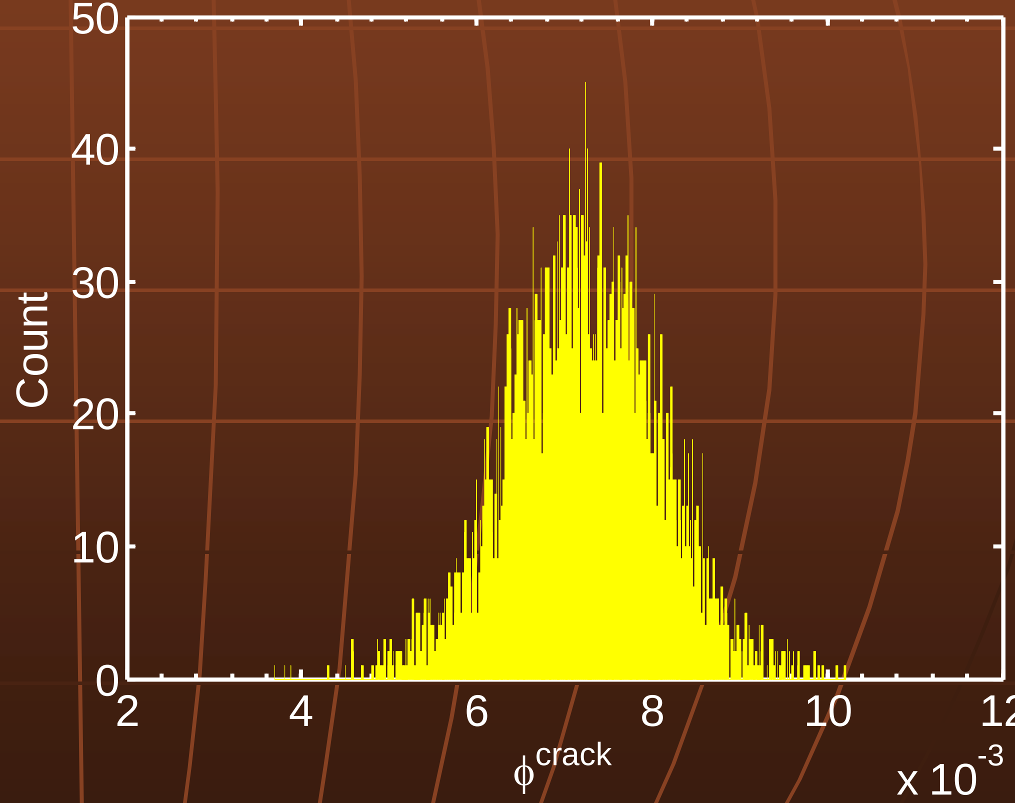
Simulate quantity of crack porosity

$$\sum_{u=1}^{U=24} \phi_u^{crack} = \phi^{crack}$$

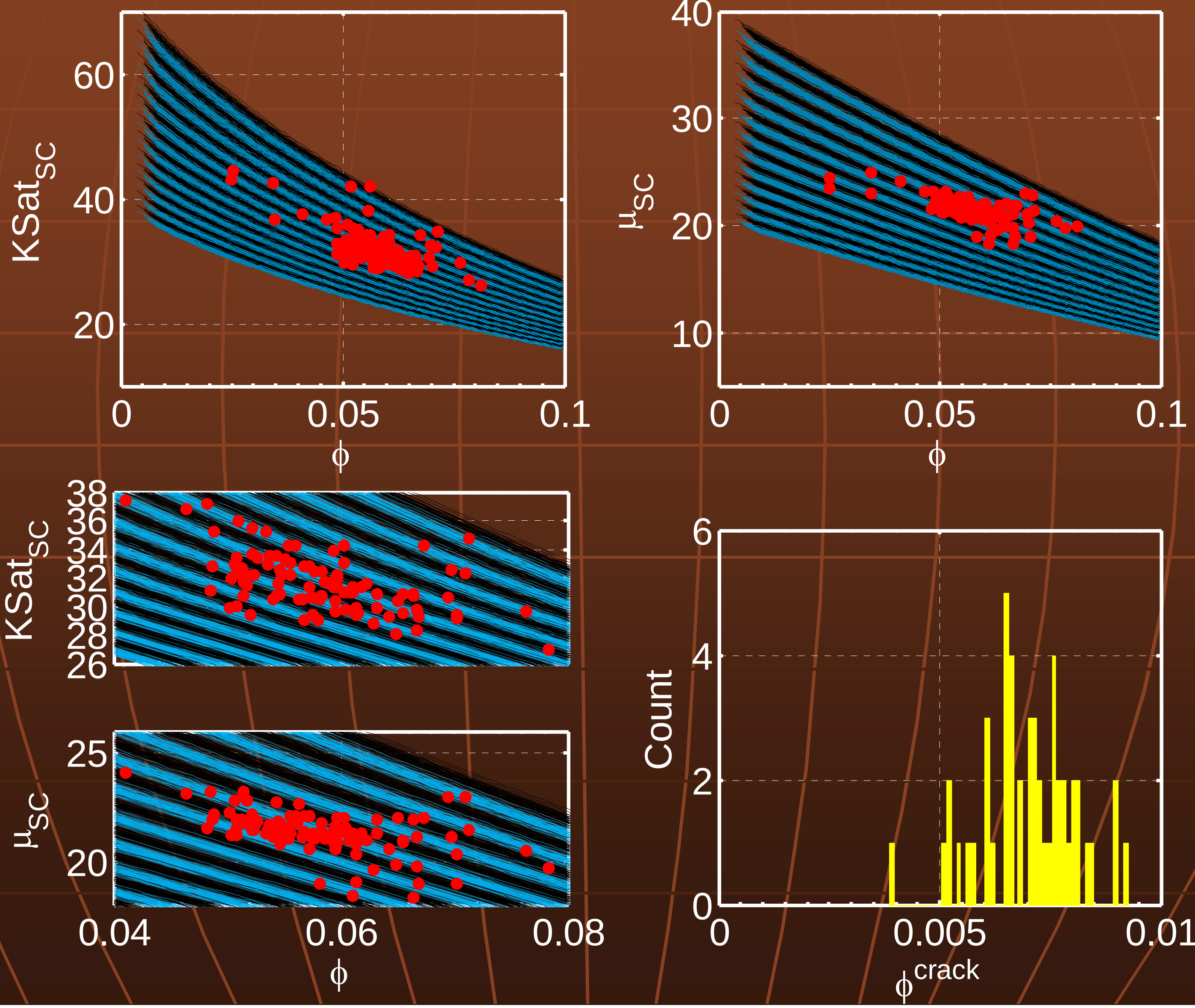
$$\varepsilon_{cd} = \frac{3\phi^{crack}}{4\pi\alpha}$$

$$0 \leq \varepsilon_{cd} \leq 0.1$$

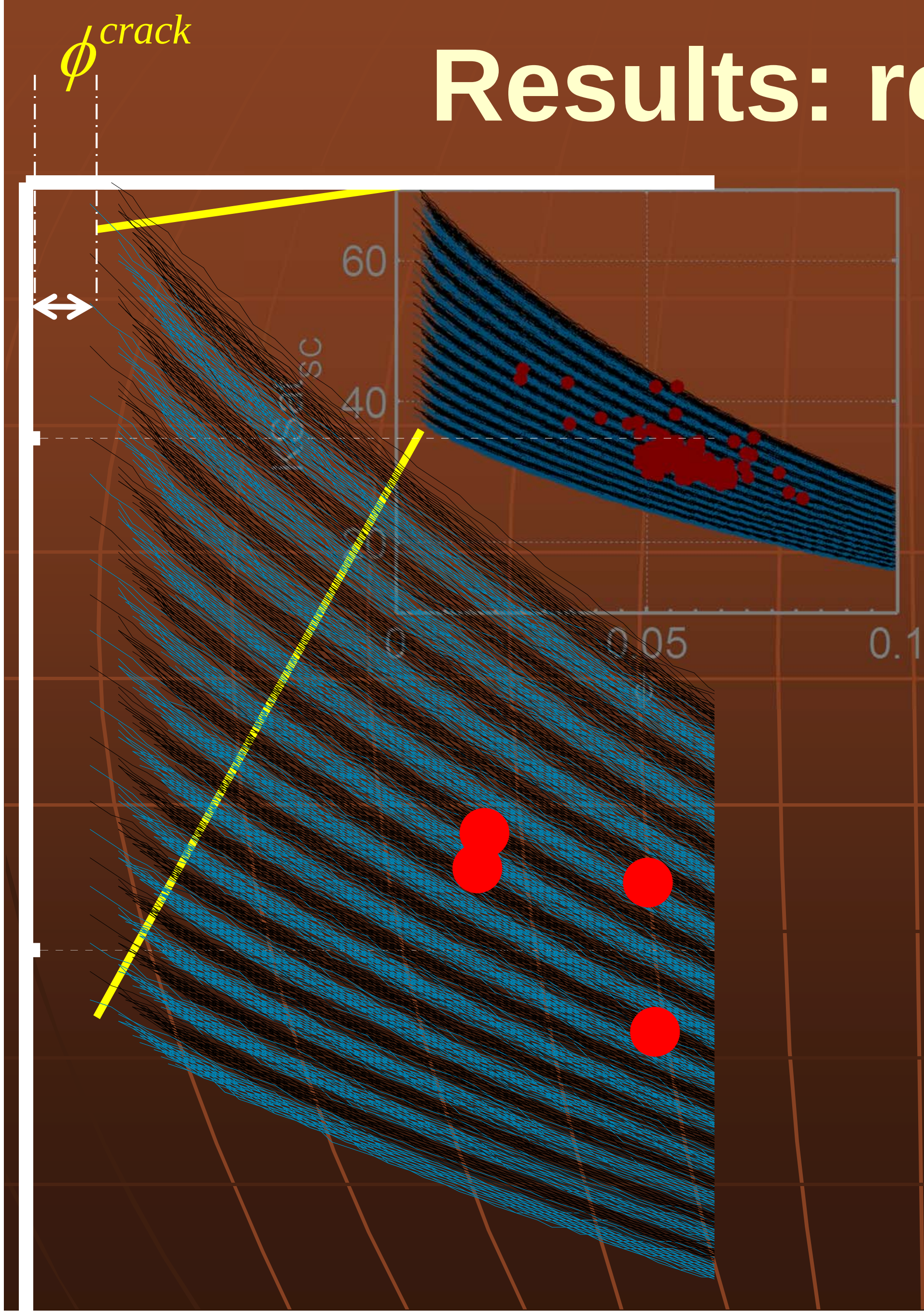
3000 simulated values of crack porosity

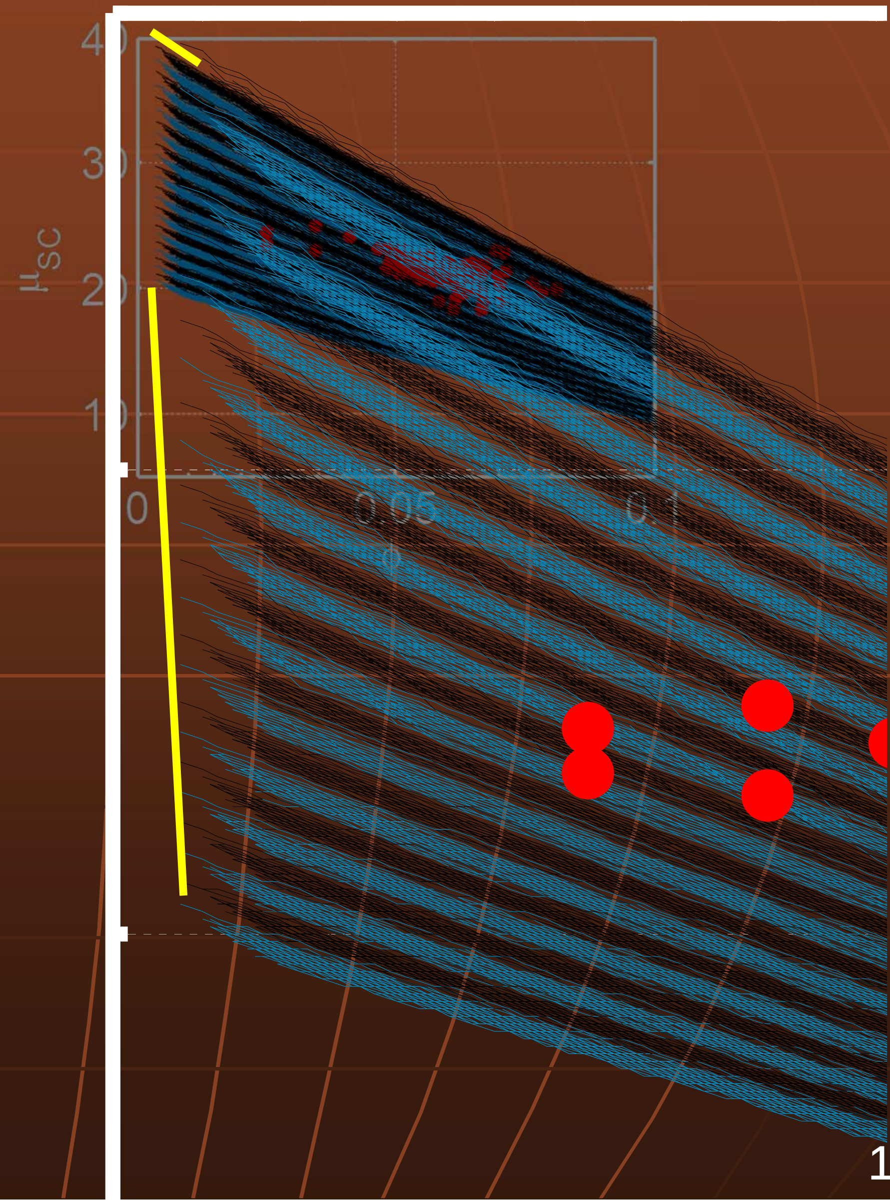


Results: realizations

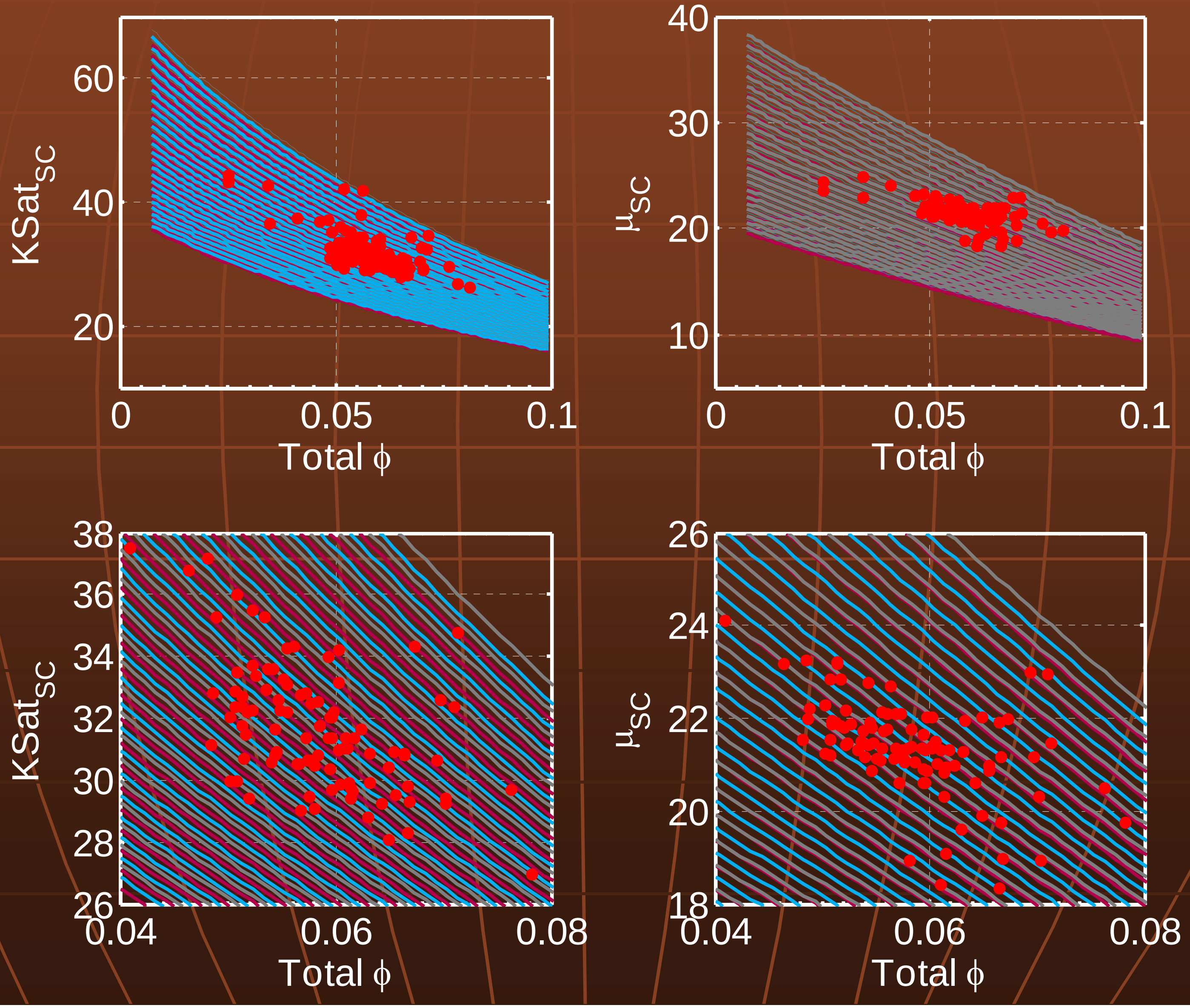


Results: realizations

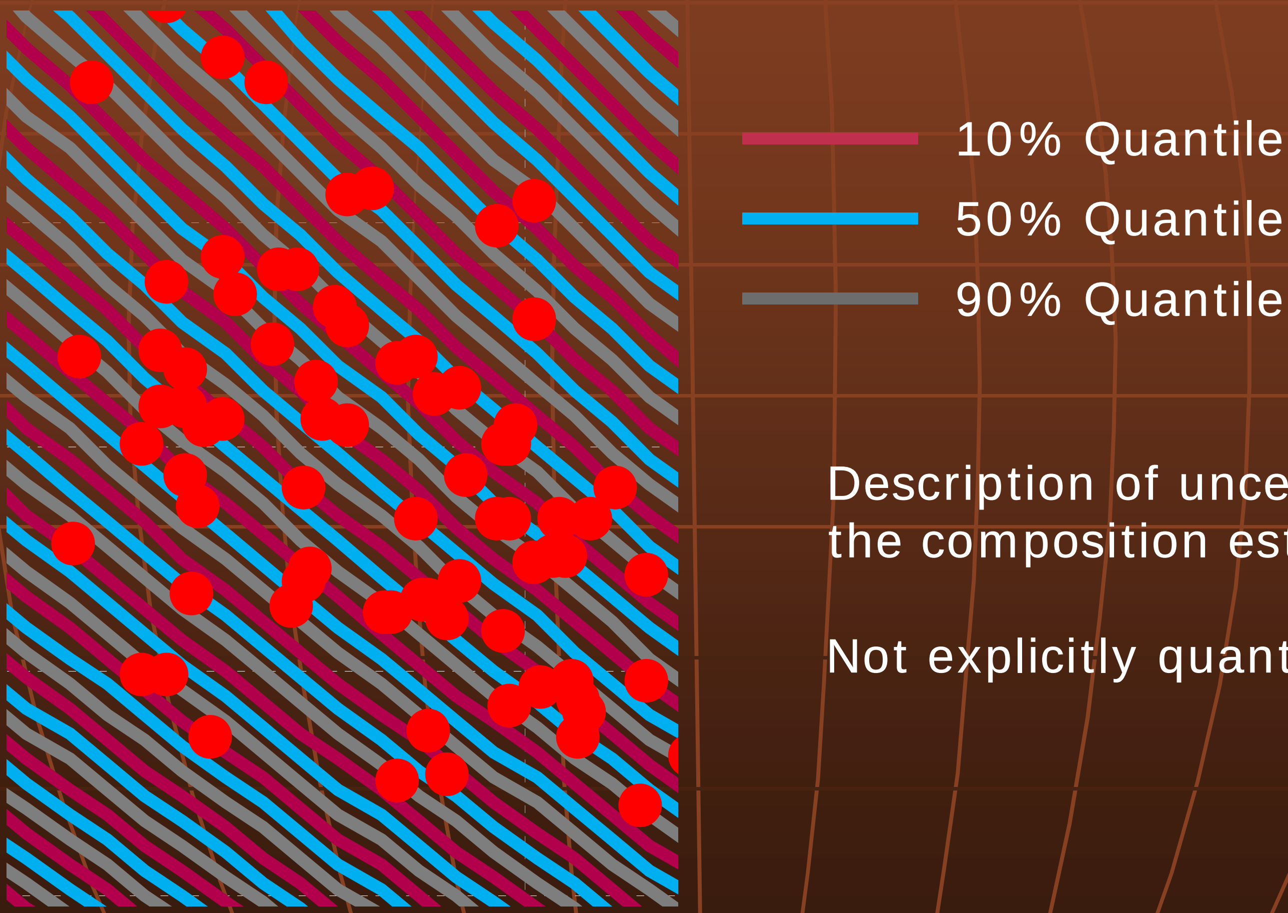




Results: quantile curves



Results: quantile curves

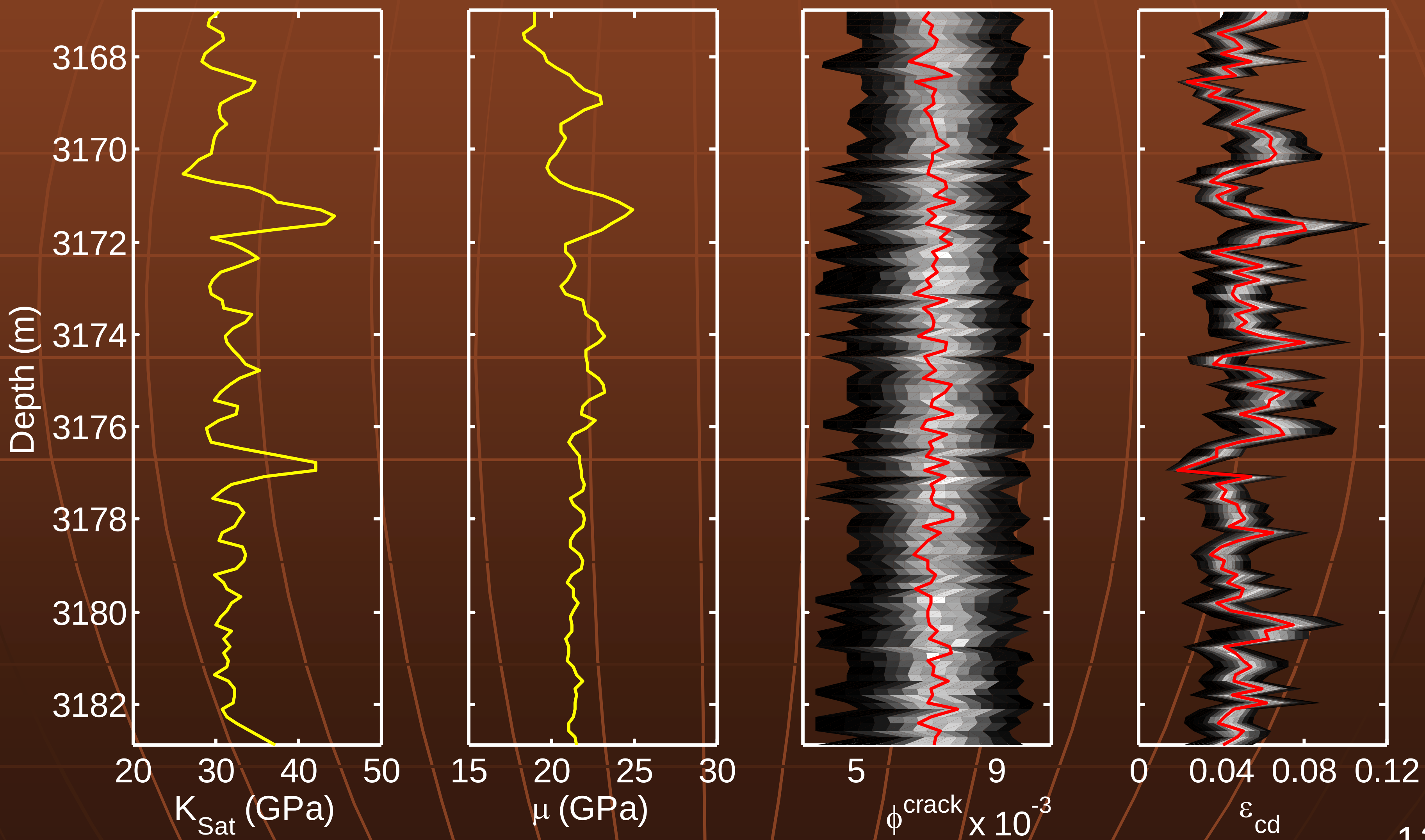


Description of uncertainty in the composition estimate

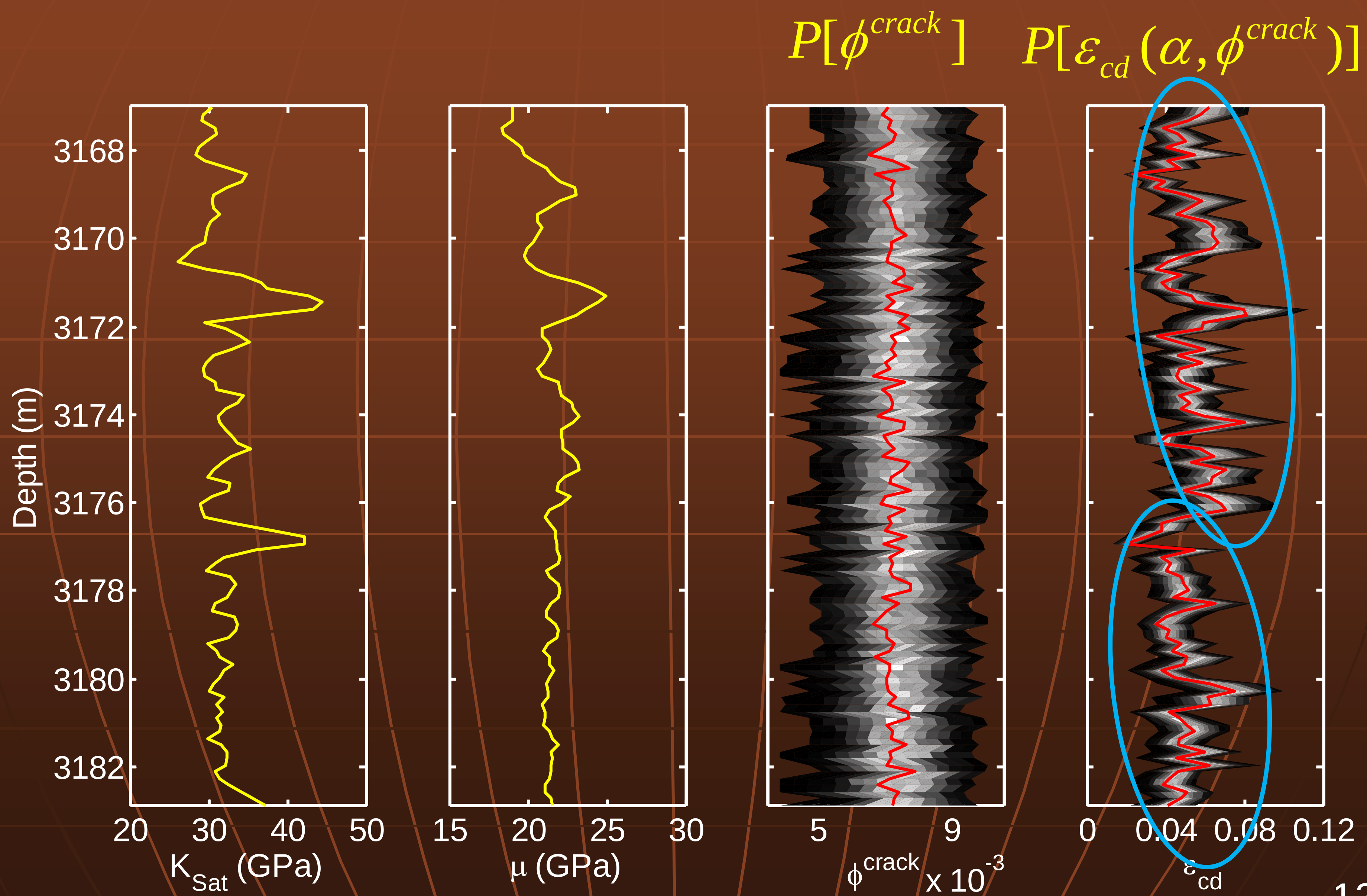
Not explicitly quantified here

Results: crack porosity and density

$P[\phi^{crack}]$ $P[\varepsilon_{cd}(\alpha, \phi^{crack})]$

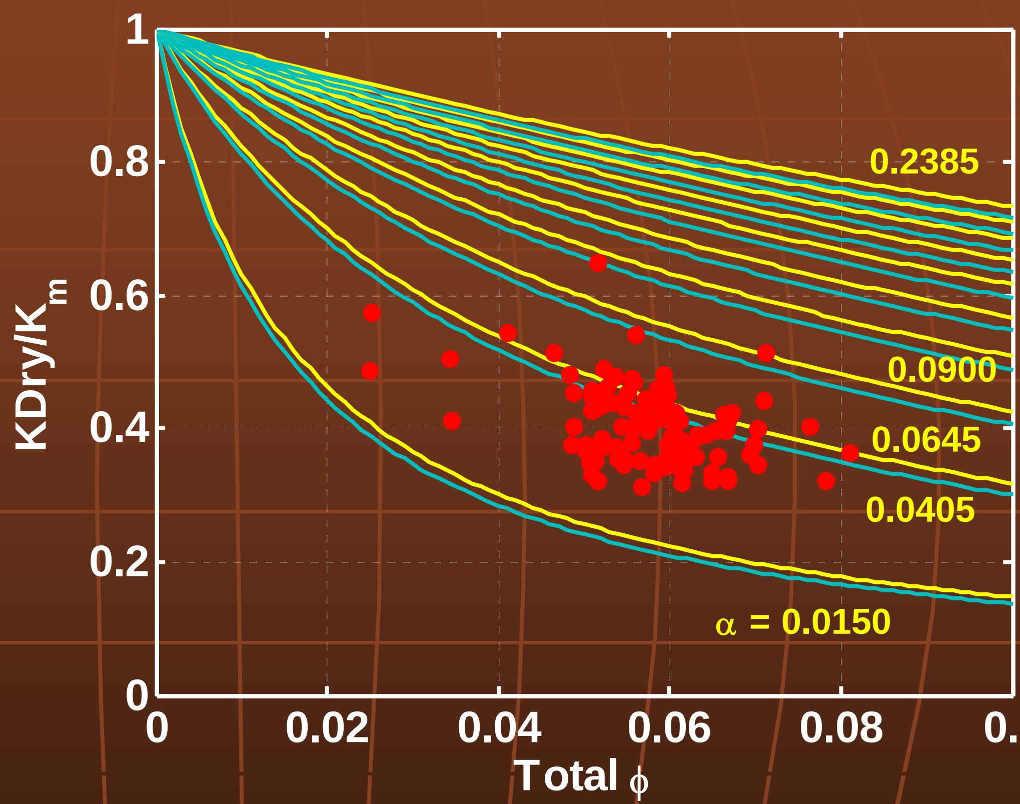


Results: crack porosity and density



Variable composition with fractured and non-fractured scenarios

From Pitman et al., 2001, USGS Professional Paper



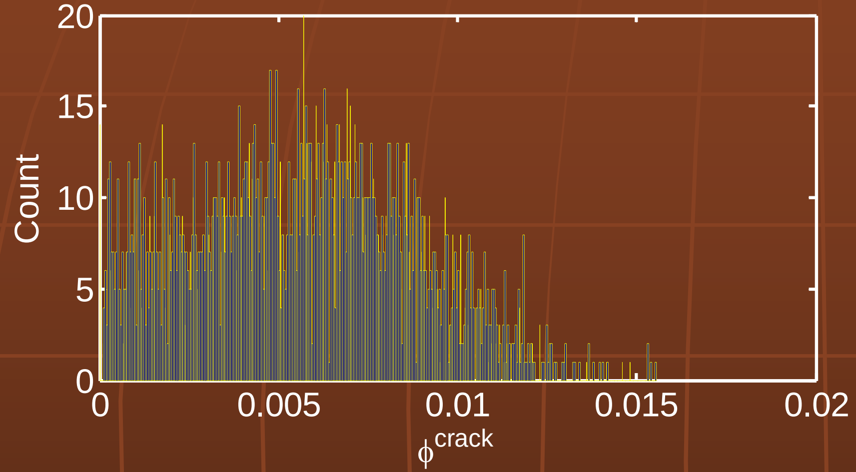
$$\varepsilon_{cd} = \frac{3\phi^{crack}}{4\pi\alpha}$$

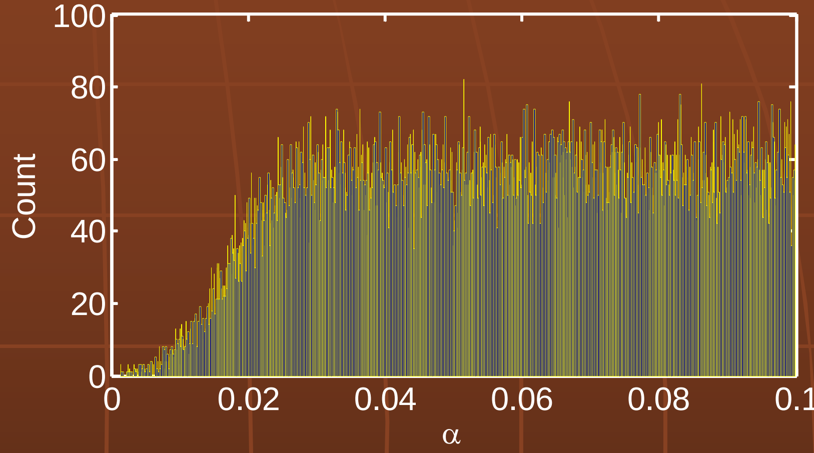
Let $\varepsilon_{cd} \rightarrow 0$

$\phi^{crack} \rightarrow 0$

Let $\alpha \rightarrow 0$

Variable composition with fractured and non-fractured scenarios



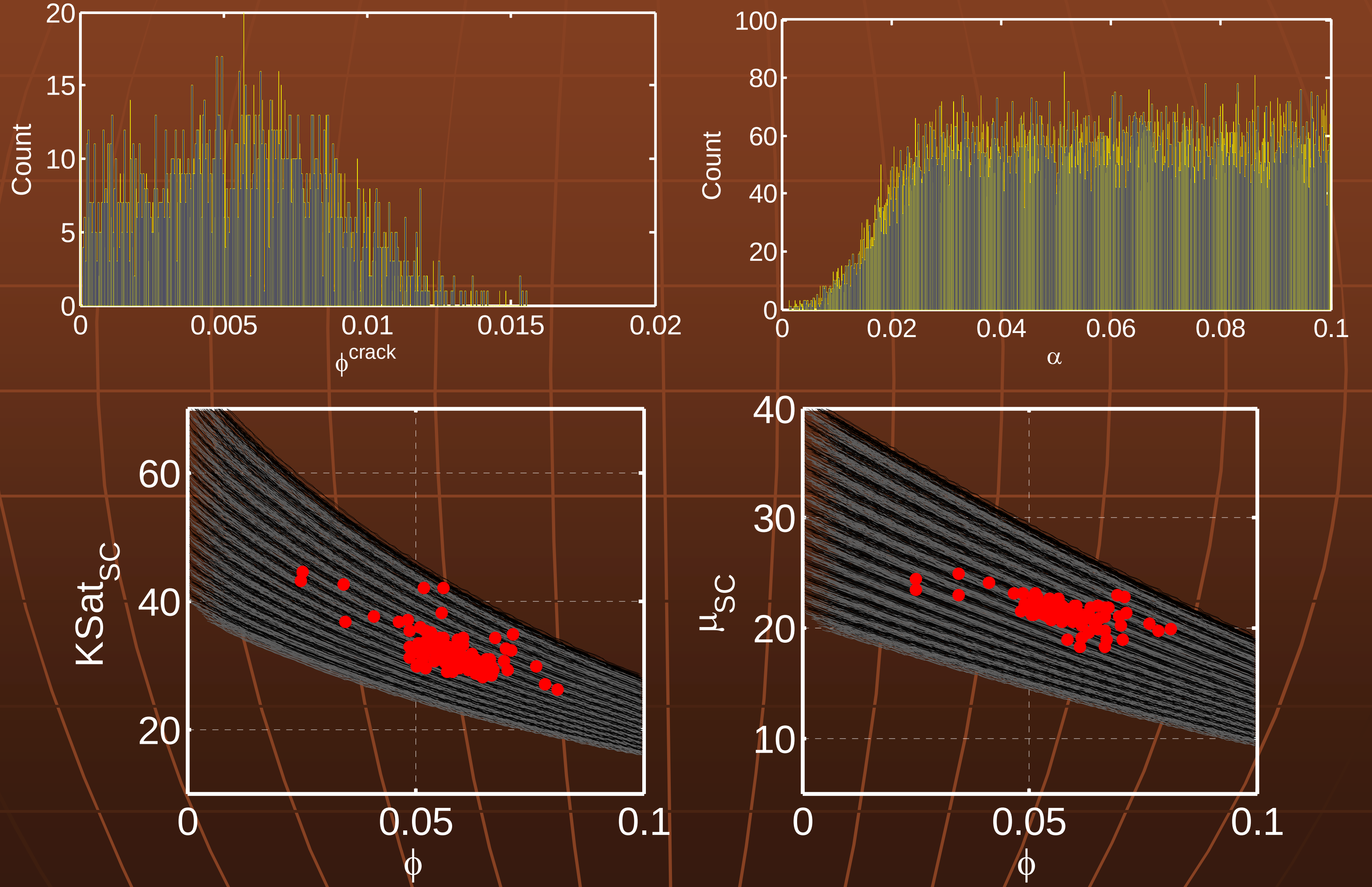


Iterative joint simulation of $\alpha, \ \phi^{crack}$

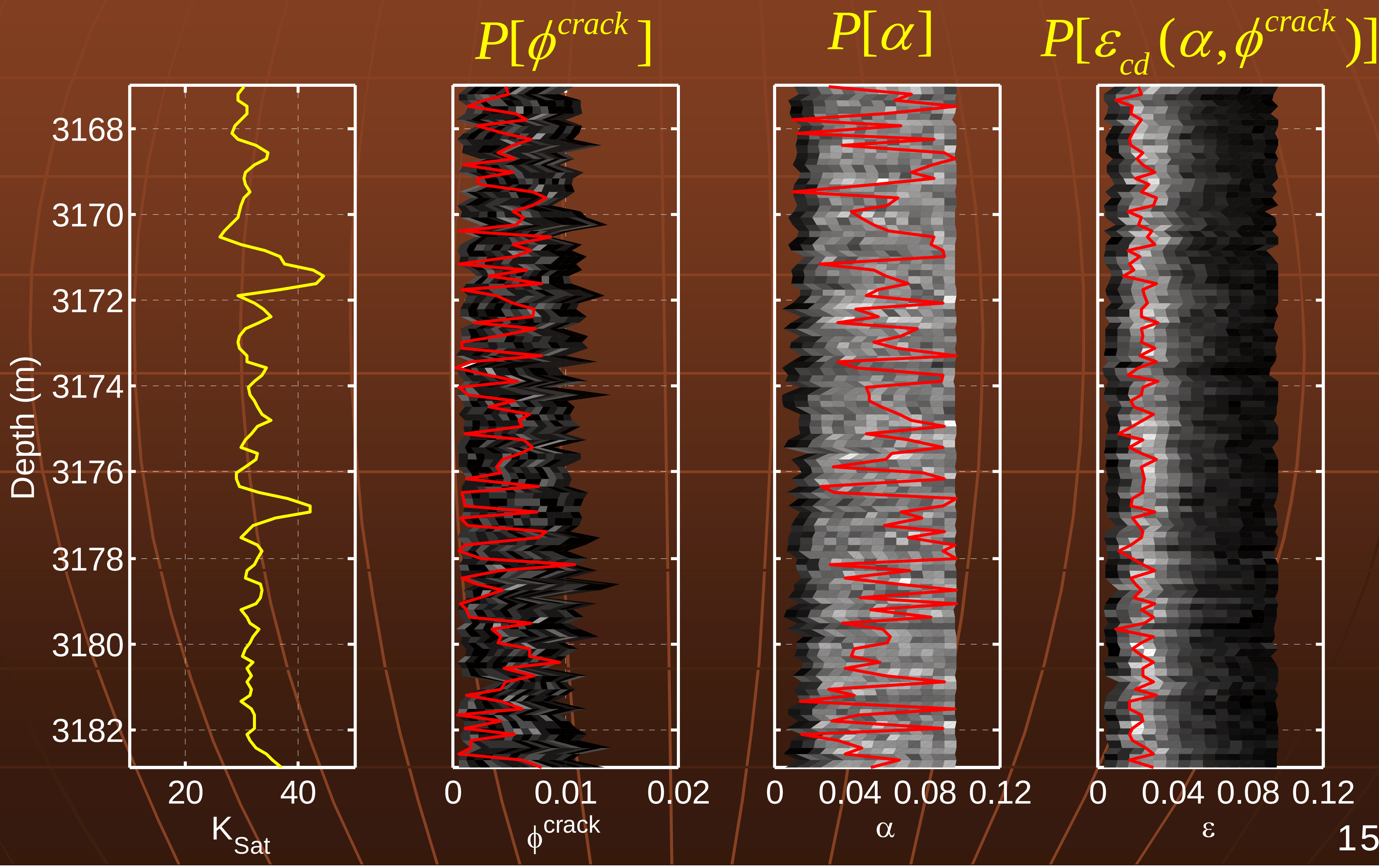
Insures $0 \le \varepsilon_{cd} \le 0.1$

$$\varepsilon_{cd} = \frac{3\phi^{crack}}{4\pi\alpha}$$

Variable composition with fractured and non-fractured scenarios



Variable composition with fractured and non-fractured scenarios



Conclusions

Modeling approaches provide estimates and uncertainty of

- Fracture density
- Fracture porosity

Two methods impose a crack density and crack porosity on each data point at depth

Modeling routines vary the number of fractures:

- Specific case: based on mapping aspect ratios
- General case: 0 to an upper limit

Self-consistent approximation provides a viable framework in which to model the effective elastic properties

Either method applicable to other tight rocks and shales

Effect of uncertainty in composition most likely will depend on the amount of heterogeneity present in other units

Acknowledgements

Thanks and appreciation go to

Kerogen Resources Inc. for the data

The EDGER forum at UT-Austin for funding.