my piezometer is stronger than yours ... !

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Renée Heilbronner [(1)(2)]
(1) Geological Institute, Basel University, Switzerland, (renee.heilbronner@unibas.ch) (2) The Arctic University, Tromsø, Norway

What's the problem ?

Grain sizes determined from general shear experiments on BHQ do not coincide with the piezometer for published by Stipp and Tullis (2003).

Possible explanation ?

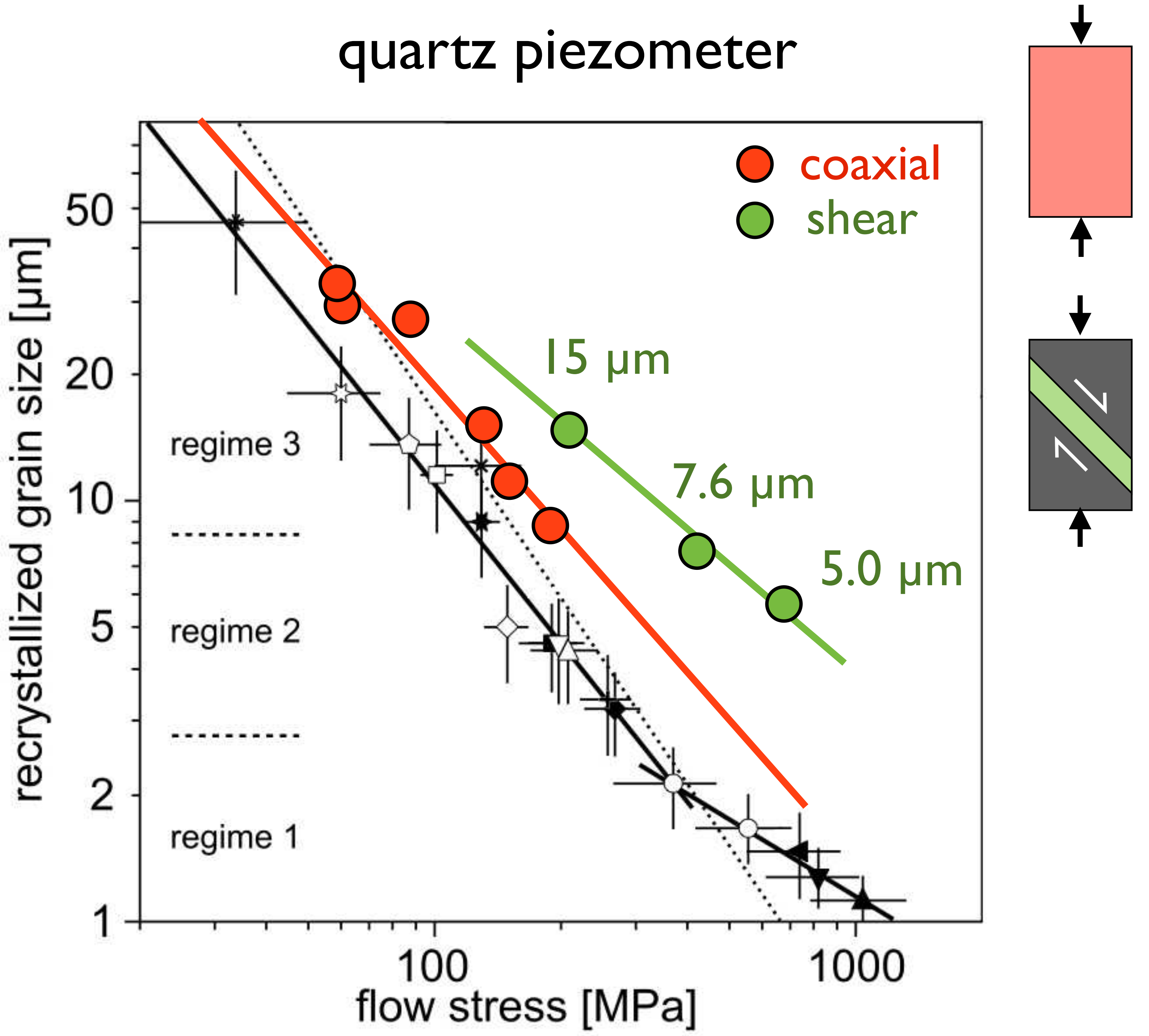
The piezometer depends on the mode of deformation. In simple shear, higher stress are required to achieve a given recrystallized grain size than in pure shear. Deformation in simple shear requires more work than in pure shear.

Great !

... but before we get excited, let's check:

1. Did we measure the grain sizes correctly, especially the very small ones ?
2. What about the difference in confining medium: solid salt in standard experiments versus molten salt for the piezometer ?
3. How do we convert the mechanical data to stess-strain curves ? Are out conversions consistent ?
4. How do we best convert τ of the shearing experiments to Δσ of coaxial experiments ?
5. ... and, in case Brian Evans is listening in, ...
   ... are we sure piezometers work at all ??

quartz piezometer



published piezometer

$d(\mu m) = 3631\ \Delta\sigma\ -1.26$

recalculated as mode of 3D grains

$D(\mu m) = 3325\ \Delta\sigma\ -1.13$

mode of 3D grains

$D(\mu m) = 1473\ \Delta\sigma\ -0.86$

What have we done to solve the problem ?

1. The grains sizes of shear and coaxial experiments and those of the piezometer experiments have been repeated, using EBSD data....
2. The grain sizes of a set of standard coax experiments (solid salt assembly) was measured.
3. The existing software for the conversion of the mechanical data (rigP, rigC, and rigS) has been re-written with the aim of making every step fully transparent. Choices concerning hitpoint definition, area correction, etc. now have to be made explicitely.
4. The run records of coaxial and shear experiments were re-analyzed demonstrating a large effect of the options on the calculataed stress levels.
5. ... and keep thinking about piezometers ...

And now ?

Was the discrepancy between the shearing and the coaxial piezometer only an artefact of the experiemntal set-up ?

In other words, does the published piezometer still hold for coaxial and shearing situations, i.e., for pure shear and simple shear ?

Or does the discrepancy between shearing and coaxial remain ?

Find the answers on my PICO !

go to overview >

overview

go to Title page

go to Introduction to the problem

Solving the problem

go to 1. Repeating the grains sizes measurements using EBSD data....

go to 2. Introducing new software for the conversion of the mechanical data.

go to a. rigP preparing the input

go to b. rigC converting coaxial experiments

go to c. rigS converting general shear experiments

go to 3. Changing the run options

go to 4. Area corrections

go to 5. Effect of options

go to 6. Which 'strain'?

go to Getting new results

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My piezometer is stronger than yours ...

Renée Heilbronner
Basel University Switzerland, Geological Institute, Department of Environmental Sciences, Basel, Switzerland
(renee.heilbronner@unibas.ch)

Recent studies (e.g., Heilbronner & Kilian, 2017, Richter, 2016) indicate that, for general shearing experiments, the quartz piezometer (Stipp & Tullis, 2003) does not correctly predict the recrystallized grain size (from the measured flow stress) or the flow stress (from the measured grain size). One may speculate whether there is an inherent strength difference between simple shear and pure shear deformation, which would then require the calibration of a second piezometer. However, before considering this possibility, it is necessary to ensure that the differential stresses and strains of the coaxial and general shearing experiments are correctly determined.

In this presentation, the focus is on Grigg's type solid medium deformation apparatuses, the general conclusions, however, may apply to other machines and other experimental set-ups too. The major concerns are: (1) How does the force applied externally to the loading piston, in combination with the axially compressed, solid confining medium, translate to the state of stress that exists inside the sample? (2) How much of the sample is homogeneously deforming and how is the strain and the strain rate best quantified?

Coaxial and general shearing experiments carried out in the dislocation creep regimes 1, 2, and 3 (as defined by Hirth & Tullis, 1992) are used to show how the stresses and strains derived from the force-displacement record depend on the choice of mechanical and geometrical corrections. Together with the less than 100% reproducibility of the Grigg's apparatus, the different corrections may lead to a rather large range of results for one and the same experiment, as will be demonstrated. Such discrepancies need to be considered when comparing coaxial and shearing experiments, or when comparing different results from different labs.

With constantly improved machine design, more and more highly resolved data can be retrieved during the experiments. To make full use of these improvements, experimentalists are urged to carefully check the choices made by the software they use (or better still, to write their own software) and to be explicit about the corrections they apply when publishing the resulting stress-strain data. - As the list of calibrations and conversions presented in this PICO is probably not complete, participants of the conference are invited to contribute.

- Heilbronner, R. & Kilian, R. (2017). The grain size(s) of Black Hills Quartzite deformed in the dislocation creep regime. Solid Earth.
- Hirth, G. & Tullis, J. (1992). Dislocation creep regimes in quartz aggregates. Journal of Structural Geology 14, 145±159.
- Richter, B. (2016). The brittle-to-viscous transition in experimentally deformed quartz gouge, Basel University PhD thesis.
- Stipp, M., and J. Tullis (2003), The recrystallized grain size piezometer for quartz, Geophys. Res. Lett., 30(21), 2088, doi:10.1029/2003GL018444.

previously on '... the piezometer ...'

2002
coaxial & shearing experiments
confining medium = solid salt

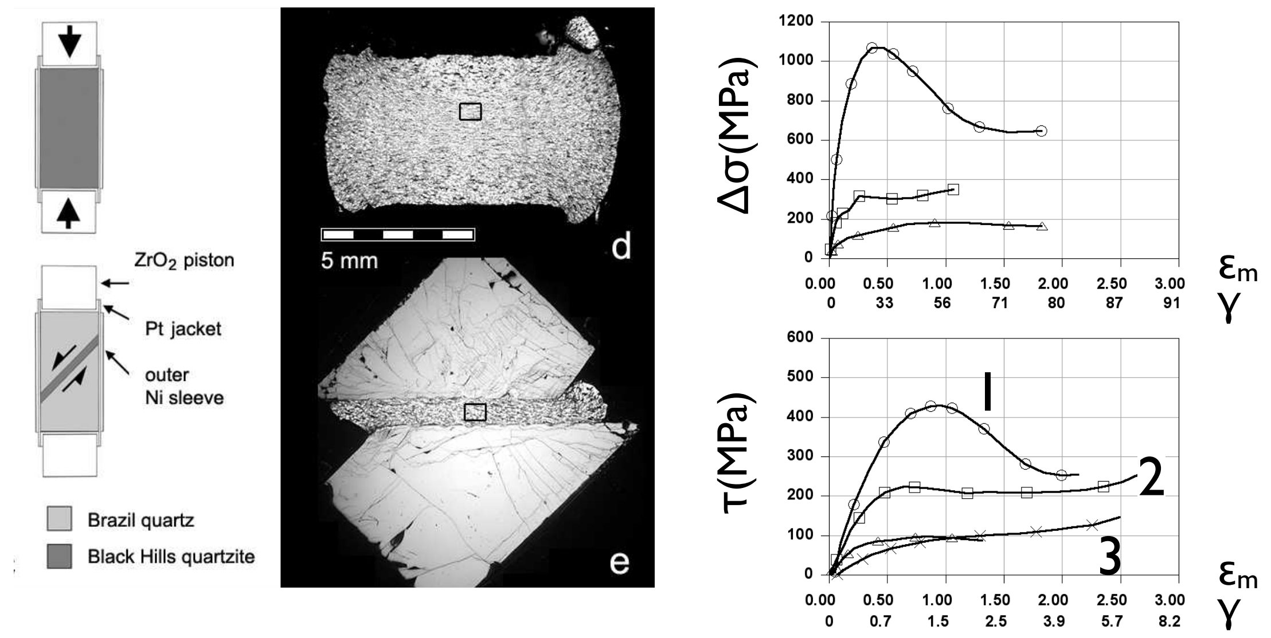


Table 1. *Experimental conditions*

Regime	Deformed sample #	Confining pressure (GPa)	T (°C)	H₂O (wt%)	Axial strain rate (s⁻¹)	Max. short. strain ε (%)	Max. strain magn.		Flow stress Δσ (MPa)‡	Annealing T (°C)§	Annealed sample #
1	w871	1.5	850	0	1.5×10^{-5}	77	1.82		650	850	w875
2	w872	1.5	900	0.17	1.5×10^{-5}	58	1.07		310	900	w874
3	w858	1.5	900	0.17	1.5×10^{-6}	78	1.84		180	900	w860
					Shear strain rate (s⁻¹)	Max. shear strain γ*	Max. strain magn.	Flattening strain (%) (magn.)†	Flow stress Δσ = 2τ (MPa)		
1	w940	1.5	850	0	3×10^{-5}	4.32	2.13	31.6 (0.46)	510	850	w943
2	w946	1.5	875	0.17	3×10^{-5}	7.18	2.81	48.8 (0.82)	420	875	w948
3	w920	1.5	900	0.17	1.5×10^{-5}	2.13	1.31	20.0 (0.27)	190	900	w921
3	w935	1.5	915	0.17	3×10^{-5}	5.65	2.49	44.0 (0.71)	210	915	w938

*Sample w920 has lower strain rate due to thicker shear zone.
†Strain magnitude equivalent to flattening strain is given in brackets.
‡Flow stress of axial samples is given as differential stress Δσ. For sample w871 final stress is indicated. Flow stress of sheared samples is given in terms of differential stress $\Delta\sigma = 2\tau$.
§Annealing time is 4 days for all samples.

R. HEILBRONNER & J. TULLIS

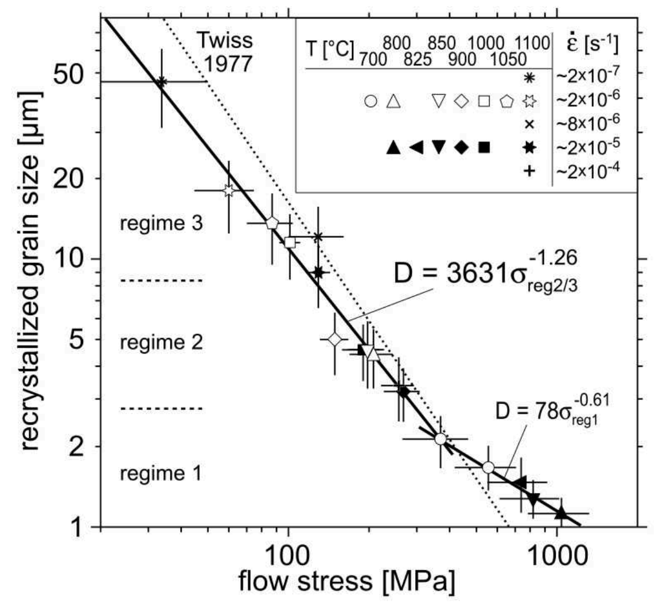
Table 2. *Results of analyses*

Sample # (regime)	Vol % recryst.	Vol % annealed	Mode grain diameter (µm)	CPO max. density (bulk texture)	CPO max. density of recryst. fraction*	Mode of orient. gradient distrib. (°)	Measured perimeter/ perimeter of equivalent circle	PARIS factor (%)	Grain boundary surface per volume (µm⁻¹)
w871 (1)	50		5	3.76	3.44		1.80	33.3	1.08
w872 (2)	40		7	4.12	3.96		1.79	35.6	0.99
w858 (3)	85		20	4.48	2.57		1.87	14.4	0.53
w875 (1 ann.)		100	20	2.04	–		1.53	0.2	0.23
w874 (2 ann.)		100	36	3.21	–		1.37	0.8	0.15
w860 (3 ann.)		100	50	3.52	–		1.32	0.9	0.12
w940 (1)	50		7	3.81	4.22	10			0.60
w946 (2)	90		8	10.9	11.1	9			0.56
w920 (3)	45		14	3.06	2.69				
w935 (3)	100		14	10.1	–	7			0.34
w943 (1 ann.)		100	32	4.04	–	4			0.25
w948 (2 ann.)		100	28	5.40	–	4			0.27
w921 (3 ann.)		100	42	2.50	–				
w938 (3 ann.)		100	30	8.50	–	4			0.25

*The annealed samples and sample w935 are 100 % recrystallized, therefore those CPOs are the same as in column 5.

Heilbronner, R. and Tullis, J. (2002). The effect of static annealing on microstructure and crystallographic preferred orientations of quartzites experimentally deformed in axial compression and shear. In: S. de Meer, M.R. Drury, J.H.P. de Bresser and G.M. Pennock (Editors), Deformation Mechanisms, Rheology and Tectonics: Current Status and Future Perspectives. Geological Society, London, Special Publication, pp. 191-218.

2003
(coaxial) piezometer experiments
confining medium = molten salt



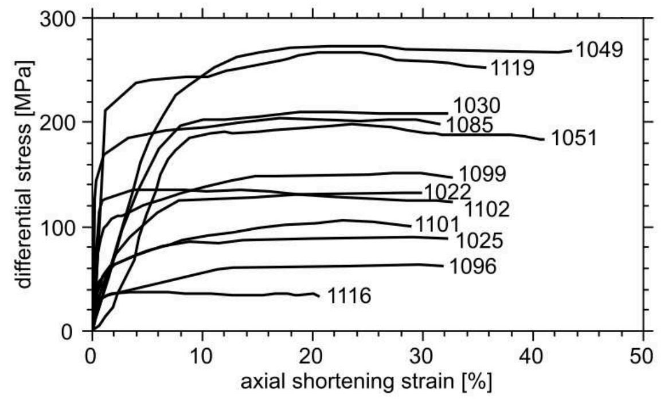


Figure 2. Stress/strain data and sample numbers for the MSC experiments on BHQ; friction corrections are described in the text. Flow stress values in Table 1 are averaged from 10% strain until the end of each run.

Table 1. Experimental Deformation Conditions and Recrystallized Grain Size Data

sample	temperature [°C]	strain rate [s⁻¹]	axial strain [%]	flow stress [MPa]	recrystallized grain size [µm]	number of grains
W-1126 - β W -1116 - β	1100 1100	$2.1–2.3*10^{-7}$	17 21	34 ± 16	46 ± 15	734
W-1066 - β W-1096 - β	1100 1100	$2.0–2.5*10^{-6}$	31 32	60 ± 15	18.0 ± 5.5	676
W-1022 - β	1100	$0.8–1.0*10^{-6}$	30	130 ± 30	12.1 ± 3.6	804
W-1029 - β W-1102 - β	1100 1100	$2.1–2.8*10^{-5}$	46 33	130 ± 13	9.0 ± 2.4	876
W-1119 - β	1100	$1.8–2.5*10^{-4}$	36	257 ± 35	3.4 ± 0.9	931
W-1025 - β	1050	$1.8–2.4*10^{-6}$	32	87 ± 17	13.6 ± 4.0	476
W-1024 - β W -1101 - β	1000 1000	$1.8–2.3*10^{-6}$	22 29	102 ± 9	11.6 ± 3.2	568
W-1051 - β	1000	$1.9–2.9*10^{-5}$	41	189 ± 30	4.6 ± 1.1	638
W-1050 - α W-1099 - α	900 900	$2.0–2.7*10^{-6}$	34 33	149 ± 18	5.0 ± 1.3	620
W-1049 - α	900	$1.8–2.8*10^{-5}$	44	268 ± 40	3.2 ± 0.7	777
W-1085 - α	850	$1.9–2.6*10^{-6}$	32	198 ± 30	4.6 ± 1.3	918
W-1030 - α	800	$1.8–2.4*10^{-6}$	32	207 ± 38	4.4 ± 1.1	651
W-739nov-α	700	$\sim 2 * 10^{-6}$	24	368 ± 100	1.9 ± 0.5	706

α and β refer to quartz stability field. Repeated runs for microstructure and mechanical data are listed within the same row. The instantaneous strain rate increase over the interval from 10% to final strain is indicated. The number of recrystallized grains measured in each sample is given. For sample W-739 from *Bishop* [1996] the recrystallized grain size was re-measured. See text for further explanations.

Stipp, M., and J. Tullis (2003), The recrystallized grain size piezometer for quartz, Geophys. Res. Lett., 30(21), 2088, doi: 10.1029/2003GL018444.

2006
shearing experiments
confining medium = solid salt

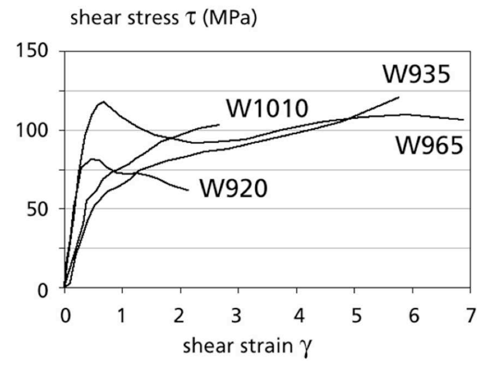


Figure 2. Shear stress–shear strain curves for the fo samples used in this study; for deformation conditions ar percent thinning see Table 1.

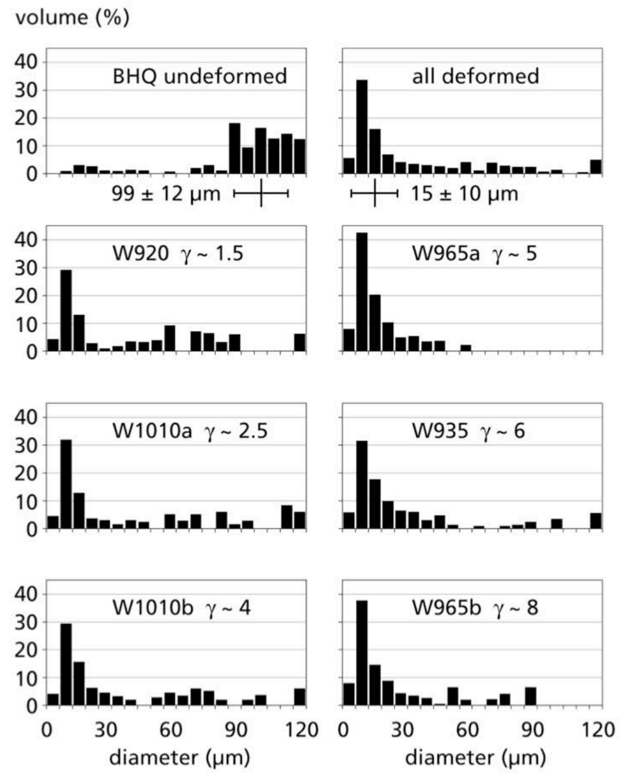


Figure 5. Grain size distribution of undeformed Black Hills quartzite (BHQ) and three experimentally sheared samples. Volume percent of 3-D grains as a function of the diameter of a sphere of the same size. Undeformed BHQ, summary of all deformed samples; W920 ($\gamma \approx 1.5$); W1010a ($\gamma \approx 2.5$); W1010b ($\gamma \approx 4$); W965a ($\gamma \approx 5$); W935 ($\gamma \approx 6$); and W965b ($\gamma \approx 8$). Average grain diameters of undeformed BHQ and recrystallized grains have been determined for grain sizes >60 and <48 μm, respectively.

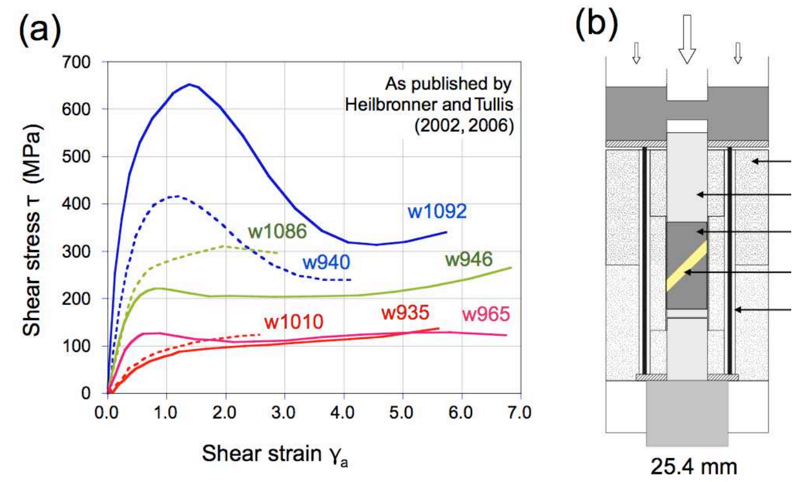
Table 1. Experimental Conditions[a]

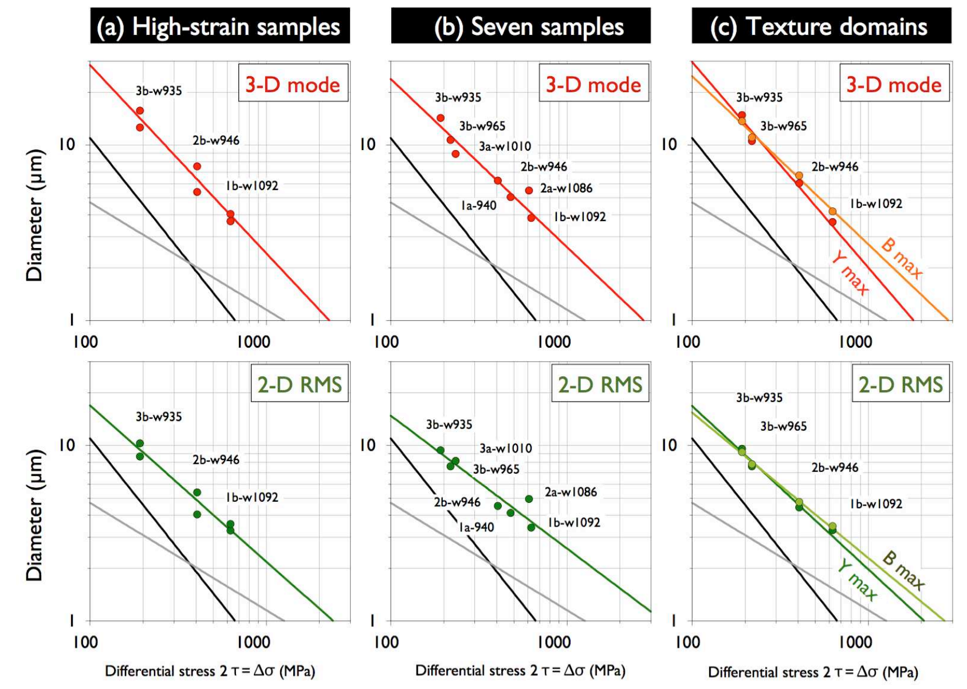
Experiment	T, °C	P_c, GPa	Thickness, mm	$\dot{\gamma}$, s⁻¹	ε_{flat}, %	γ_{tot}	e_{mag}	t, s
W920	900	1.50	2.03	1.25×10^{-5}	20	2.1	1.3	1.68×10^{-5}
W1010	915	1.55	1.27	1.98×10^{-5}	19	2.7	1.6	1.28×10^{-5}
W935	915	1.50	1.27	1.98×10^{-5}	46	5.8	2.5	2.02×10^{-5}
W965	915	1.55	1.25	2.01×10^{-5}	40	6.9	2.8	2.41×10^{-5}

[a] Values are for T, temperature; P_c, confining pressure; thickness, original thickness of sample; $\dot{\gamma}$ shear strain rate; ε_{flat}, thinning strain (percent of original thickness); γ_{tot}, total bulk shear strain; e_{mag}, strain magnitude; t, duration of experiment. All samples had 0.17 wt % H_2O added.

*Heilbronner, R. and Tullis, J., (2006). Evolution of c-axis pole figures and grain size during dynamic recrystallization: Results from experimentally sheared quartzite.
J. Geophys. Res., 111: B10202, doi:10.1029/2005JB004194.*

2017
shearing experiments,
revisited, EBSD data





1	2	3	4	5	6
		3-D diameter		2-D diameter	
Map	No. of grains	Mode (= mean) of $v(D)$	SD of $v(D)$	RMS of $h(d)$	Mean of $h(d)$
Grain size of undeformed Black Hills Quartzite from 2-D grain size ($0 < d \leq 150\,\mu m$) – Fig. 4					
BHQ undef. EBSD data	216	101.6	5.3	77.2	70
BHQ undef. CIP data	1146	101.5	13.8	90	86.5
Recrystallized grain size from 2-D grain size ($0 < d \leq 25\,\mu m$) – Fig. 9					
1a-w940	5914	5	2	4.1	3.6
1b-w1092	34 115	3.8	1.4	3.4	3
2a-w1086	4377	5.5	2.2	5	4.1
2b-w946	19 279	6.3	3	4.5	3.8
3a-w1010-s34+s36	12 233	8.9	3.4	8.2	6.7
3b-w935	13 354	14.7	7	9.4	8
3c-w965-s40	10 910	10.7	4.4	7.6	6.6

Table 1. Mechanical data for general shear experiments of Black Hills Quartzite.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18
Regime	Sample	T [°C]	$\dot{\gamma}_{min}$ [$10^{-5}\,s^{-1}$]	$\dot{\gamma}_{max}$ [$10^{-5}\,s^{-1}$]	P [GPa]	H_2O [wt %]	τ_{peak} [MPa]	τ_{flow} [MPa]	τ_{last} [MPa]	$\Delta\sigma$ [MPa]	45° d. [mm]	th_0 [mm]	th_f [mm]	γ_a	γ_{eff}	γ_{true}
1a	w940	850	1.46	2.5	1.5	–	413	238	238	476	3.6	1.27	0.87	4.1	2.8	2.7
1b	w1092	850	0.5	2.43	1.55	–	647	314	338	628	5.05	1.45	0.88	5.7	3.5	3.3
2a	w1086	875	1.33	2.6	1.58	–	269	300	294	600	2.49	1.14	0.87	2.9	2.2	2.2
2b	w946	875	1.04	3.08	1.5	0.17	220	201	265	402	4.44	1.24	0.65	6.8	3.6	3.3
3a	w1010	915	1.53	2.13	1.55	0.17	–	115	119	230	2.65	1.27	1.03	2.6	2.1	2.1
3b	w935	915	1.53	2.82	1.5	0.17	–	103	133	206	3.87	1.27	0.69	5.6	3	2.9
3c	w965	915	1.3	2.91	1.55	0.17	125	107	121	214	5.07	1.25	0.75	6.8	4.1	3.9

(1) Dislocation creep regimes: 1, 2, 3; a, b, c = low, high, very high shear strain. (2) Sample number, (3) temperature, (4) minimum shear strain rate (at beginning of experiment, calculated from measured shearing and thinning of sample, for constant applied displacement rate), (5) maximum shear strain rate (at end of experiment, calculated as above), (6) confining pressure (confining medium NaCl), (7) amount of water added, (8) shear stress at peak or yield, (9) steady-state shear stress, (10) shear stress at end of experiment, (11) differential stress calculated as $2\tau_{flow}$, (12) displacement of forcing block parallel to 45° precut, (13) thickness of sample at start (th_0), (14) thickness of sample at end of experiment (th_f), (15) apparent shear strain $\gamma_a = \tan(\Psi)$ at end of experiment as indicated on stress–strain plots of shear experiments where Ψ = shear angle = $\arctan(d/th_f)$, (16) effective shear strain $\gamma_{eff} = \tan(\Psi)/k$ where $k = th_0/th_f$, (17) true shear strain $\gamma_{true} = \tan(\Psi)2\ln(k)/(k2-1)$.

Heilbronner, R. & Kilian, R. (2017). The grain size(s) of Black Hills Quartzite deformed in the dislocation creep regime. Solid Earth, 8, 1071–1093, 2017, doi.org/10.5194/se-8-1071-2017.

2017
piezometer experiments,
revisisted, EBSD data

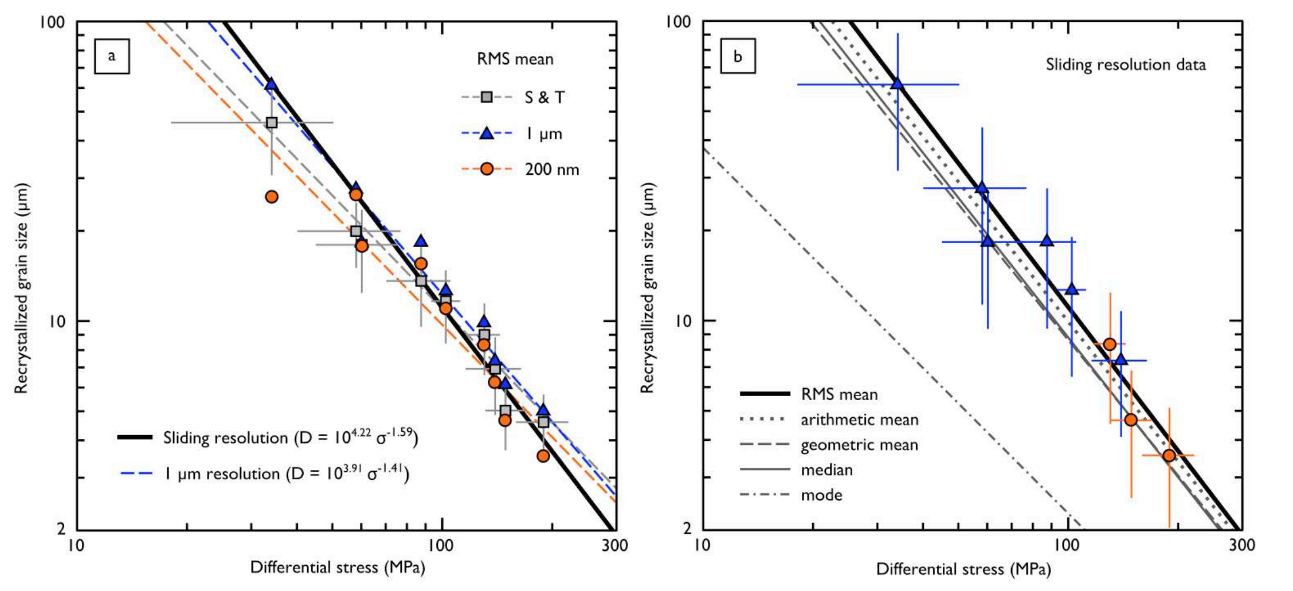


Figure 4. Log-log plots of recrystallized grain size versus differential stress. (a) The published RMS recrystallized grain sizes measured by CIP [*Stipp and Tullis*, 2003] (dashed grey line), and the RMS mean grain sizes for EBSD defined recrystallized grains extracted from 1 µm (dashed blue) and 200 nm (dashed orange) step size EBSD data. The sliding resolution RMS piezometer, which incorporates data from the 200 nm maps at the highest stresses, is shown in black. (b) The sliding resolution piezometer calculated from RMS, arithmetic and geometric means, and the median and mode data (equations for all are given in the supporting information Table S1). Error bars are shown for the Stipp and Tullis CIP data (Figure 4a) and the sliding resolution EBSD data (Figure 4b).

Table 1. List of Samples Together With Differential Stress [From *Stipp and Tullis*, 2003; *Stipp et al.*, 2006] Together With EBSD Step Size, Area, Indexing Rate, and Statistics Extracted From EBSD Data[a]

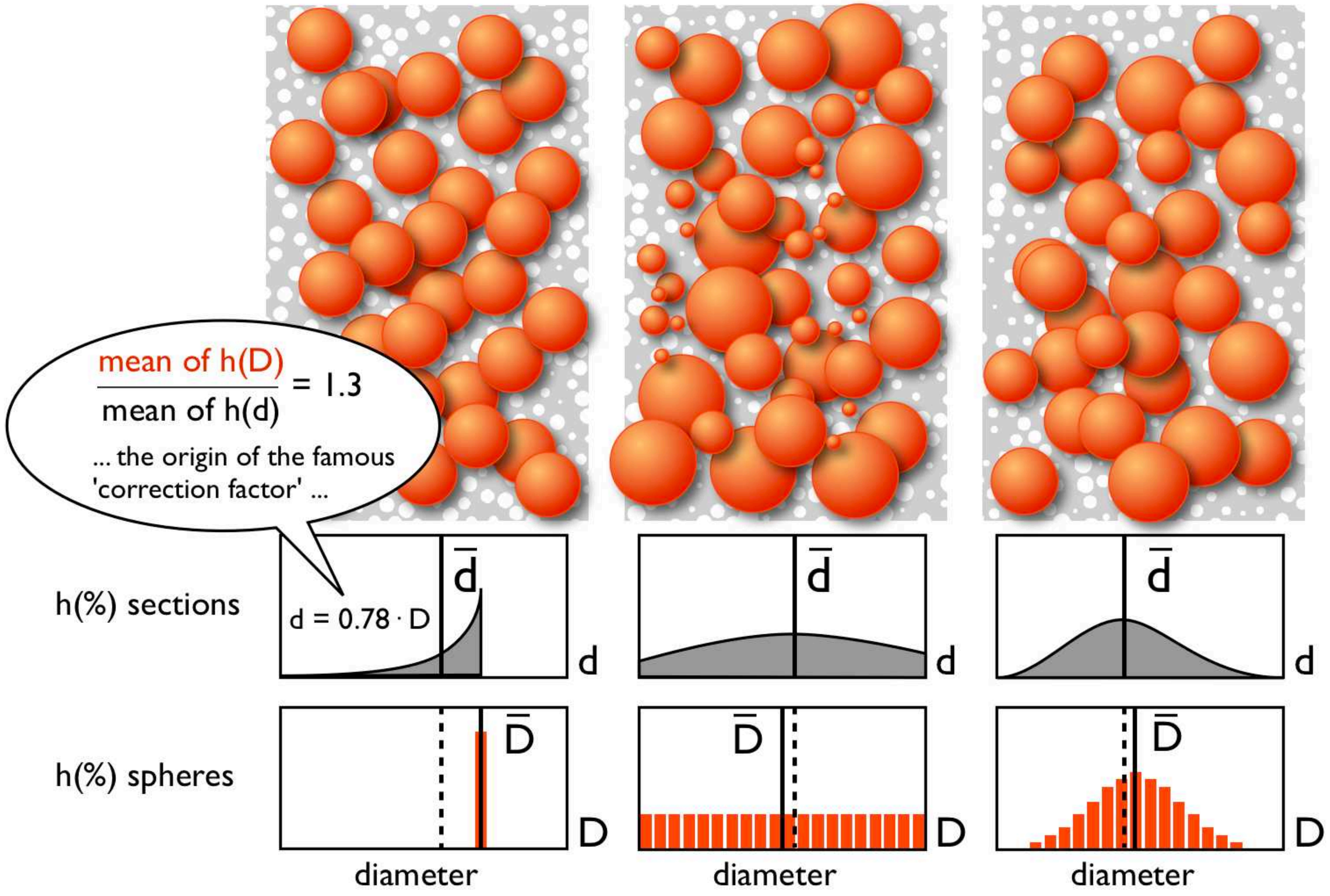
Sample	Stress (MPa)	Step Size	Area (mm²)	Raw Indexing Rate (%)	Total No. of Grains	No. of Relict Grains	No. of Rex. Grains	Stipp and Tullis d (µm)	EBSD RMS d (µm)	EBSD Arithmetic d (µm)	EBSD Geometric d (µm)	EBSD Median d (µm)	EBSD Mode d (µm)	EBSD Error 1σ (µm)
W1126	34 ± 16	1 µm[b]	3.61	97.1	1064	236	828	46 ± 15	61.0	53.5	45.5	49.0	5.16	29.5
		200 nm	0.096	95.0	64	22	42		25.9	18.1	7.28	6.84	0.939	19.0
W1143	58 ± 18	1 µm[b]	1.40	97.9	1615	255	1360	19.9 ± 4.9	27.5	22.2	18.0	18.1	4.48	16.2
		200 nm	0.096	98.3	99	25	74		26.1	21.0	17.0	17.5	2.82	15.7
W1066	60 ± 15	1 µm[b]	2.70	97.3	5973	1201	4772	18 ± 5.5	18.2	15.9	13.6	14.2	3.39	8.82
		200 nm	0.104	85.1	193	71	122		17.9	15.8	13.6	13.9	3.72	8.61
W1025	87 ± 17	1 µm[b]	2.24	97.1	3639	807	2832	13.6 ± 4.0	18.3	16.0	13.7	14.3	8.46	8.85
		200 nm	0.060	98.2	149	52	97		15.5	13.1	11.0	10.0	2.77	8.37
W1024	102 ± 9	1 µm[b]	1.28	96.4	3832	769	3063	11.6 ± 3.2	12.6	11.0	9.55	9.84	3.04	6.10
		200 nm	0.112	96.8	396	115	281		10.8	9.64	8.54	8.77	1.94	4.94
W1029	130 ± 13	1 µm	1.20	96.0	7491	1328	6163	9.0 ± 2.4	9.83	8.70	7.67	7.74	2.88	4.58
		200 nm[b]	0.104	96.2	739	185	554		8.37	7.44	6.58	6.61	1.51	3.83
W1081	139 ± 24	1 µm[b]	0.898	96.6	2339	497	1842	6.9 ± 2.0	7.34	6.57	5.89	5.88	2.82	3.27
		200 nm	0.096	97.5	238	82	156		6.13	5.45	4.81	4.74	1.11	2.82
W1050	149 ± 18	1 µm	0.894	93.7	6104	762	5342	5.0 ± 1.3	6.09	5.32	4.81	4.58	2.52	2.97
		200 nm[b]	0.086	91.9	943	234	709		4.63	4.14	3.71	3.65	0.492	2.07
W1051	189 ± 30	1 µm	0.905	85.0	8641	1114	7527	4.6 ± 1.1	5.03	4.61	4.32	4.13	2.28	2.01
		200 nm[b]	0.096	89.4	1449	299	1150		3.53	3.19	2.89	2.89	0.711	1.51

[a] Measurement errors in differential stress and grain size (1 standard deviation) are indicated.
[b] EBSD data used to define the sliding resolution piezometer.

Cross, A.J., Prior, D.J., Stipp, M., Kidder, S. ((2017), The recrystallized grain size piezometer for quartz: An EBSD-based calibration, Geophys. Res. Lett., 44, doi:10.1002/2017GL073836.

< go to overview >

which mean grain size ?

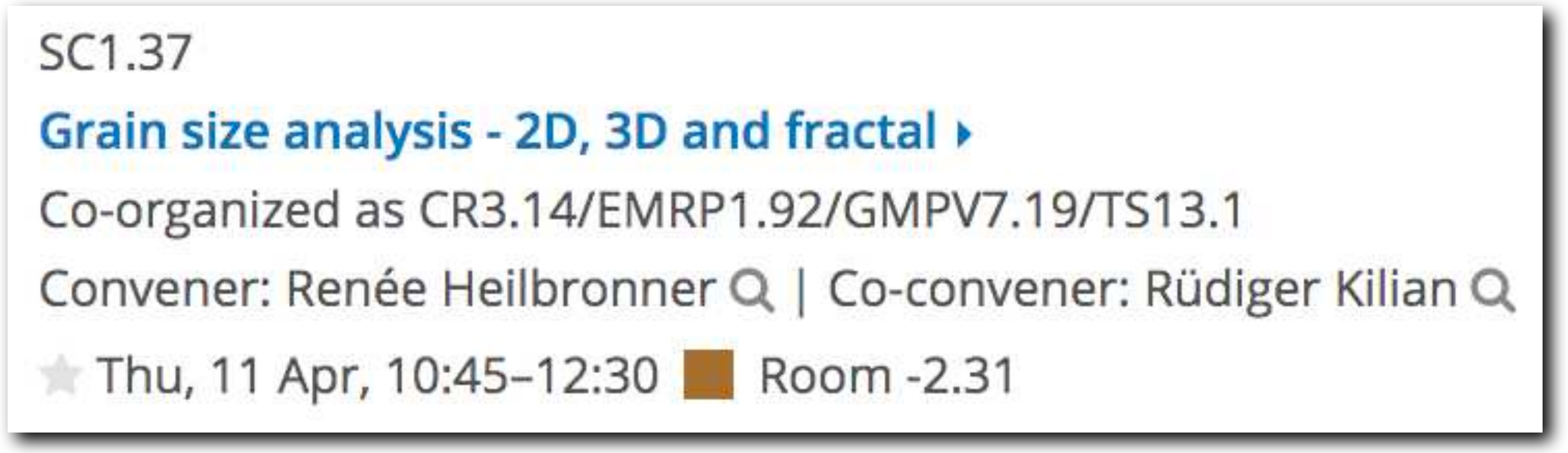


Two reasons for using 3D modes of volume fractions:

'2D mean'
The mean (or RMS) of the size distribution of 2D sections depends strongly on the shape of the distribution h(d); depending on the skewness, the mode may be smaller, larger or equal to the mean.
This is the measure used by Stipp & Tullis (2003) and by Cross et al. (2017) to defined the recrystallized grain size of the piezometer.

'3D mode'
Physically, the most important grain size is the mode of the volume-weighted size distribution of 3D spheres vol%(D); this is the grain size that occupies the largest volume fraction.
This is the measure I propose to use instead.

Not convinced ?
More on tomorrows short course SC1.37



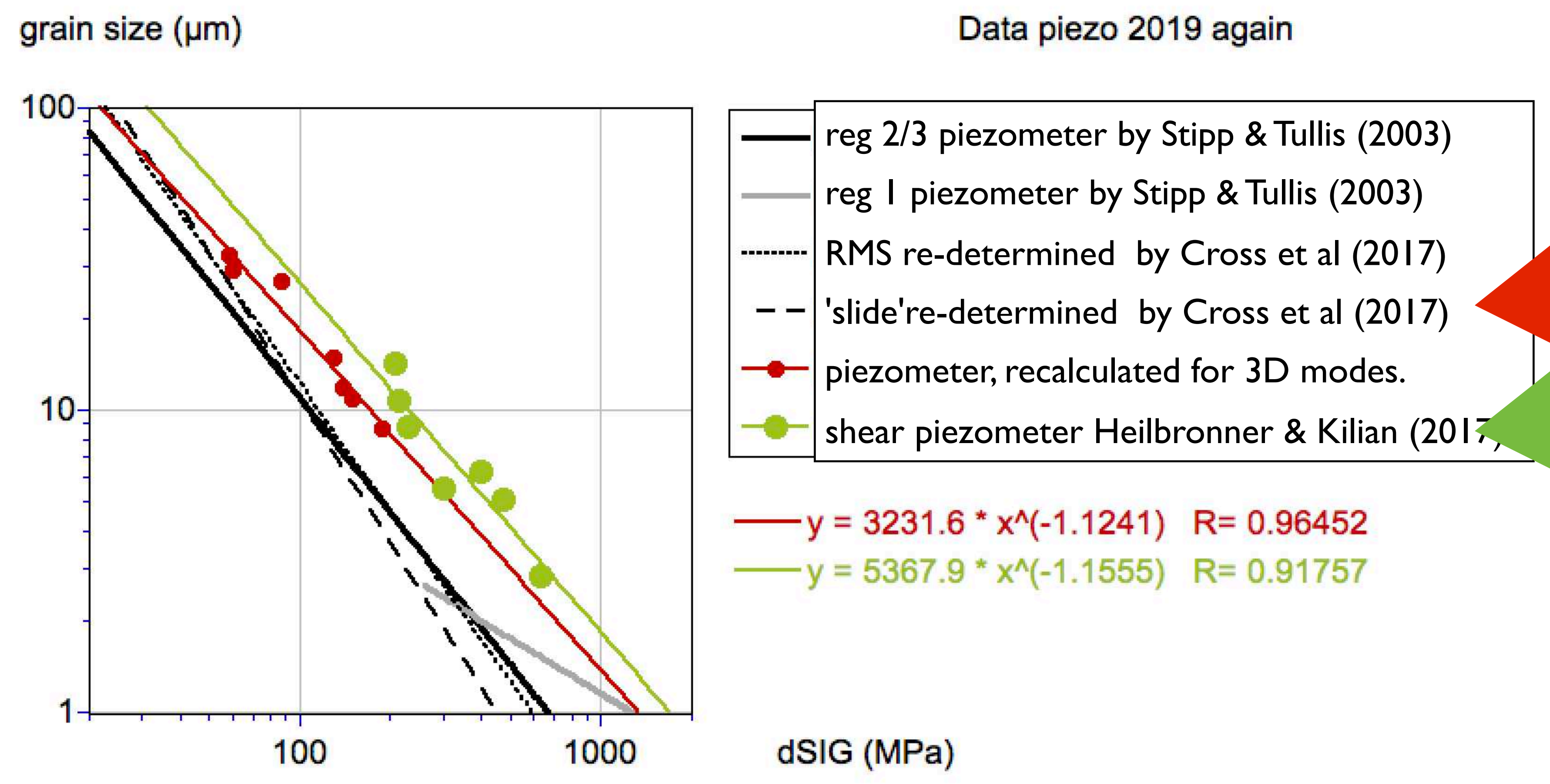
SC1.37
Grain size analysis - 2D, 3D and fractal ▸
Co-organized as CR3.14/EMRP1.92/GMPV7.19/TS13.1
Convener: Renée Heilbronner | Co-convener: Rüdiger Kilian
Thu, 11 Apr, 10:45–12:30 Room -2.31

< go to overview >

check grain size shear SSA vs. piezometer MSA (reg 2/3)

As a first step, the grain sizes of the piezometer experiments (Stipp & Tullis, 2013) and those of the general shear experiments (Heilbronner & Kilian, 2017) are plotted.
In order to compare the 3D modes of the shear experiments (green), the 3D modes of a set of EBSD maps of the piezometer samples (courtesy Stipp & Prior) are calculated (red).

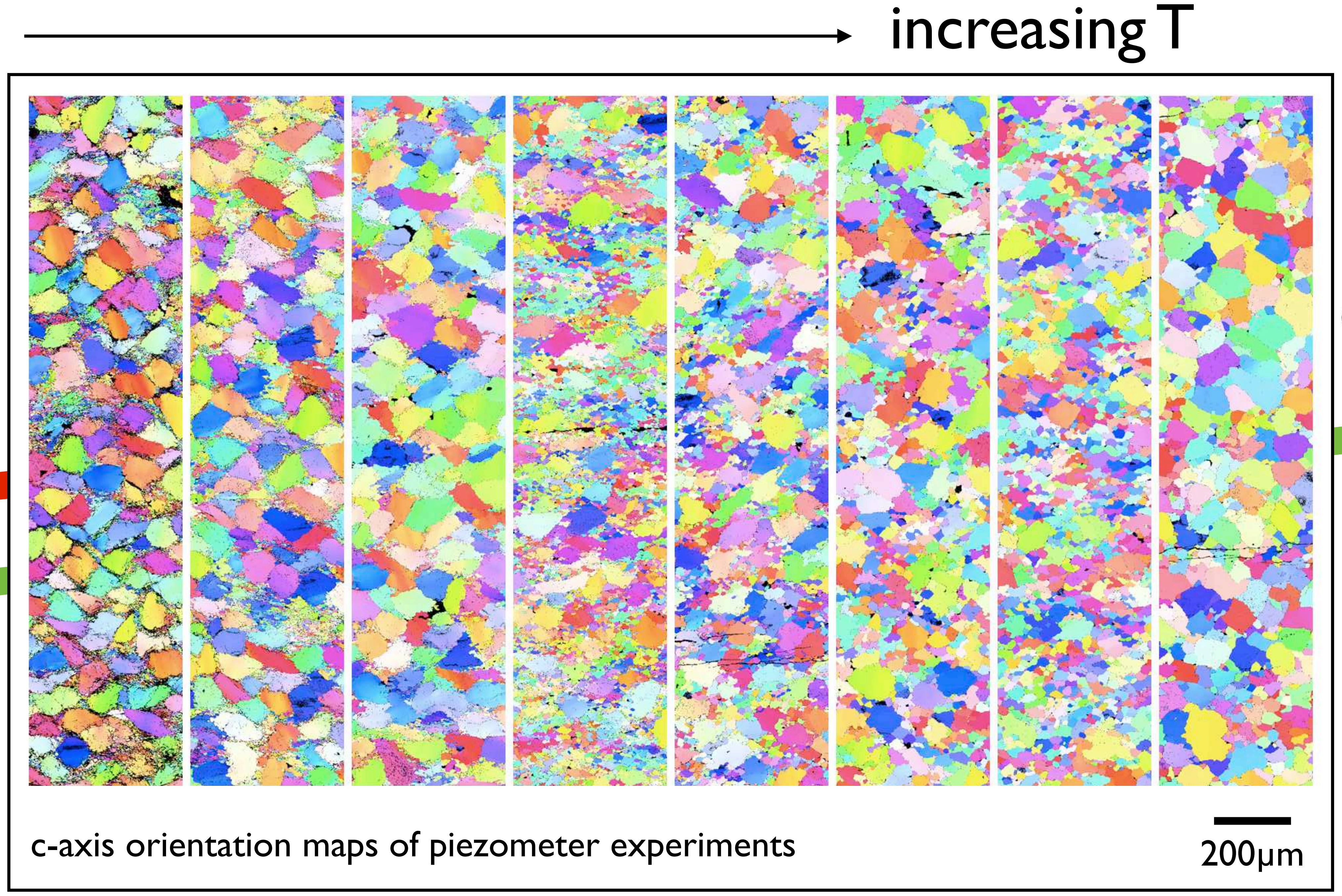
For the definition of 2Dmean and 3Dmode see previous slide



The piezometer experiments were carried out in a molten salt cell (MSC), allegedly for better stress resolution, compared to the general shear experiments which were carried out as standard experiemnts with a solid salt assembly (SSA).
In other words, the comparison was:
(SSA shear) versus (MSC coax)

Black Hills quartzite deformed at
900-1100°C, 1.5 GPa and 10^{-5} - 10^{-6} s^{-1}

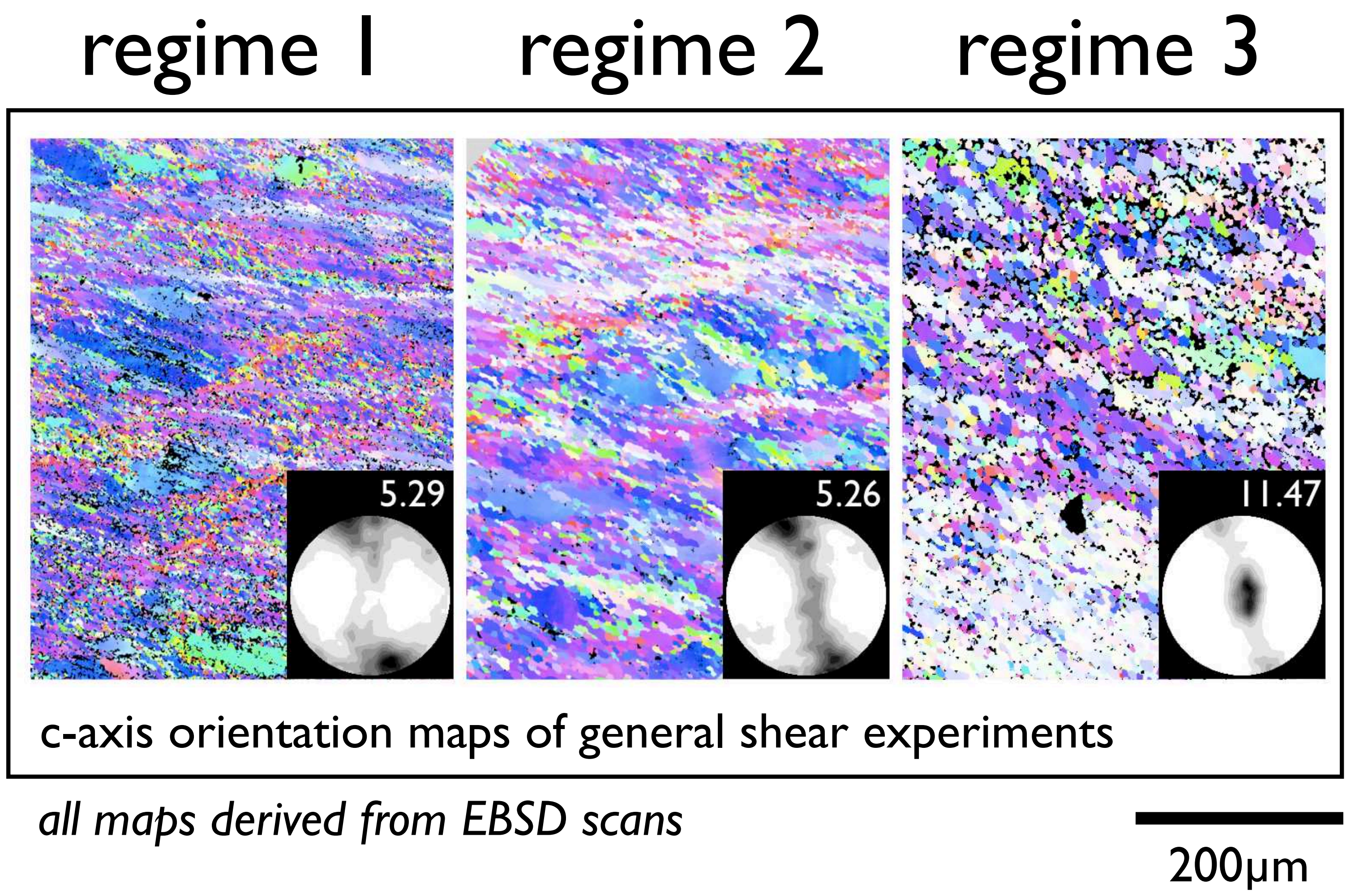
molten salt cell (MSC)



c-axis orientation maps of piezometer experiments

Black Hills quartzite deformed at
850 - 915°C, 1.5 GPa and 10^{-5} s^{-1}

solid salt assembly (SSA)



c-axis orientation maps of general shear experiments

all maps derived from EBSD scans

Observation:

The piezometer (3D modes) of SSA shear experiments plots above the reg2/reg3 branch (dark red line) of the 3Dmodes recalculated for the piezometer published by Stipp & Tullis (2003) !

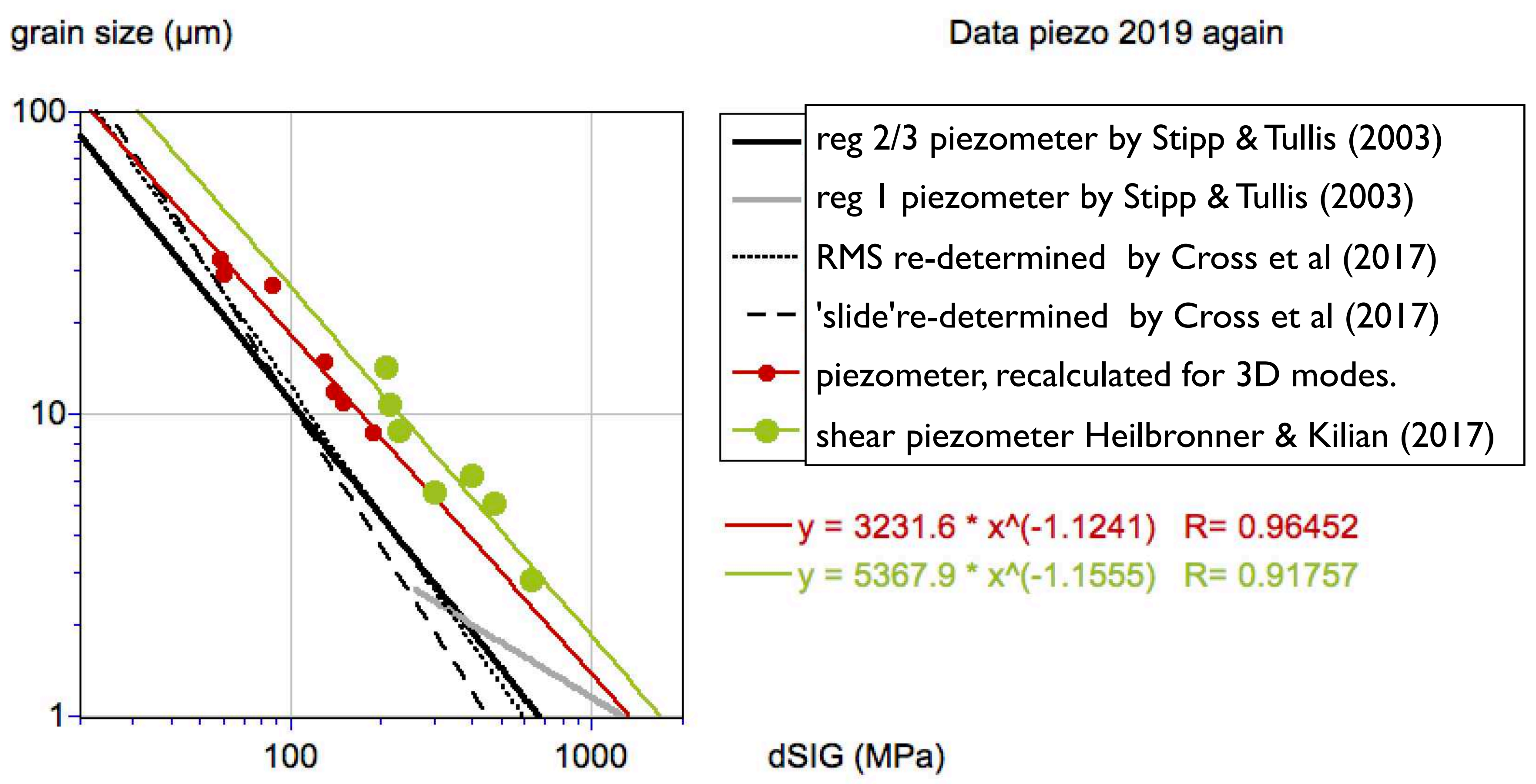
check grain size   coaxial SSA vs. piezometer MSA (reg2/3)

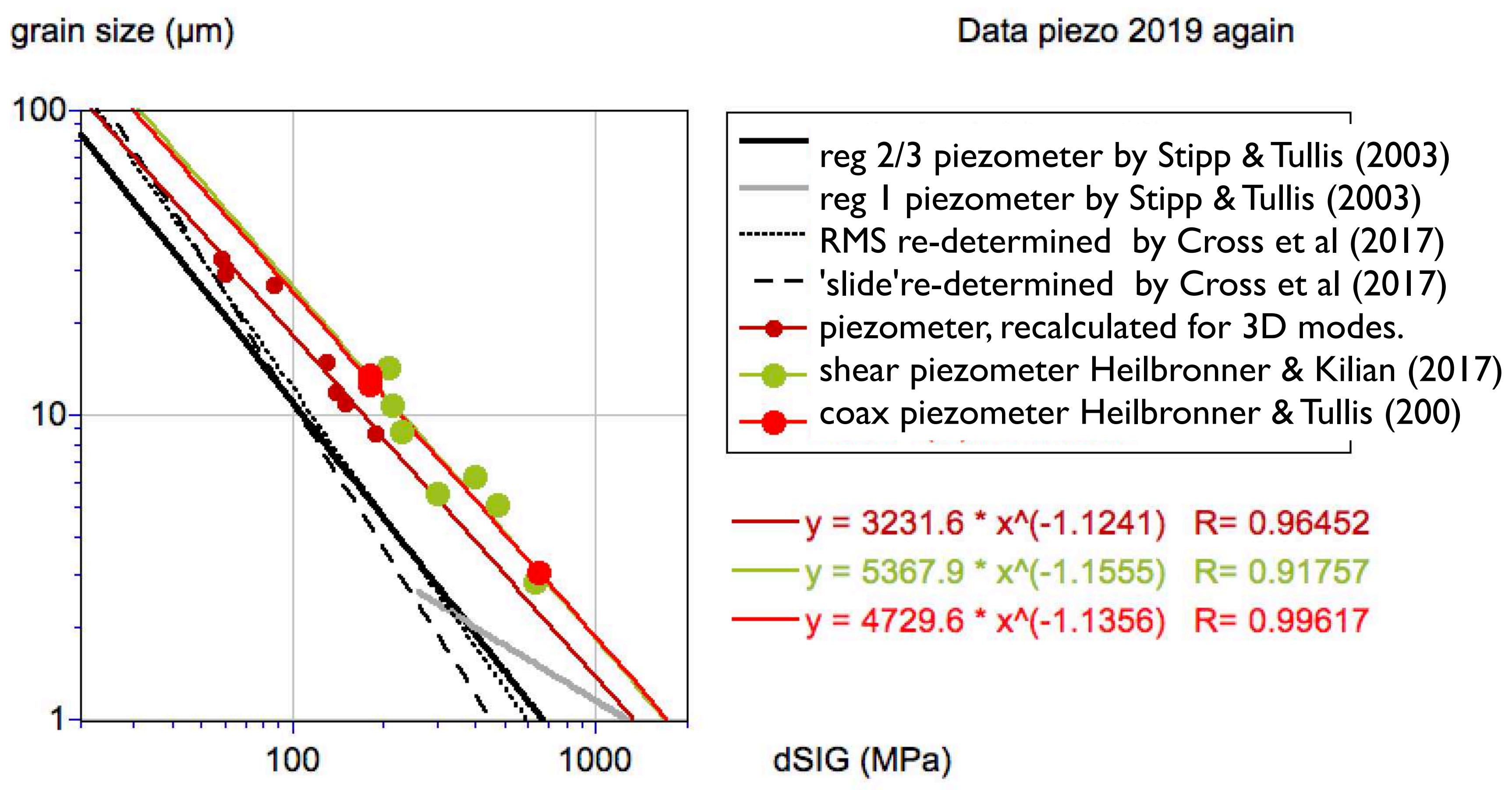
Next, in order to check if discrepancies can be explained by the different mechanical behaviour of the confining medium (with the SSA possibly carrying some differential stress, compared to the MSC which only supports hydrostatic pressure), a set of standard SSA coaxial experiments varried out in the context of an aannealing study (Heilbronner & Tullis, 2002) were analyzed.

Black Hills quartzite deformed at 850 - 915°C, 1.5 GPa and 10^{-5} s^{-1}

solid salt assembly (SSA)

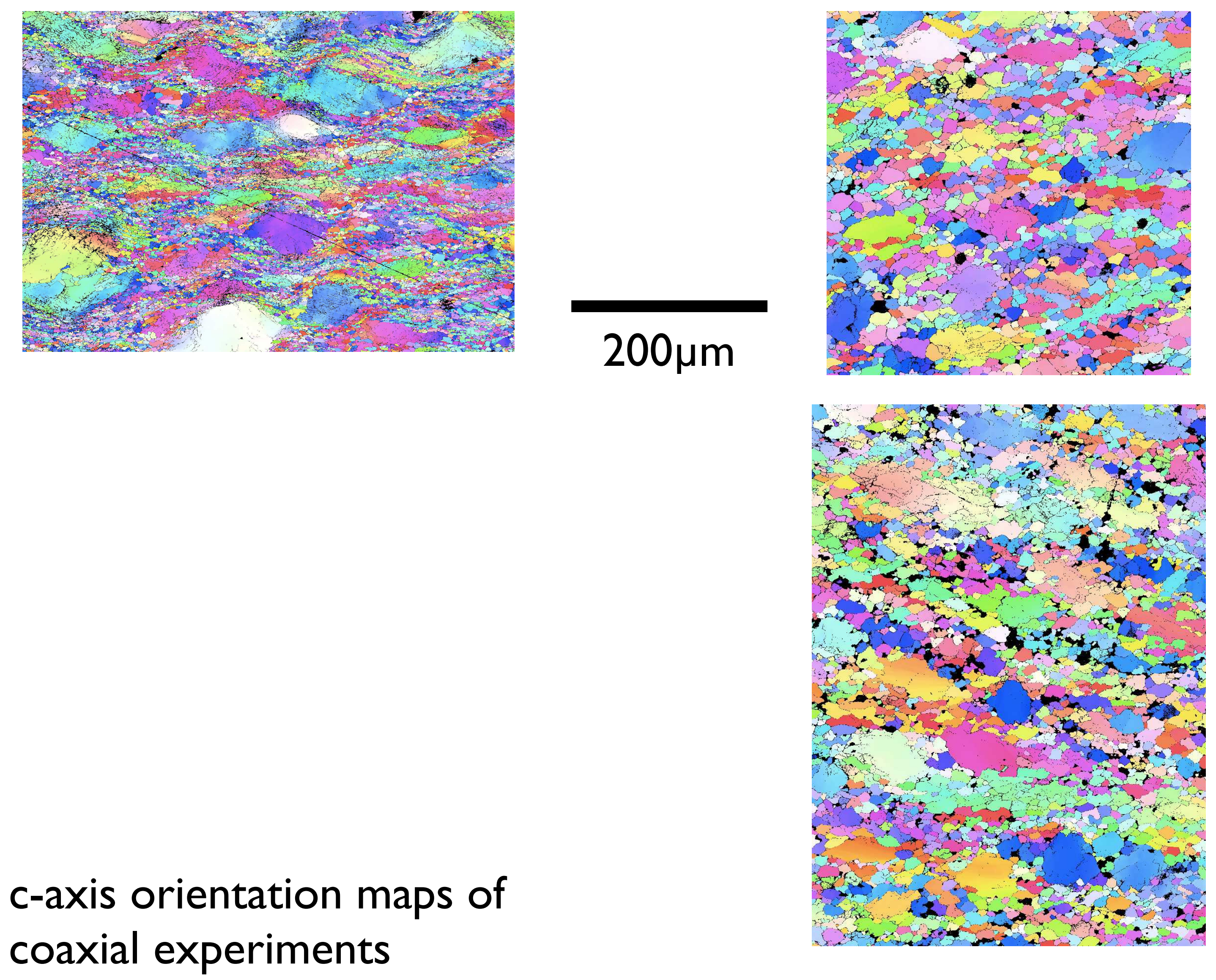
all maps derived from EBSD scans





new data

regime 1 regime 3



c-axis orientation maps of coaxial experiments

Observation:

The piezometer (3D modes) from SSA coax experiments also plots above the reg2/reg3 branch (dark red line) of the 3D modes recalculated for the piezometer published by Stipp & Tullis (2003) !

⇒ Stress felt by sample depends on solid vs. fluid confining medium ?!?!

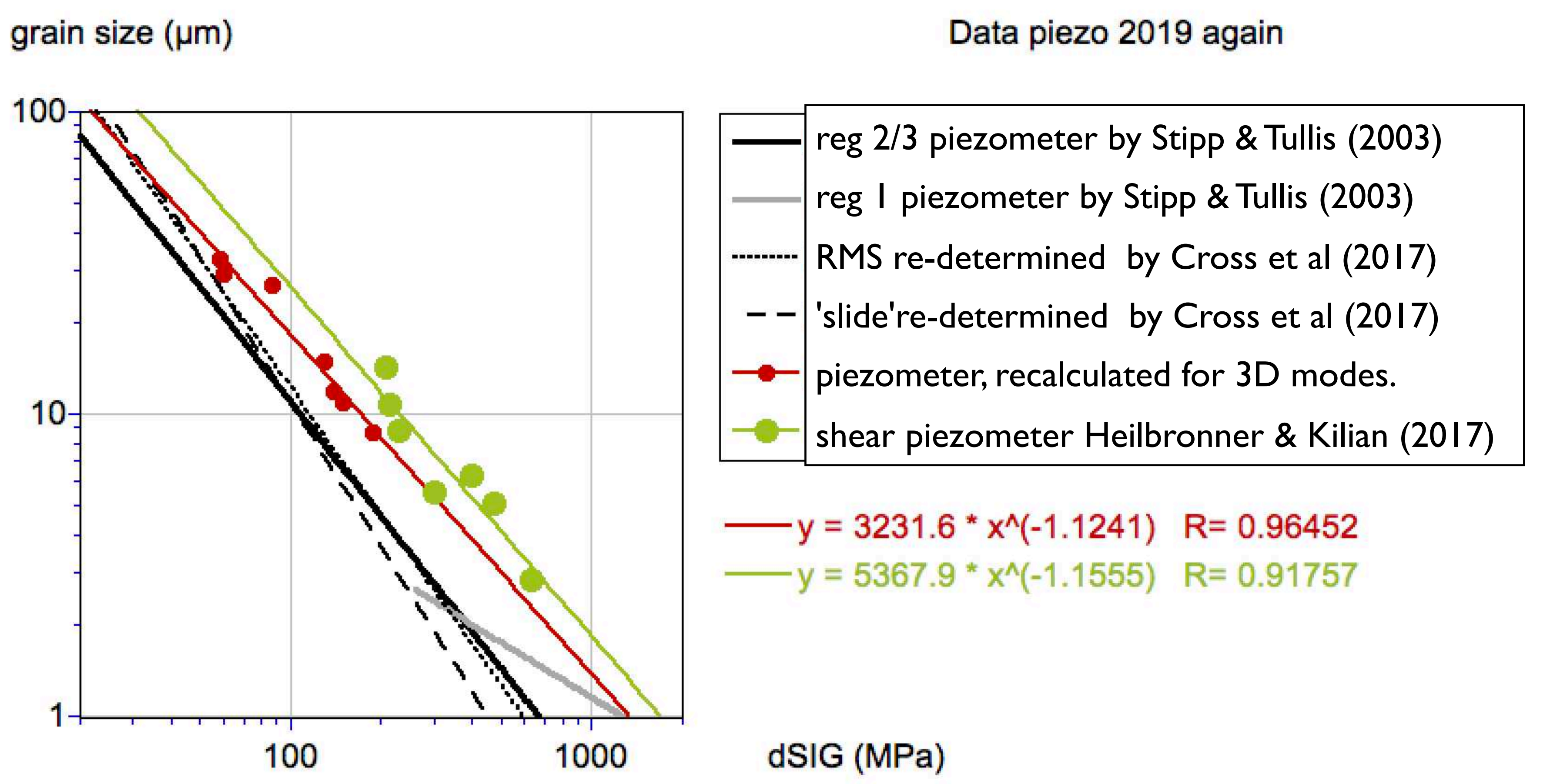
< go to overview >

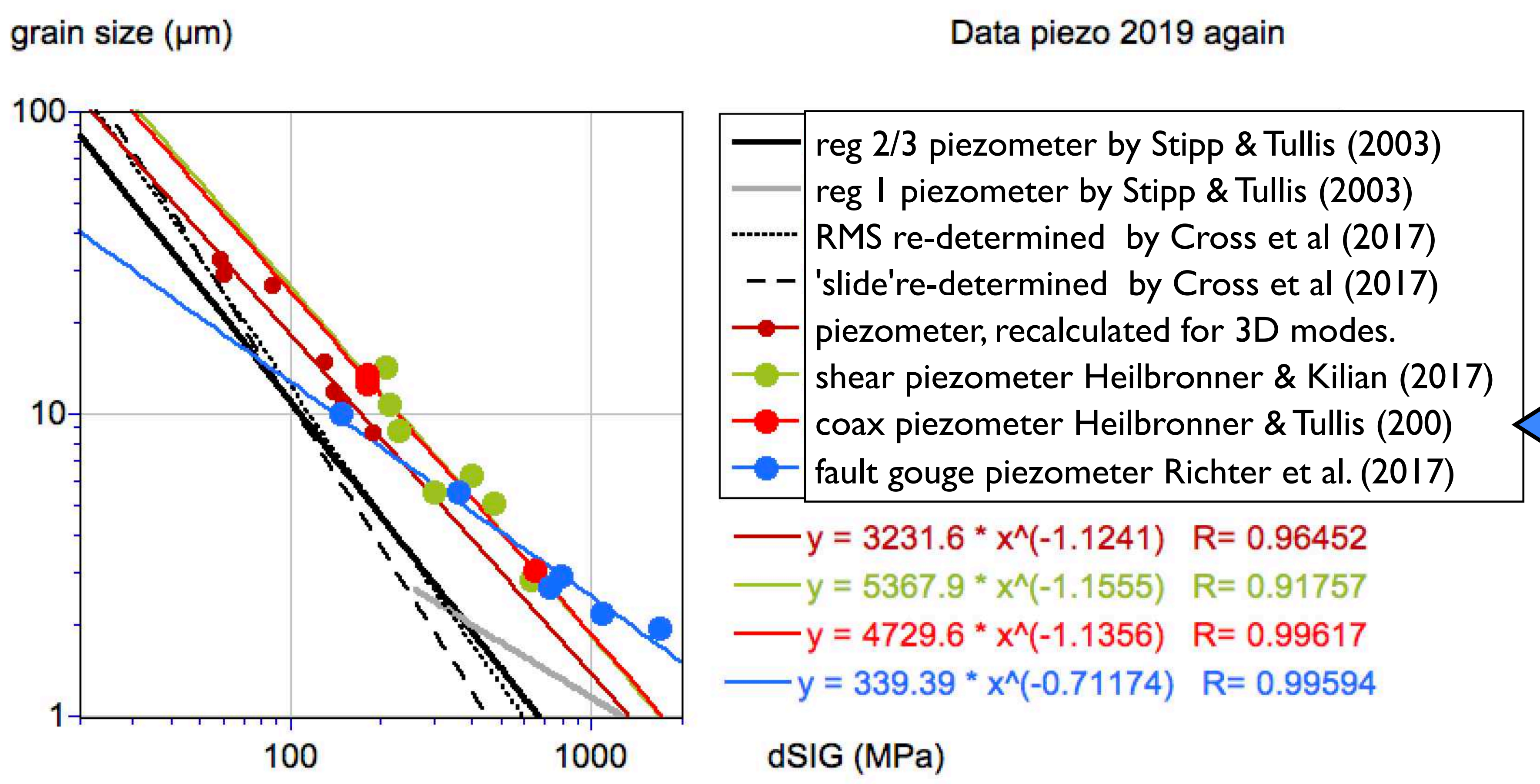
check grain size fault gouge SSA vs. piezometer MSA (reg1)

Finally, in order to get information for the very small grain size, we also checked the grain size of general shear general experiments (SSA) on fault gouge (crushed single crystal) carried out by Richter et al. (2016, 2018).

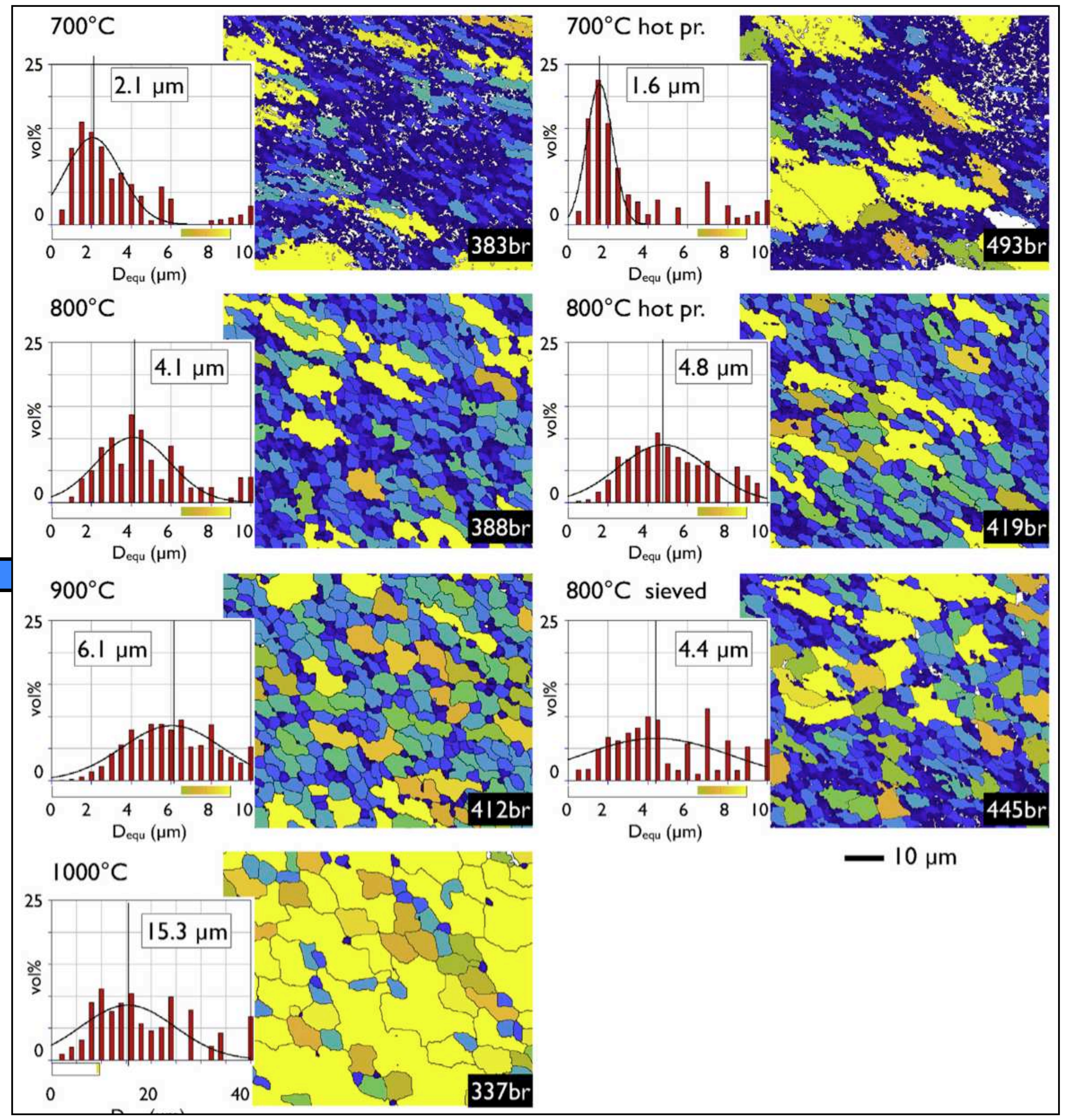
Quartz fault gouge deformed at
700 - 900°C, 1.5 GPa and 10^{-5} s^{-1}

solid salt assembly (SSA)





new data



Observation:

The piezometer (3D modes) derived from SSA shear experiments on quartz fault gouge also plots above the reg 1 branch (grey) of the piezometer (2D RMS) published by Stipp & Tullis (2003) !

Note: No EBSD maps were available to re-determine the grain sizes of the reg1 branch of the piezometer, nor could their 3D modes be re-calculated.

< *go to overview* >

new software for the conversion of mechanical data

Three new 'rig' programs have been written for the explicit conversion of mechanical data (force, displacement, confining pressure) to stress strain curves and other mechanical output (strain rate, equivaent viscosity etc.)

rigP: convert run record to input file XXX.in.txt
rigC: calculates stress strain from from XXX.in.txt for coaxial experiments
rigS: calculates stress strain from from XXX.in.txt for shearing experiments

The idea is to make every choice explicit (no default values)

- type of hitpoint
- friction correction
- value of σ_1 and σ_3 at start of experiment
- area correction
- strain determination
- etc.

It is hoped that by writing rig programs in this manner, in future, stress strain curves from different labs should return the same results (... if the same experiments are analyzed with the same options, of course).

Two 'standard' conversions routines are examined in the following
- Brown for axial experiments
- Tromsø for shearing experiments

The effect of changing the options (txpe of hitpoint, area correction, etc.) will be demonstrated.

rigP (= Prepare)

This program prepares the input file for rigC and rigS.
(the format of this input file is the same for both)

rigP is only concerned with converting the recorded data to:
- time (s),
- axial load (kN) as f(t),
- confining pressure (MPa) as f(t),
- displacement of loading piston (mm),

and to provide information concerning:
- sample geometry (lengths (mm), widths (mm), angles (°)),
- temperature setting (°C).

rigC (= Coaxial) rigS (= Shear)

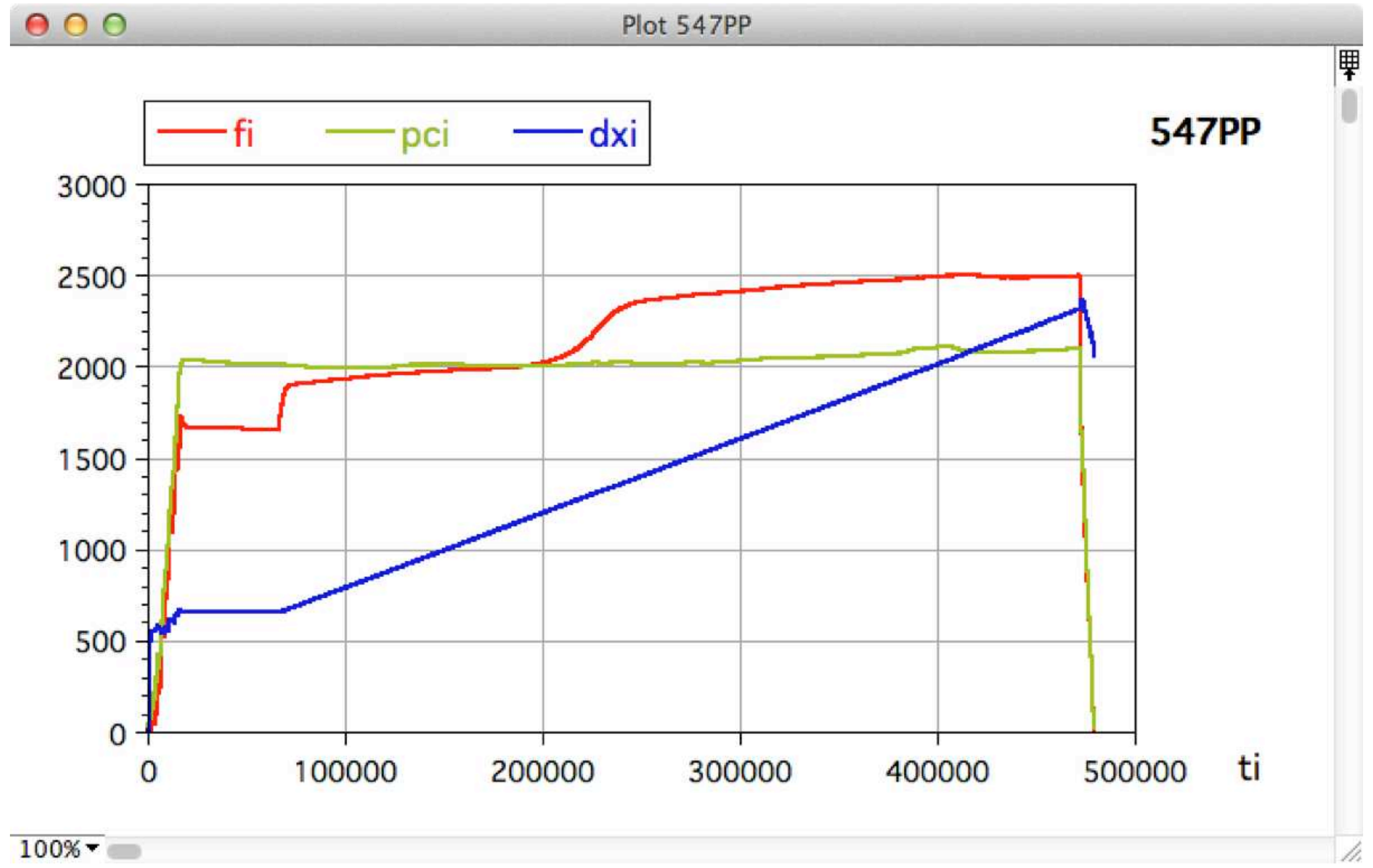
The following options are selected via dialogue:
- choice of hitpoint,
- friction correction (yes/no),
- salt correction (confining pressure increase) (yes/no),
- value of principal stresses, σ_1 and σ_3, at the start of the experiment,
- definition of differential stress, $\Delta\sigma$,
- choice of area corrections,
- geometrical choices concerning sample thinning,
- choice of strain calculations.

< go to overview >

rigP (= Prepare input files)

plot of Labview file

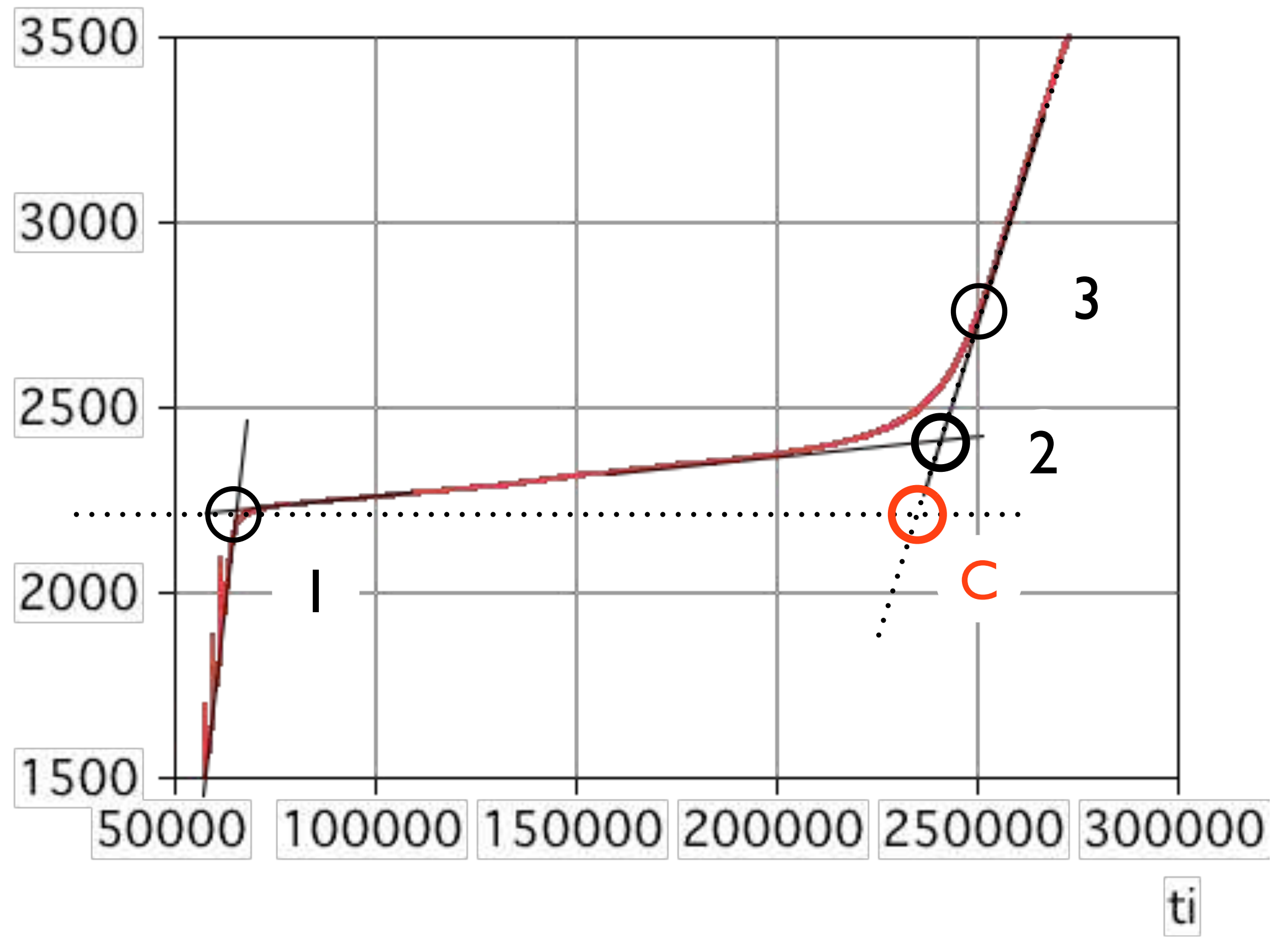
Plot 547PP.qpc



ti	time (s)
fi	force
pci	confining pressure
dxi	displacement
DLTi	displacement

source:
Labview file547PP.txt

determination of hitpoint



Numbers from run record

① = start of run-in
ti = ilead = 65432
fi = loadlead = 2222

② = hitpoint (2) = 'classical' hitpoint
intersection of line fits
ti = ihit = 240586
fi = loadhit = 2410

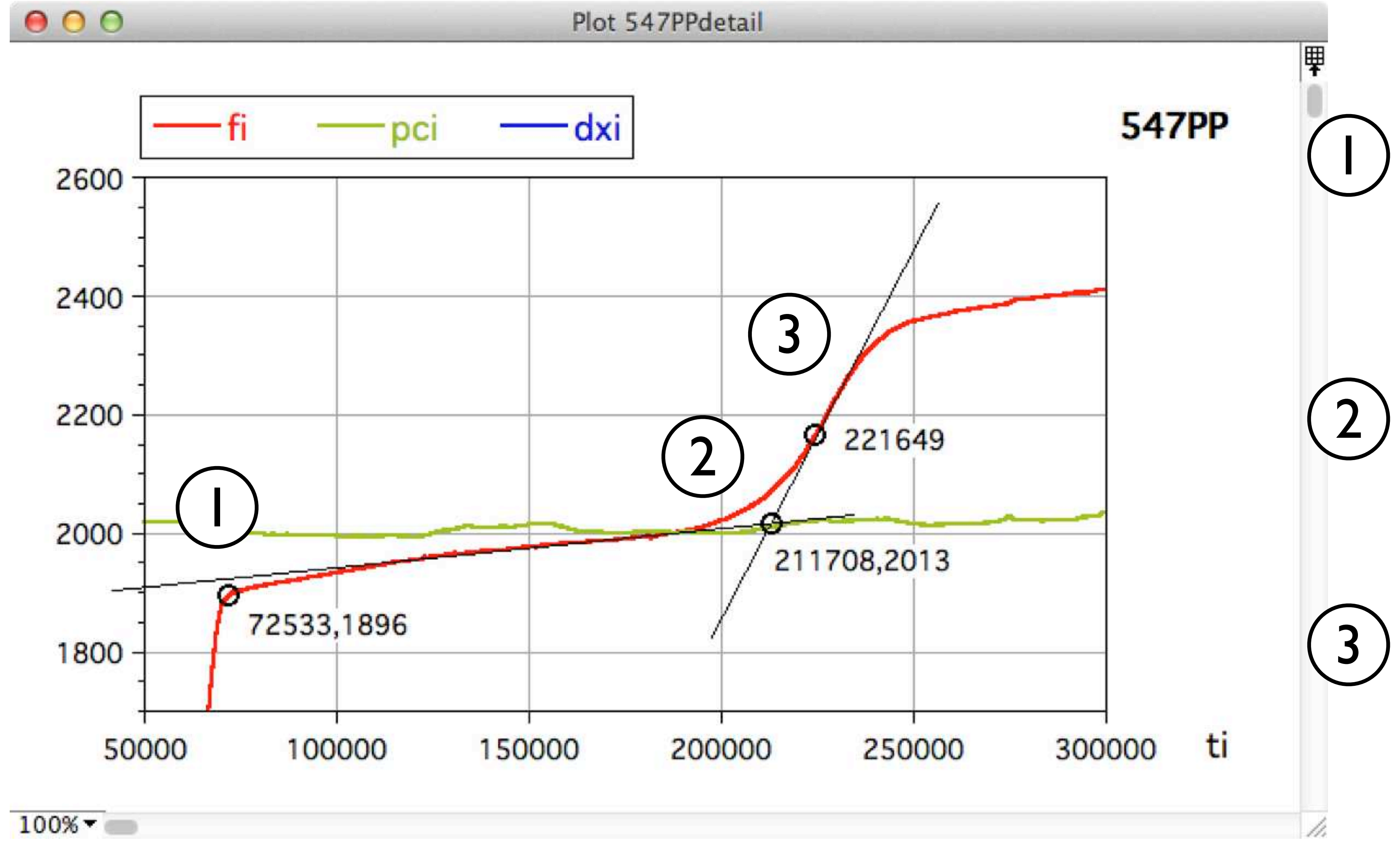
③ = from here on recorded data is used
ti = istart = 251775
fi = from load curve

Calculated in rigP from A, B and C

Ⓒ = hitpoint (1) = 'lead hitpoint'
ti = extrapolated
line fit (A→B)
fi = loadlead = 2222
same as C

data points selected in run record

Plot 547PPdetail.qpc



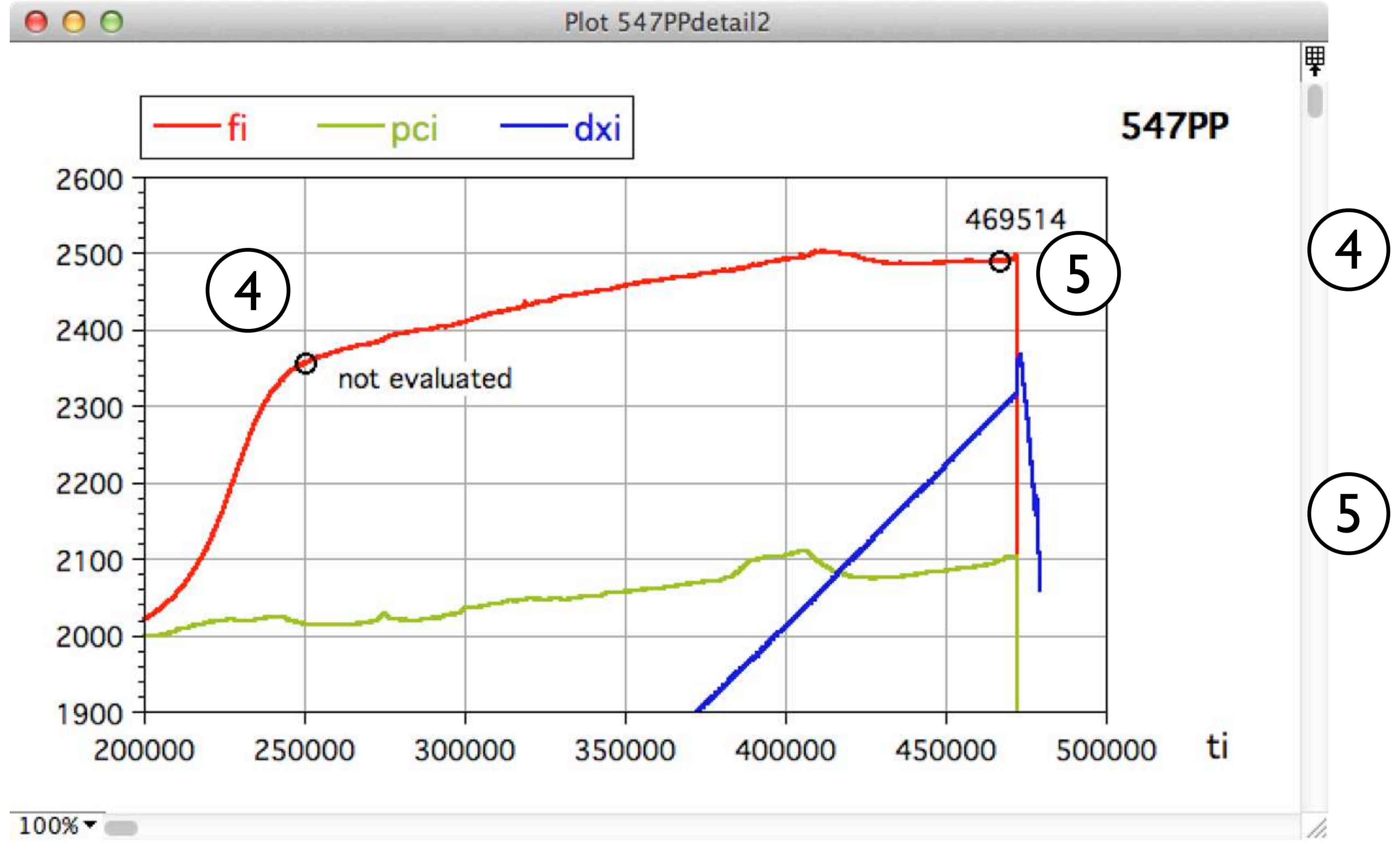
① point where σ_1 piston touches lead
ti = ilead = 72533
fi = loadlead = 1896

② hitpoint 2 (classical)
ti = ihit1 = 211708
fi = loadhit1 = 2013

③ first point to be used from curve
ti = istart = 221649

data points selected in run record

Plot 547PPdetail2.qpc



④ peak load / yield point
start of 'steady state'
ti = ishear = 0

⑤ end experiment
ti = iend = 469514

< go to overview >

rigC (for coaxial experiments)

how to run rigC

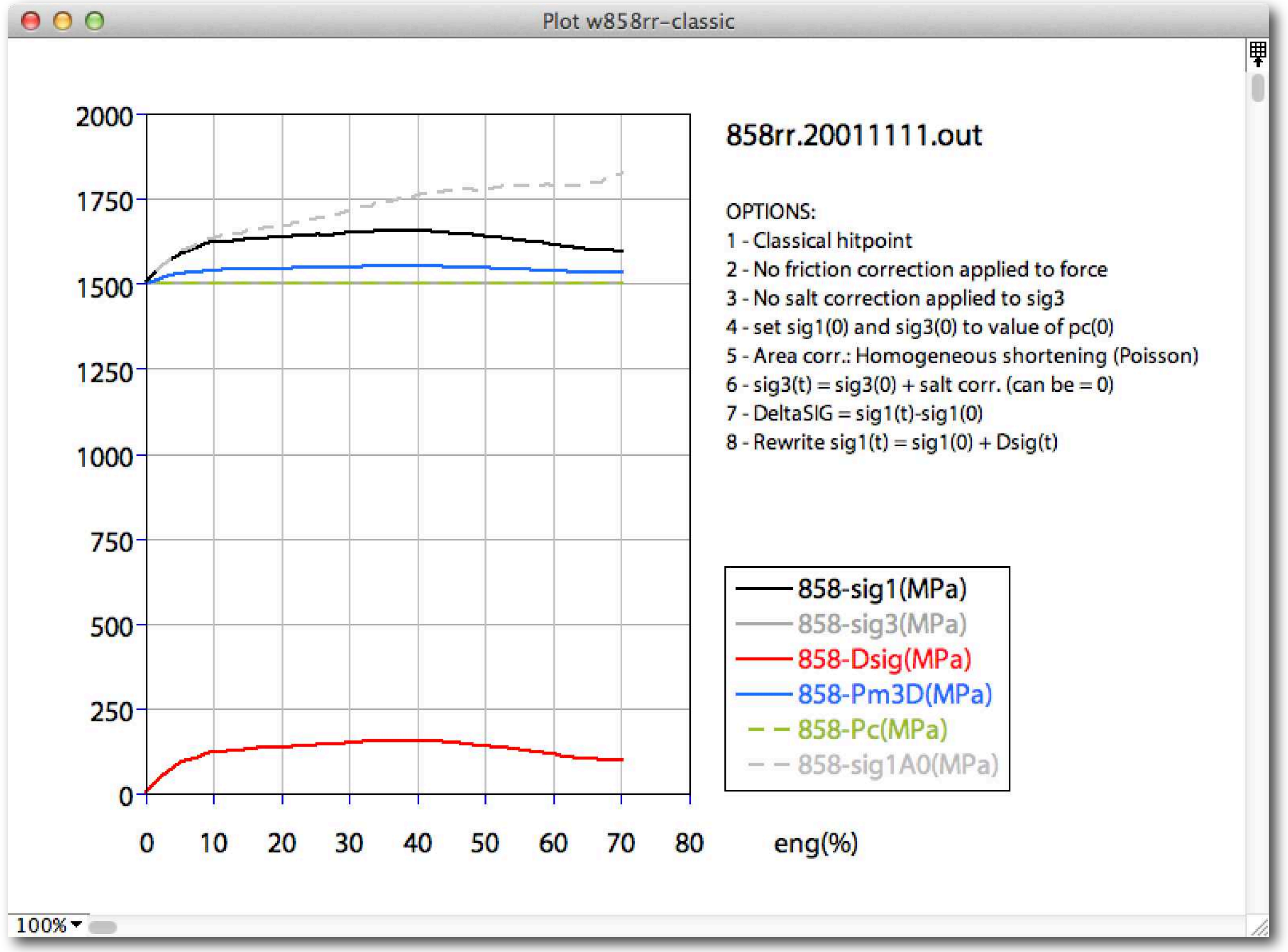
using file XXX.in.txt

```
rigC06
--------------------------------------------
--
Program rigC                  Basel,
2018-12-06
Uses input file with header and 5 columns
t(s), F(kN), Pc(MPa), d(mm), x(free)
1st line = hitpoint 1  2nd line = hitpoint 2
Explicit options
1-Select hitpoint (1=lead, 2=classical)
2-Friction correction for F
3-Salt correction for pc
4-Defining sig1(0) and sig3(0) at time=0
5-Options for area correction for sig1
6-Definition of sig3(t)
7-Options for differential stress Dsig(t)
8-Optional re-definition of sig1(t)
--------------------------------------------
Name of input file:
858rr.in.txt

--------------------------------------------
  input file: 858rr.in.txt
  header: Run record = w858 manual re-done
RH 201-11-27
  rig number:           1
  nominal Pc(MPa):        1500
  temperature(°C):         900
  log displacement rate of sig1
piston(ms-1):     -8

Correction for rig stiffness is not optional
```

```

Select hitpoint (1=lead, 2=classical)
2
Friction correction for F ? (1=yes  0=no)
0
Salt correction for pc ? (1=yes  0=no)
0
Defining sig1(0) and sig3(0) at time=0
1: set sig1(0) and sig3(0) to value of pc(0)
2: sig1(0)=sig3(0)=1/16*F/A(0)+15/16*pc(0)
3: use sig1(0) and sig3(0)=pc(0) as measured
1
Options for area correction
1: Homogeneous shortening of sample
2: Barreling of sample
3: No area correction
1
Definition of sig3(t)
1: sig3(t) = sig3(0) + salt corr. (can be = 0)
2: sig3(t) = sig3(t) + salt corr. (can be = 0)
1
Options for differential stress Dsig(t)
1: Dsig(t) = sig1(t)-sig1(0)
2: Dsig(t) = sig1(t)-sig3(t)
1
Optional re-definition of sig1(t)
1: sig1(t) = sig1(0) + Dsig(t)
2: sig1(t) = sig3(t) + Dsig(t)
3: leave sig1(t) as calculated
1
Name of output file ? [547PP.10122223.out.txt]
(return=default) >
<return>
 ---------------------------------
 result file = 858rr.20011111.out.txt
 ---------------------------------
```

red = input

output file of rigC


Plot w858rr-classic

858rr.20011111.out

OPTIONS:
1 - Classical hitpoint
2 - No friction correction applied to force
3 - No salt correction applied to sig3
4 - set sig1(0) and sig3(0) to value of pc(0)
5 - Area corr.: Homogeneous shortening (Poisson)
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig1(0)
8 - Rewrite sig1(t) = sig1(0) + Dsig(t)

```
Input file =  858rr.in.txt
Run record = w858 manual re-done RH 201-

rig          Pc(MPa)    T(°C)    d-rate(ms-1)
Tromsoe 1        1500        900           -8
diameter(mm)  length(mm)  time of max load
      6.220      13.820          0.0

OPTIONS:
1 - Classical hitpoint
2 - No friction correction applied to force
3 - No salt correction applied to sig3
4 - set sig1(0) and sig3(0) to value of pc(0)
5 - Area corr.: Homogeneous shortening (Poisson)
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig1(0)
8 - Rewrite sig1(t) = sig1(0) + Dsig(t)

 t(s)  858-Fc(kN)  858-Pc(MPa) d(mm) dcorr(mm)  858-sig1A0(MPa)  858-sig1(MPa)  858-sig3(MPa)  858-Dsig(MPa)  858-Pm2D(MPa)
       0.0      5.1463  1500.0000     0.0000     0.0000  1500.0000  1500.0000  1500.0000     0.0000  1500.0000  ... etc.
    6236.0      5.7401  1500.0000     0.1168     0.1163  1519.5420  1519.3774  1500.0000    19.3775  1509.6887
   12471.0      6.3339  1500.0000     0.2464     0.2454  1539.0841  1538.3901  1500.0000    38.3902  1519.1951
   18707.0      6.9277  1500.0000     0.3683     0.3668  1558.6261  1557.0701  1500.0000    57.0701  1528.5350
   24942.0      7.4028  1500.0000     0.4877     0.4858  1574.2617  1571.6512  1500.0000    71.6513  1535.8257
   31178.0      7.7986  1500.0000     0.6096     0.6074  1587.2876  1583.4514  1500.0000    83.4514  1541.7257
   37413.0      8.1153  1500.0000     0.7290     0.7265  1597.7102  1592.5737  1500.0000    92.5737  1546.2869
   43649.0      8.3133  1500.0000     0.8458     0.8431  1604.2263  1597.8677  1500.0000    97.8677  1548.9338
   49884.0      8.5508  1500.0000     0.9652     0.9623  1612.0426  1604.2407  1500.0000   104.2407  1552.1204
   56120.0      8.7091  1500.0000     1.0871     1.0841  1617.2522  1608.0544  1500.0000   108.0544  1554.0272
   62355.0      9.1050  1500.0000     1.2065     1.2032  1630.2814  1618.9391  1500.0000   118.9391  1559.4695
   68591.0      9.2634  1500.0000     1.3335     1.3300  1635.4944  1622.4545  1500.0000   122.4544  1561.2273
   74826.0      9.3029  1500.0000     1.4580     1.4545  1636.7943  1622.3972  1500.0000   122.3973  1561.1986
   81062.0      9.4217  1500.0000     1.5799     1.5763  1640.7040  1624.6554  1500.0000   124.6554  1562.3276
   87297.0      9.5009  1500.0000     1.6916     1.6879  1643.3105  1625.8070  1500.0000   125.8070  1562.9036

... etc.
```

< go to overview >

rigS (for general shearing experiments)

how to run rigC

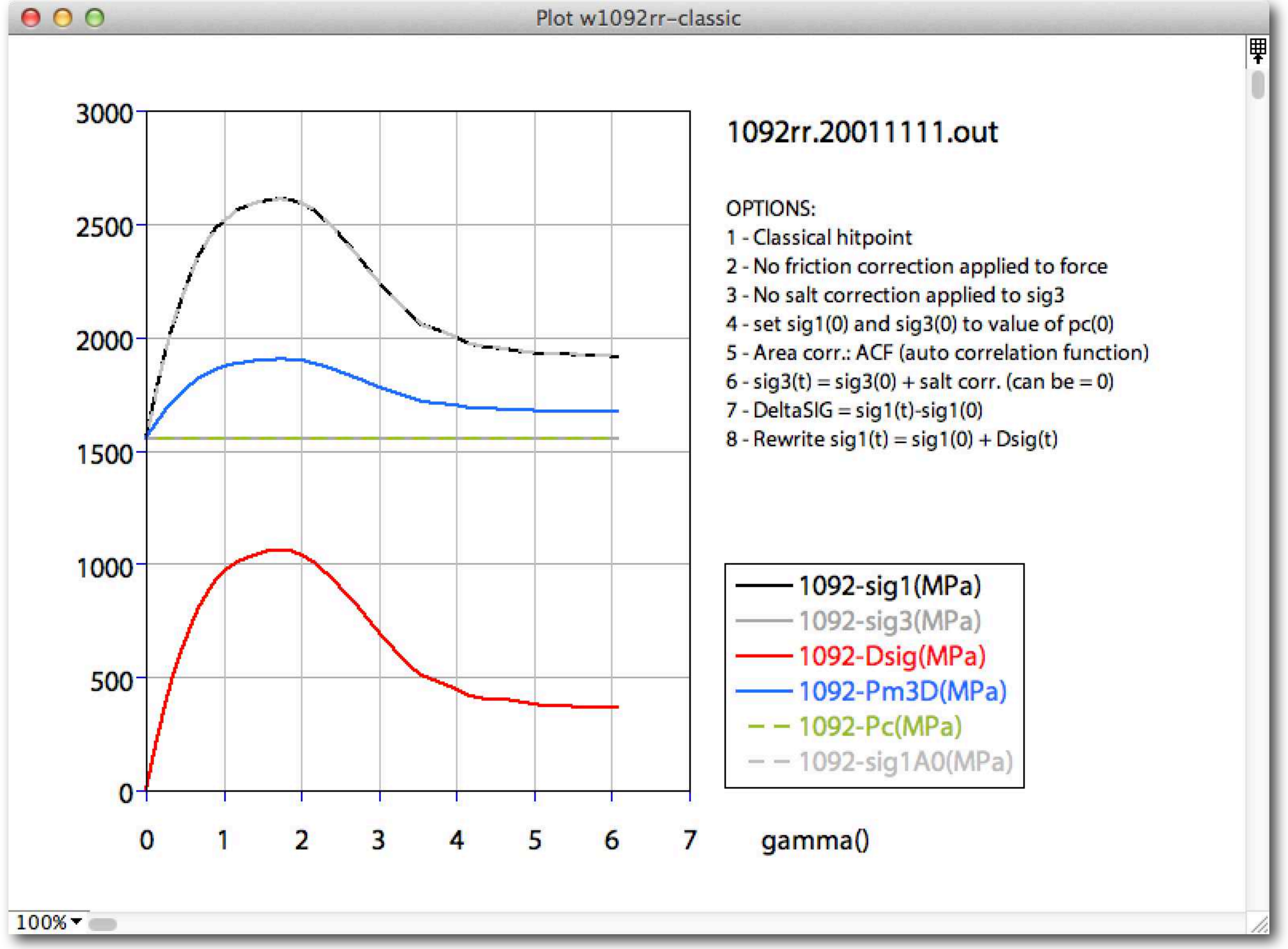
using file XXX.in.txt

```
 rigS
---------------------------------------------
--
Program rigS                  Basel,
2018-12-10
Uses input file with header and 5 columns
t(s), F(kN), Pc(MPa), d(mm), x(free)
1st line = hitpoint 1  2nd line = hitpoint 2
Explicit options
 1-Select hitpoint (1=lead, 2=classical)
 2-Friction correction for F
 3-Salt correction for pc
 4-Defining sig1(0) and sig3(0) at time=0
 5-Definition of sig3(t)
 6-Options for differential stress Dsig(t)
 7-Optional re-definition of sig1(t)
 8-Options for area (overlap) correction
---------------------------------------------
Name of input file:
1092rr.in.txt

---------------------------------------------
  input file: 1092rr.in.txt
  header: Run record = w1092 manual re-done
RH 201
  rig number:             1
  nominal Pc(MPa):          1550
  temperature(°C):           850
  log displacement rate of sig1
piston(ms-1):           -8

Correction for rig stiffness is not optional
```

red = input

```
Select hitpoint (1=lead, 2=classical)
2
Friction correction for F ? (1=yes  0=no)
0
Salt correction for pc ? (1=yes  0=no)
0
Defining sig1(0) and sig3(0) at time=0
1: set sig1(0) and sig3(0) to value of pc(0)
2: sig1(0)=sig3(0)=1/16*F/A(0)+15/16*pc(0)
3: use sig1(0) and sig3(0)=pc(0) as measured
1
Area correction for piston overlap
1: ACF (auto correlation function)
2: Modified ACF (delayed overlap)
3: Cosine square overlap
4: No area correction
1
Definition of sig3(t)
1: sig3(t) = sig3(0) + salt corr. (can be = 0)
2: sig3(t) = sig3(t) + salt corr. (can be = 0)
1
Options for differential stress Dsig(t)
1: Dsig(t) = sig1(t)-sig1(0)
2: Dsig(t) = sig1(t)-sig3(t)
1
Optional re-definition of sig1(t)
1: sig1(t) = sig1(0) + Dsig(t)
2: sig1(t) = sig3(t) + Dsig(t)
3: leave sig1(t) as calculated
1
Name of output file ? [1092rr.20011111.out.txt]
(return=default) >
result file = 1092rr.20011111.out.txt
<return>
------------ done ---------------
surfer-172-30-2-210-hotspot:Desktop heilbronner$
```

output file of rigS



1092rr.20011111.out

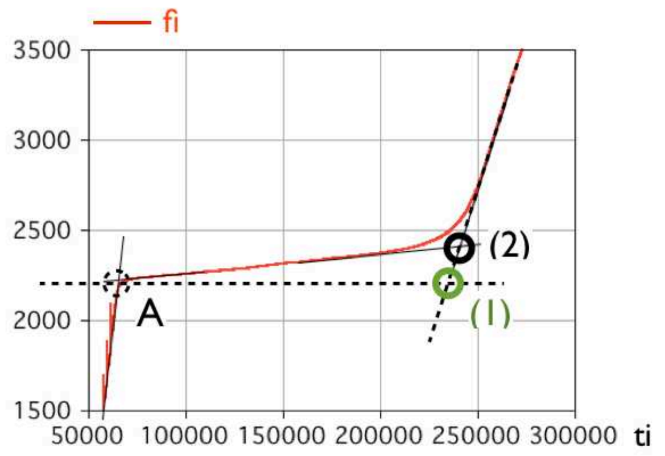
OPTIONS:
1 - Classical hitpoint
2 - No friction correction applied to force
3 - No salt correction applied to sig3
4 - set sig1(0) and sig3(0) to value of pc(0)
5 - Area corr.: ACF (auto correlation function)
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig1(0)
8 - Rewrite sig1(t) = sig1(0) + Dsig(t)

```
Input file =  1092rr.in.txt
Run record = w1092 manual re-done RH 201

rig         Pc(MPa)    T(°C)    d-rate(ms-1)
Tromsoe 1          1550         850          -8
diameter(mm)  length(mm)  time of max load
       6.300        0.000           0.0

OPTIONS:
1 - Classical hitpoint
2 - No friction correction applied to force
3 - No salt correction applied to sig3
4 - set sig1(0) and sig3(0) to value of pc(0)
5 - Area corr.: ACF (auto correlation function)
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig1(0)
8 - Rewrite sig1(t) = sig1(0) + Dsig(t)

 t(s)  1092-Fc(kN)  1092-Pc(MPa) d(mm) dcorr(mm)  1092-sig1A0(MPa)  1092-sig1(MPa)  1092-sig3(MPa)  1092-Dsig(MPa)
        0.0      55.4210   1550.0000      0.0000      0.0000   1550.0000   1550.0000   1550.0000      0.0000   1550.0000  ...etc.
     9353.0      62.5470   1550.0000      0.1905      0.1845   1778.5995   1778.5995   1550.0000    228.5995   1664.2998
    15589.0      67.1390   1550.0000      0.3175      0.3076   1925.9091   1925.9091   1550.0000    375.9091   1737.9546
    21824.0      71.2560   1550.0000      0.4445      0.4312   2057.9810   2057.9810   1550.0000    507.9810   1803.9905
    28060.0      75.0560   1550.0000      0.5715      0.5550   2179.8833   2179.8833   1550.0000    629.8833   1864.9417
    34295.0      77.9060   1550.0000      0.6960      0.6770   2271.3105   2271.3105   1550.0000    721.3105   1910.6553
    40531.0      80.5980   1550.0000      0.8204      0.7992   2357.6689   2357.6689   1550.0000    807.6689   1953.8345
    46766.0      82.8150   1550.0000      0.9449      0.9219   2428.7896   2428.7896   1550.0000    878.7896   1989.3948
    53002.0      84.7150   1550.0000      1.0719      1.0473   2489.7407   2489.7407   1550.0000    939.7407   2019.8704
    59237.0      85.9820   1550.0000      1.1963      1.1706   2530.3857   2530.3857   1550.0000    980.3857   2040.1929
    65473.0      86.9320   1550.0000      1.3259      1.2994   2560.8613   2560.8613   1550.0000   1010.8613   2055.4307
    71708.0      87.5650   1550.0000      1.4605      1.4335   2581.1675   2581.1675   1550.0000   1031.1675   2065.5837
    77944.0      88.0400   1550.0000      1.5875      1.5601   2596.4053   2596.4053   1550.0000   1046.4053   2073.2026
    84179.0      88.3570   1550.0000      1.7145      1.6868   2606.5747   2606.5747   1550.0000   1056.5747   2078.2874
    90415.0      88.5150   1550.0000      1.8415      1.8137   2611.6431   2611.6431   1550.0000   1061.6431   2080.8215

... etc.
```

< go to overview >

options for rigC and rigS

DEFINITION OF THE HIT POINT

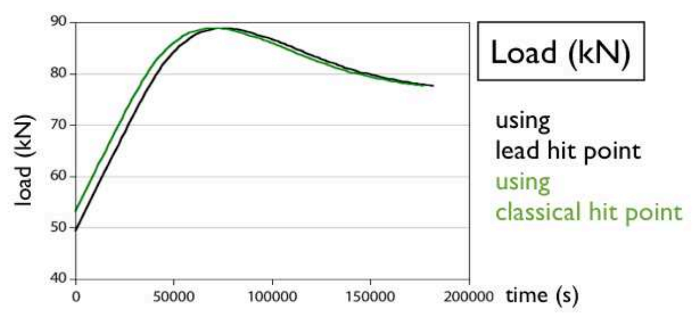


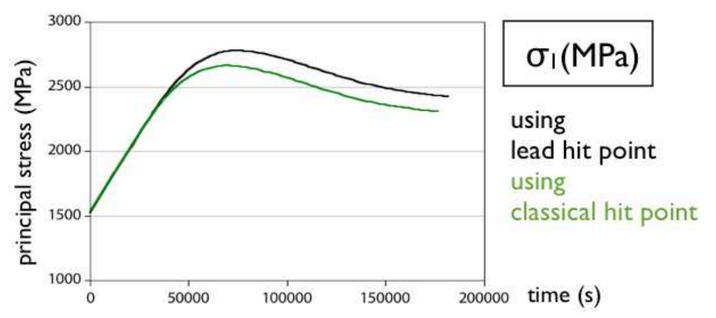
Raw data of sample 383
fi = force
ti = time

Experimental conditions:
T = 700°C, Pc = 1.5 GPa, $\dot{\gamma} = 10^{-5}\ s^{-1}$

We use hit point (1) defined by the 'leadhit'. Justification: Fluid inclusions indicate that the load accumulated during run-in is 'felt' by sample., See Tarantola et al. (2010)

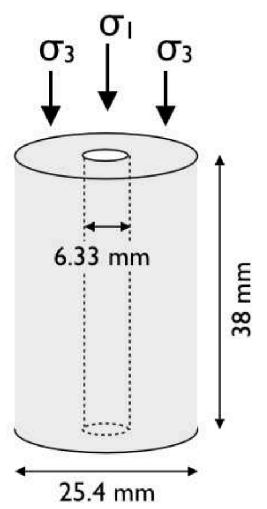
A = lead hit	ti = ilead = 65432 fi = loadlead = 2222
hit point (1)	ti = extrapolated fi = loadlead = 2222
hit point (2) = 'classical' hitpoint	ti = ihit = 240586 fi = loadhit = 2410





The net effect of choosing the lead hit point versus the classical hit point is to decrease the load at time 0, and thus to increase $\Delta\sigma$ and τ.
As time 0 is advanced, the total shear displacement and hence the total shear strain is increased

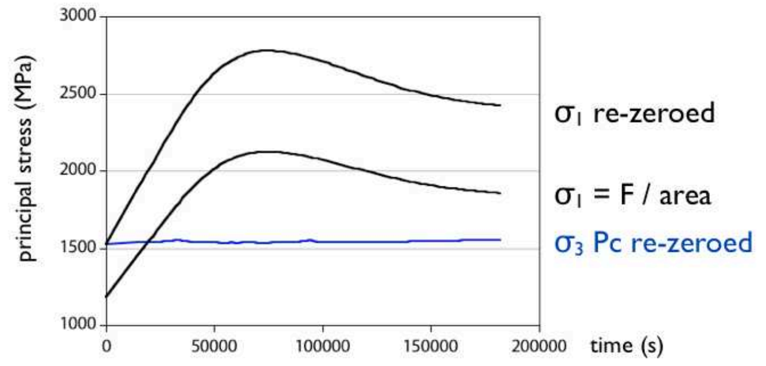
CALCULATING PRINCIPAL STRESSES



What is confining pressure at start of experiment ?

Measured values at t = 0:
$\sigma_1(0)$ = Load / (Area of σ_1 - piston)
$\sigma_3(0)$ = Confining pressure Pc
Note: typically $\sigma_1(0) \neq \sigma_3(0)$

Set $\sigma_3(0) = \sigma_1(0)$ = confining pressure
$\sigma_0 = 1/16 \cdot (\sigma_1(0) + 15 \cdot \sigma_3(0))$
$\sigma_0 = 1/16 \cdot (F(0)/A + 15 \cdot Pc(0))$
Note: diameter of σ_1 - piston = 1/4 of diameter of sample assembly (including confining medium)



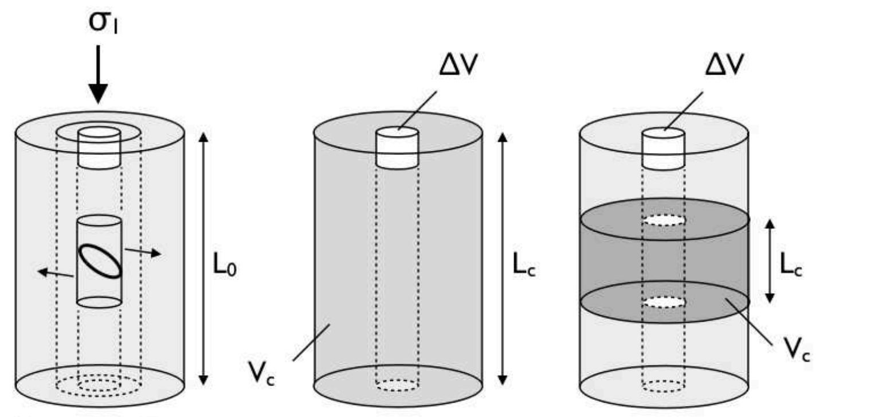
$$\sigma_1(t) = \sigma_0 + (F(t) - F(0)) / A$$
$$\sigma_3(t) = \sigma_0 + (Pc(t) - Pc(0))$$

$$\Delta\sigma(t) = \sigma_1(t) - \sigma_3(t)$$
$$p_{mean} = 0.5 \cdot (\sigma_1(t) + \sigma_3(t))$$

$$\tau(t) = \sin(2\alpha) \cdot 0.5 \cdot \Delta\sigma(t)$$
$$\sigma_n(t) = p_{mean} + \cos(2\alpha) \cdot \Delta\sigma(t)$$

At the start of the experiment (hit point):
$\Delta\sigma = 0 \implies \sigma_1(0) = \sigma_3(0) = Pc(0))$
$\sigma_1(0)$ and $\sigma_3(0)$ can be set to $\sigma_1(0)$ or $\sigma_3(0)$ or a proportion of $\sigma_1(0) : \sigma_3(0) = 1 : 15$ (corresponding to the cross sectional area of the $\sigma_1(0)$ and $\sigma_3(0)$ pistons.

THE SALT CORRECTION



forcing blocks escape sideways → compression of confining medium

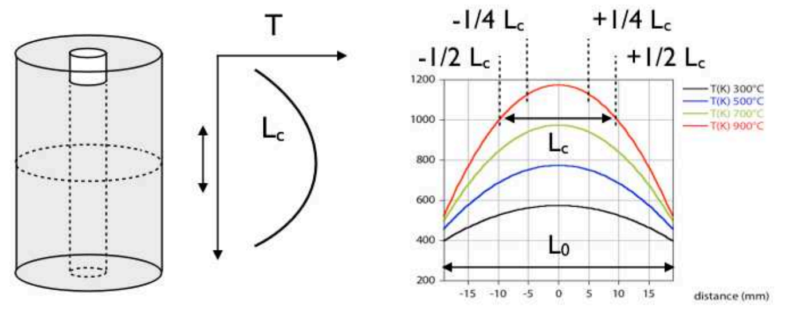
→ compression over full length of sample assembly $L_c = L_0 = 38$ mm

→ compression over central part of sample assembly $L_c = 12$ mm

Basic idea:
As the σ_1 piston advances, the confining medium cannot expand and is therefore subjected to an additional bulk compression. The additional confining pressure ΔPc is calculated as

$$\Delta Pc = \beta \cdot \Delta V / V_c$$

where
β = bulk modulus and
$\Delta V/V_c$ = relative volume decrease
V_c = compressed part of confining medium



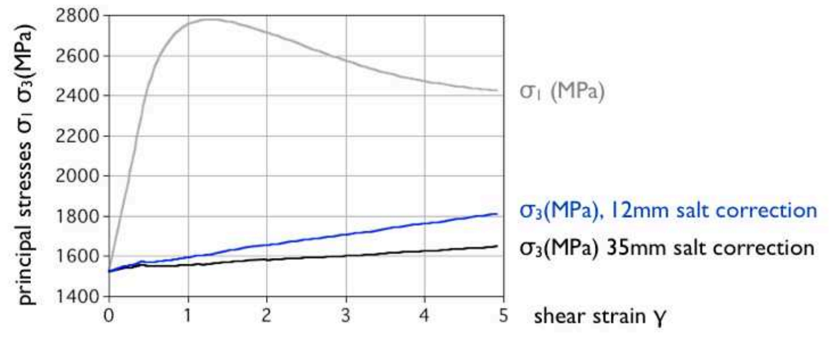
Measured temperature - profiles in sample assemblies (Pec, PhD thesis, 2014)

Considering only the central part of the confining medium is based on the T-gradient. The high conductivity induces cooling from the center towards both ends of assembly.

The pertinent T for a given pressurized length is at ± 1/4 of L_c.

bulk compressibility β for NaCl						
T (°C)	0 kb	3 kb	5 kb	10 kb	15 kb	20 kb
100						
200	39.0	39.9	40.4			
300	35.7	36.7	37.4	38.7	39.7	40.4
400	32.6	33.7	34.4	35.8	37.0	37.9
500	30.0	31.0	31.7	33.2	34.4	35.4
600	28.0	28.9	29.5	30.8	32.1	33.1
700	26.7	27.4	27.8	29.0	30.0	31.0
800	25.9	26.3	26.7	27.5	28.4	29.3
900			25.9	26.5	27.2	27.9
1000				25.9	26.4	26.9
1100						26.2

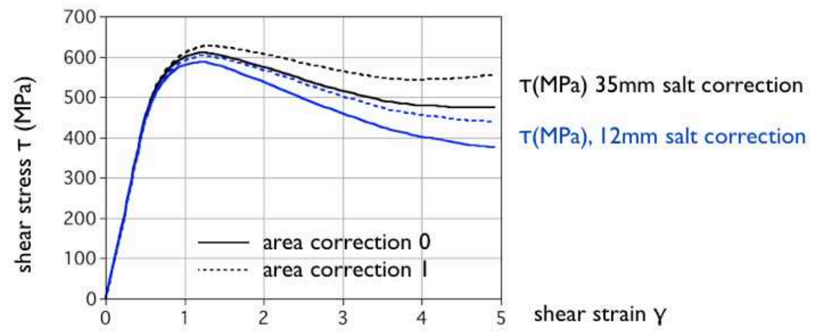
bulk compressibility β for KI						
T (°C)	0 kb	3 kb	5 kb	10 kb	15 kb	20 kb
100						
200	26.0	26.4	26.6			
300	24.5	25.0	25.3	25.9	26.3	26.6
400	23.0	23.6	23.9	24.6	25.1	25.5
500	21.8	22.3	22.6	23.3	23.9	24.4
600	21.0	21.4	21.6	22.2	22.8	23.3
700	20.6	20.8	20.9	21.4	21.8	22.3
800	20.6	20.6	20.6	20.8	21.2	21.5
900			20.6	20.6	20.7	21.0
1000				20.6	20.6	20.6
1100						20.5



σ_1 is not affected by the increase in Pc.
Only σ_3 is affected by the salt correction.

For increasing salt correction, Pc increases, $\Delta\sigma$ and τ decrease.

$\Delta Pc(d)$ is calculated for given Pc and T as a function of piston advancement.



At higher temperatures, the bulk compressibility β and the effect of the salt correction decrease, i.e., the samples weaken less.

The net effect of the salt correction is to increase the confining pressure.

< go to overview >

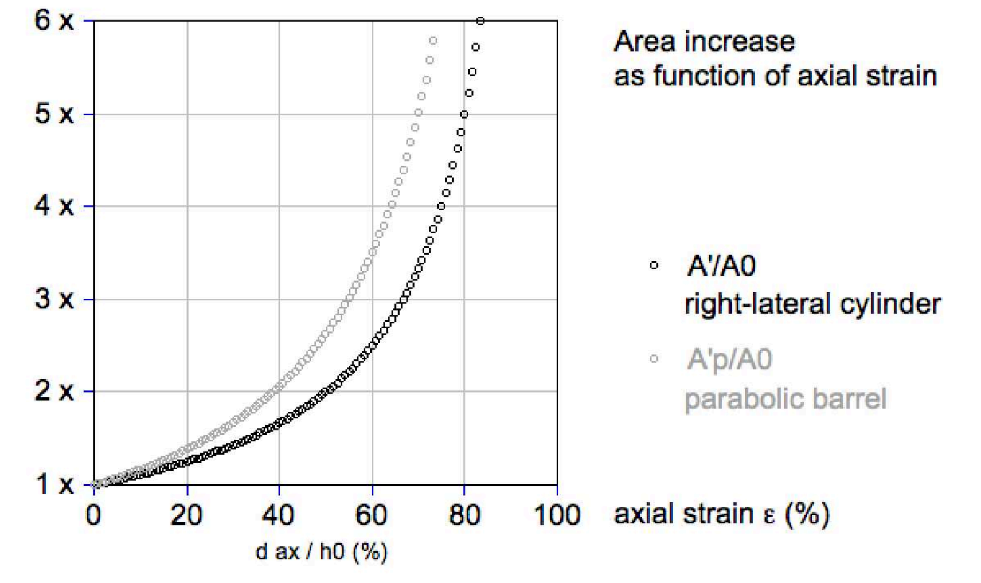
area correction

for coaxial experiments

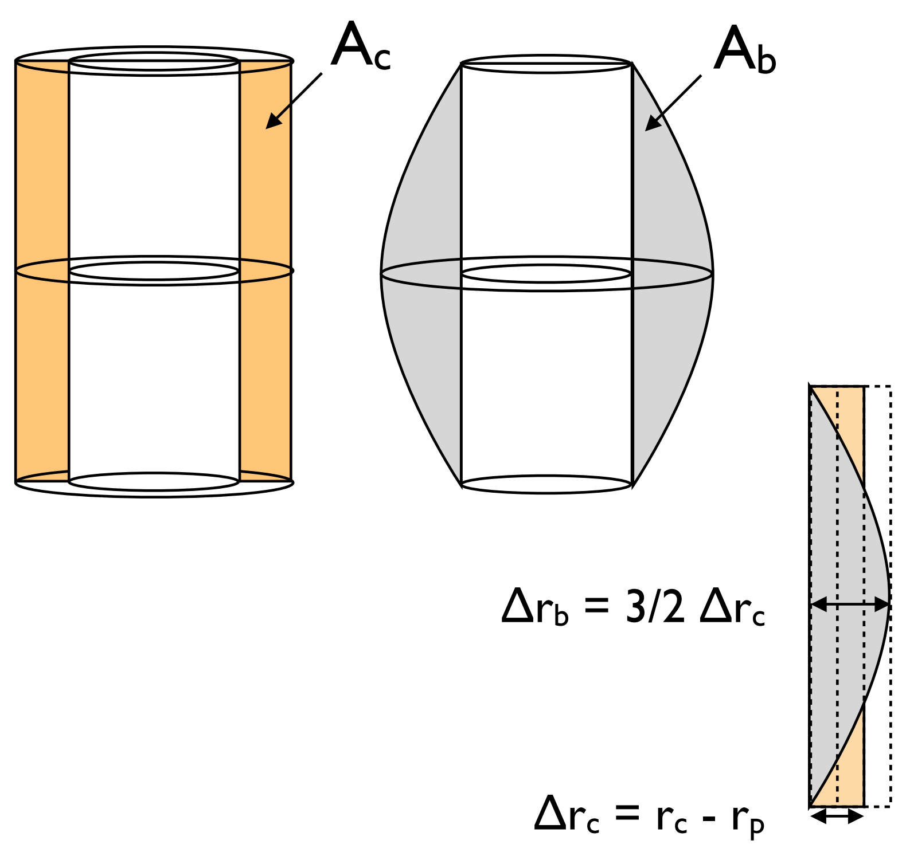
Two types of area correction:

1 = classical (Poisson):
volume conserving homogeneous widening of sample

2
straight-sided cylinder deforms to barrel shape

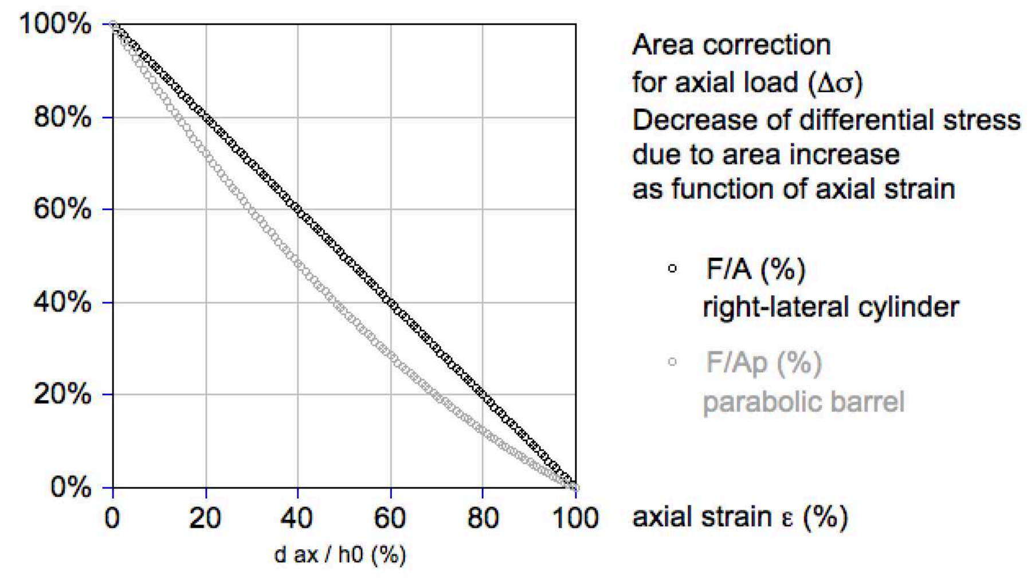


The math behind it



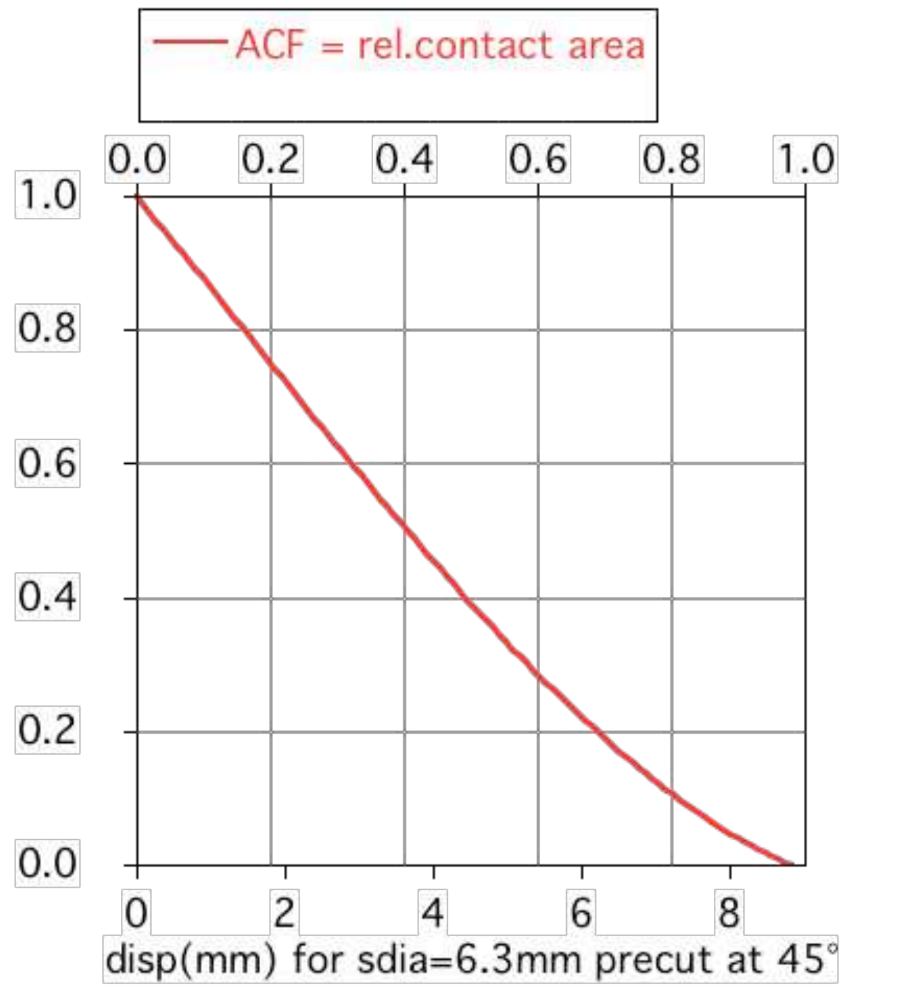
$\Delta r_b = 3/2\ \Delta r_c$

$\Delta r_c = r_c - r_p$

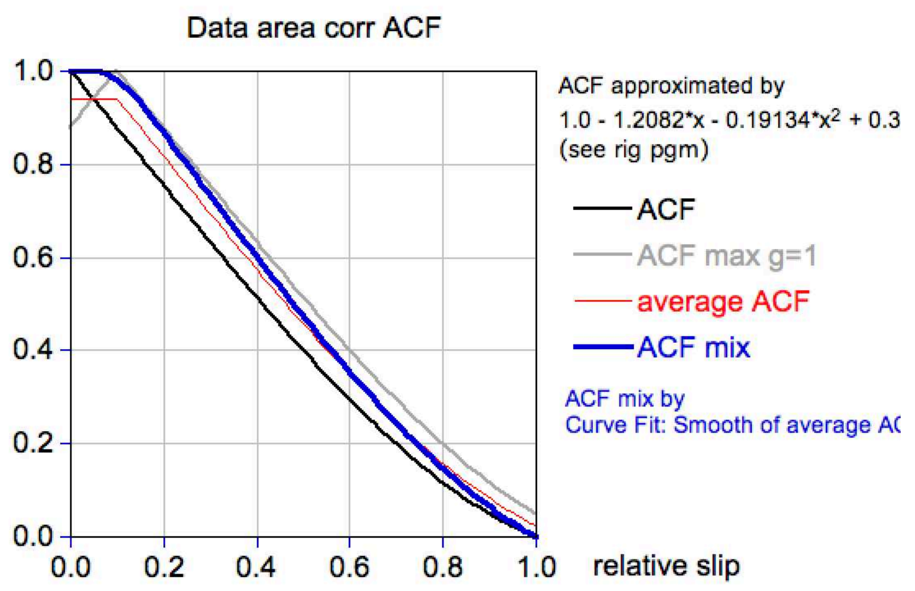


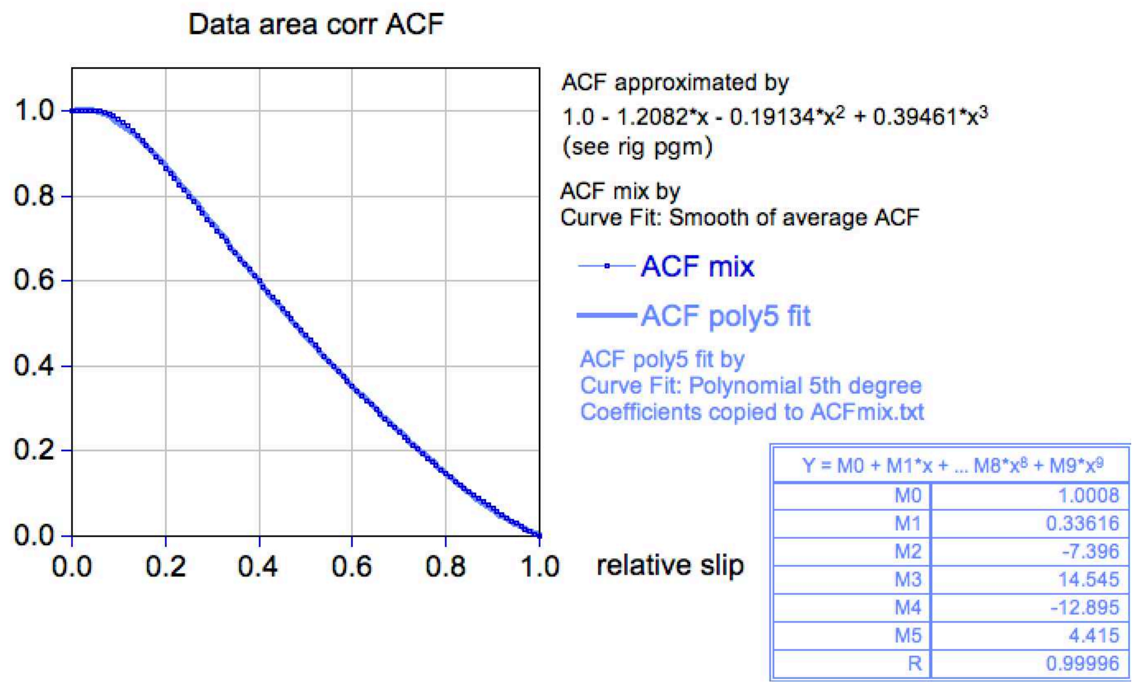
In coaxial set-ups, the net effect of the area correction is a displacement-dependent weakening.

for shearing experiments

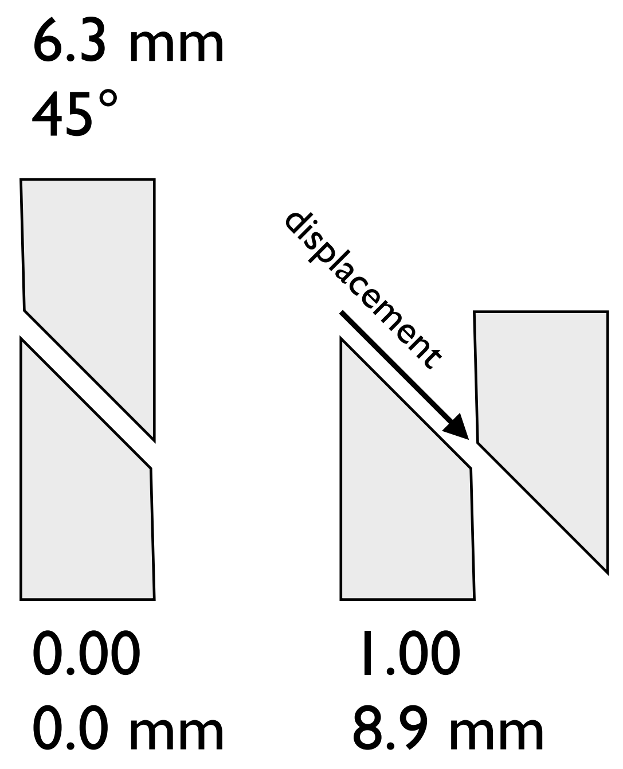


ACF approximation in Kaleidagraph (function ACF in rigS6)
c2=1.00-1.2082*c0-0.19134*c0*c0+0.39461*c0*c0*c0

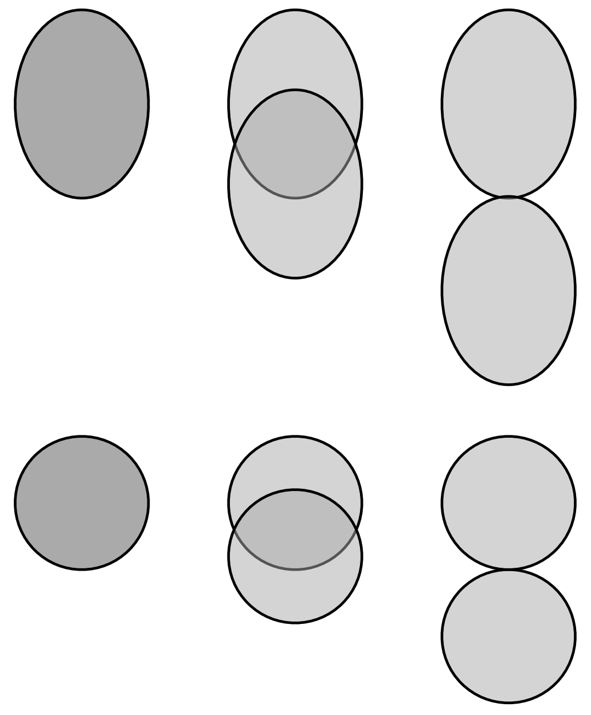




Y = M0 + M1*x + ... M8*x⁸ + M9*x⁹	
M0	1.0008
M1	0.33616
M2	-7.396
M3	14.545
M4	-12.895
M5	4.415
R	0.99996

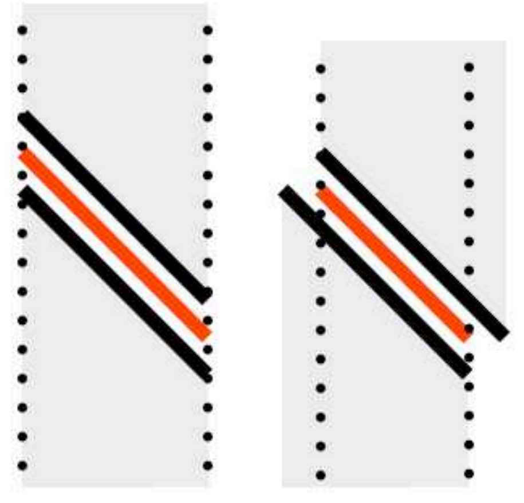


relative displacement
displacement along precut

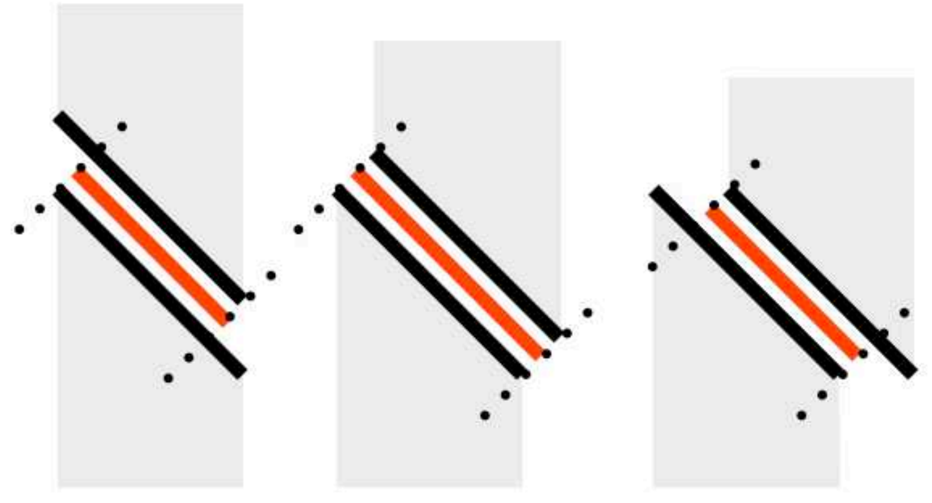


area overlap with increasing displacement

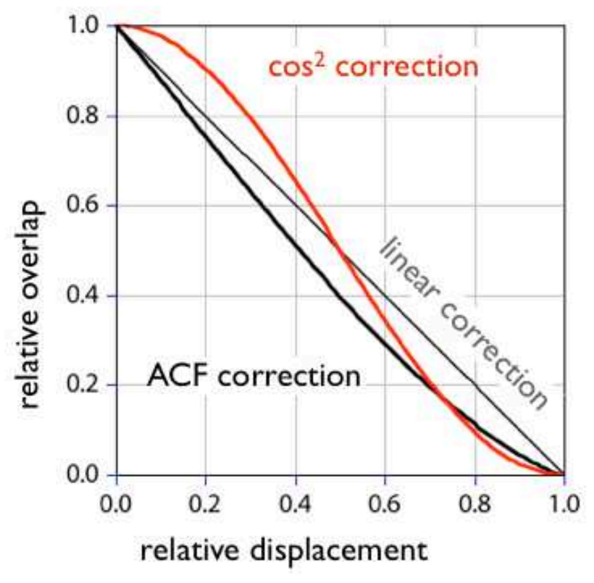
area overlap with increasing displacement - looking down compression axis
⇒ ACF



area correction 0
projection along axis
⇒ max. overlap at start

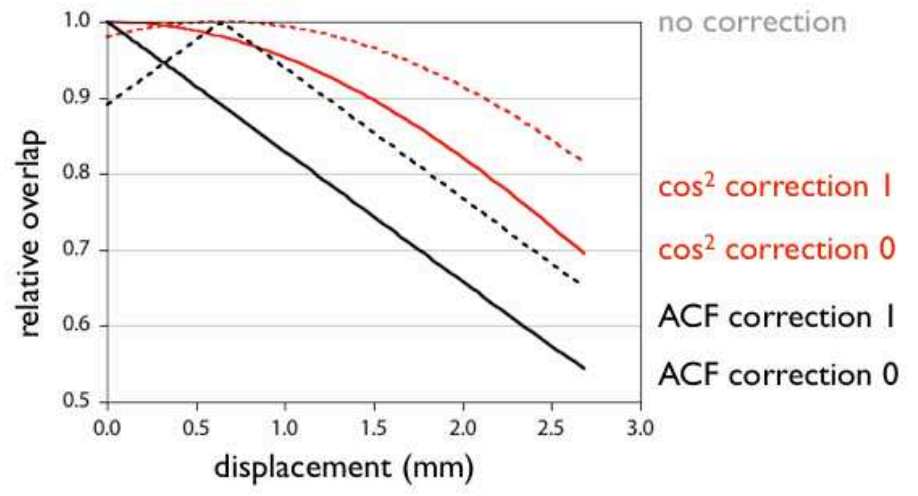


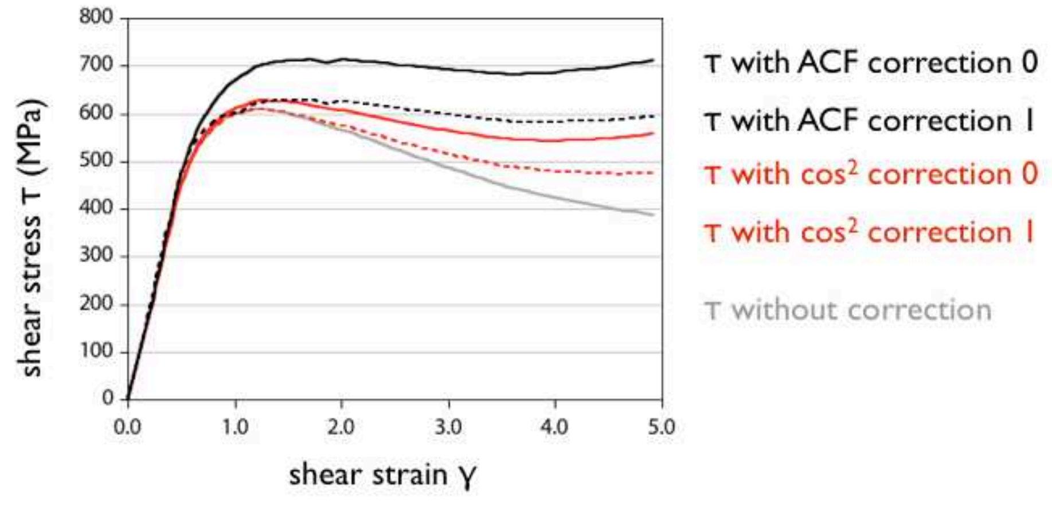
area correction 1
projection normal to shear zone
⇒ max. overlap at gamma = 1



The alumina forcing blocks are assumed to be undeformed. The area correction applies only to the sample in the 45° pre-cut.

The correct function for the overlap is the autocorrelation function (ACF). However, to avoid the discontinuity at γ = 1, the ACF function is approximated by a cos² - function.



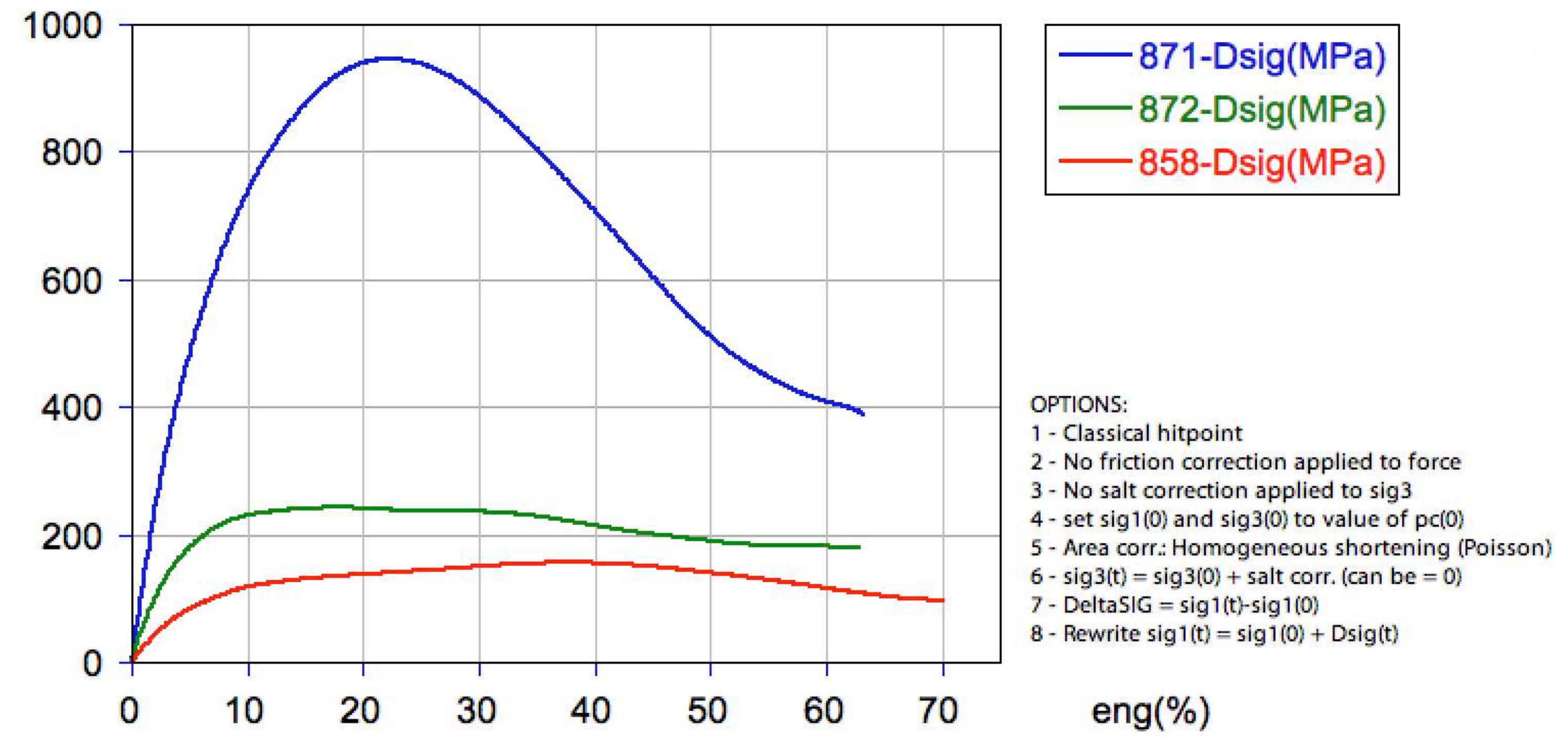


In shearing set-ups, the net effect of the area correction is a displacement-dependent strengthening.

< go to overview >

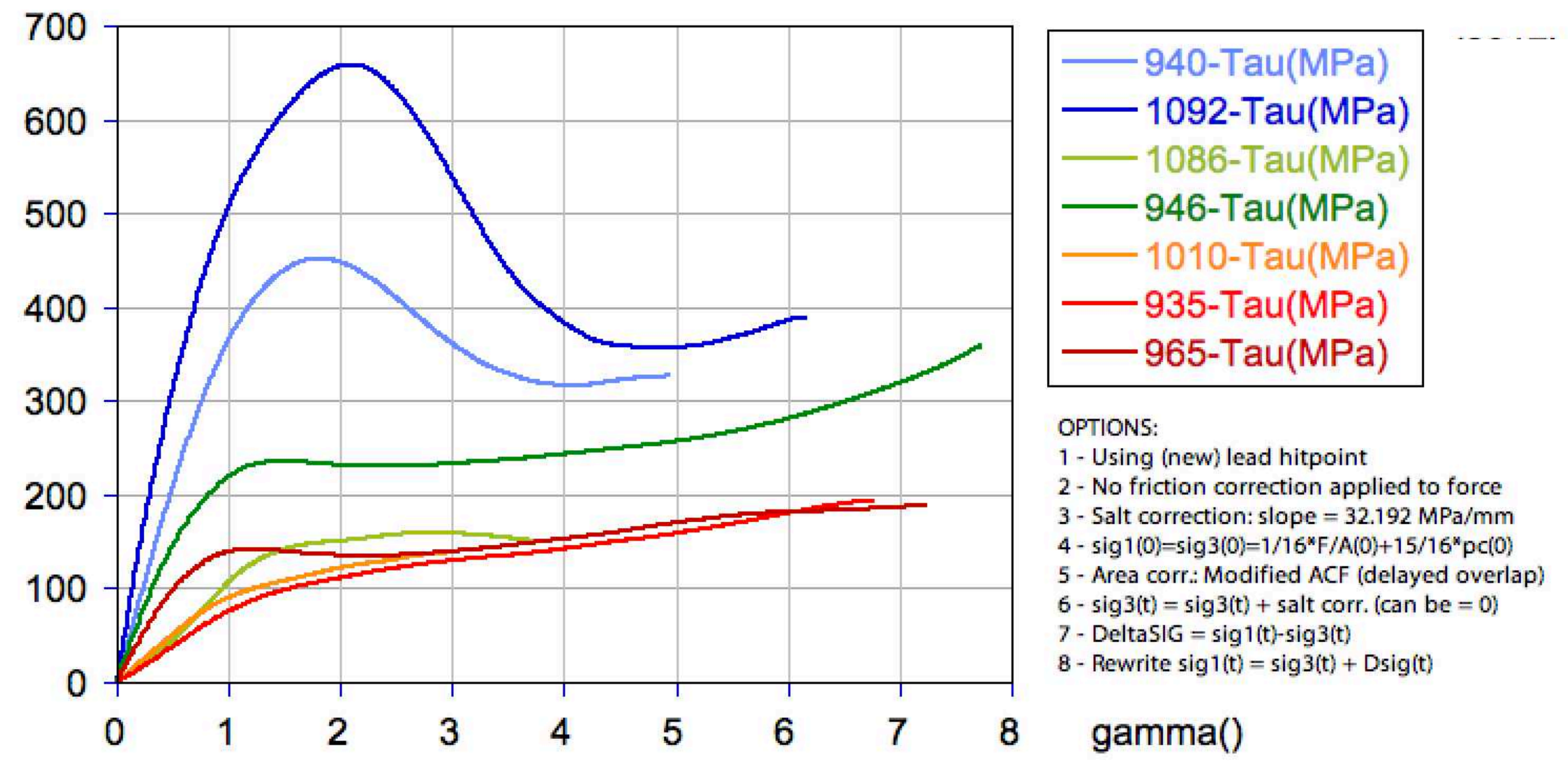
stress strain plots for different run options

coaxial experiments



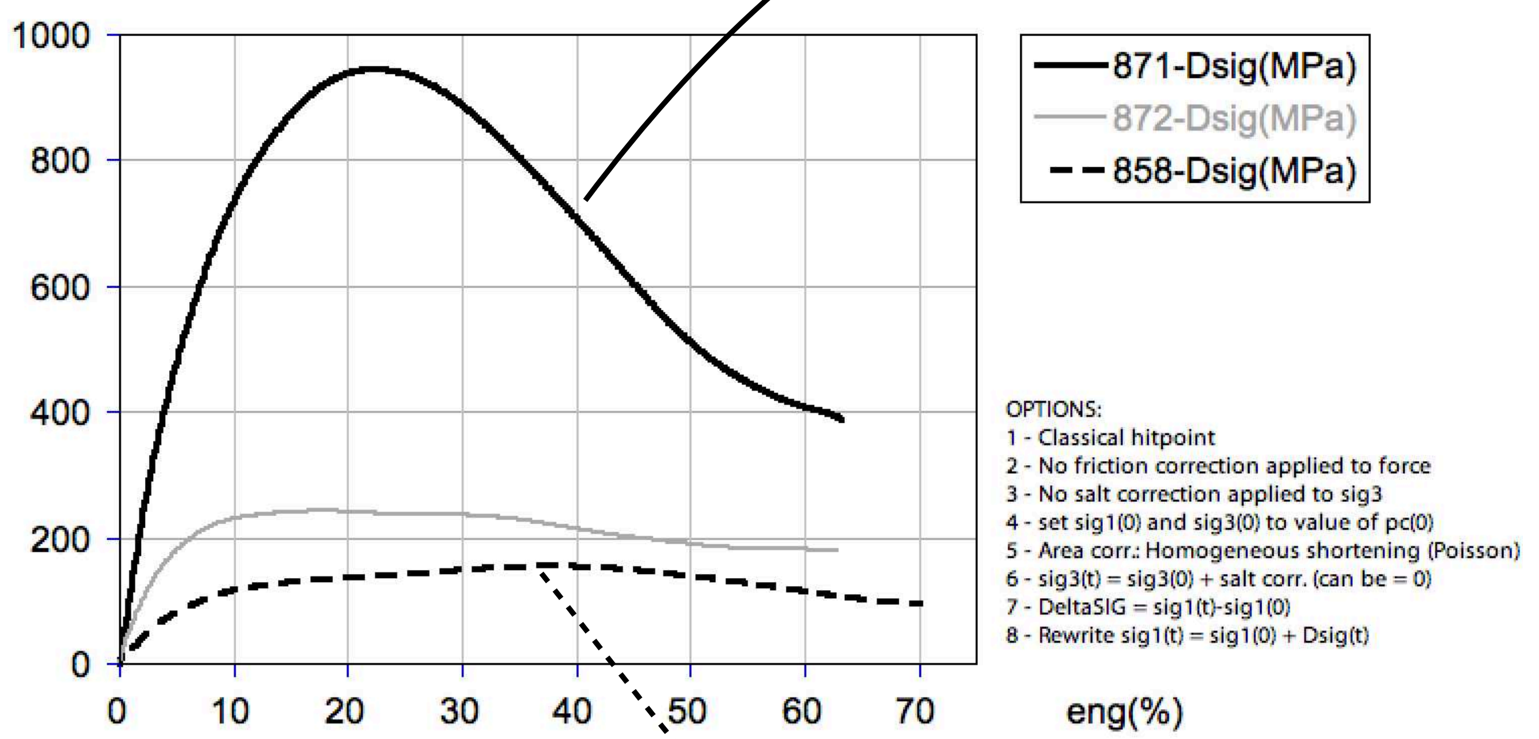
COAX CLASSIC OPTIONS:	denoted:
1 - Classical hitpoint	2
2 - No friction correction applied to force	0
3 - No salt correction applied to sig3	0
4 - set sig1(0) and sig3(0) to value of pc(0)	1
5 - Area corr.: Homogeneous shortening (Poisson)	1
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)	1
7 - DeltaSIG = sig1(t)-sig1(0)	1
8 - Rewrite sig1(t) = sig1(0) + Dsig(t)	1

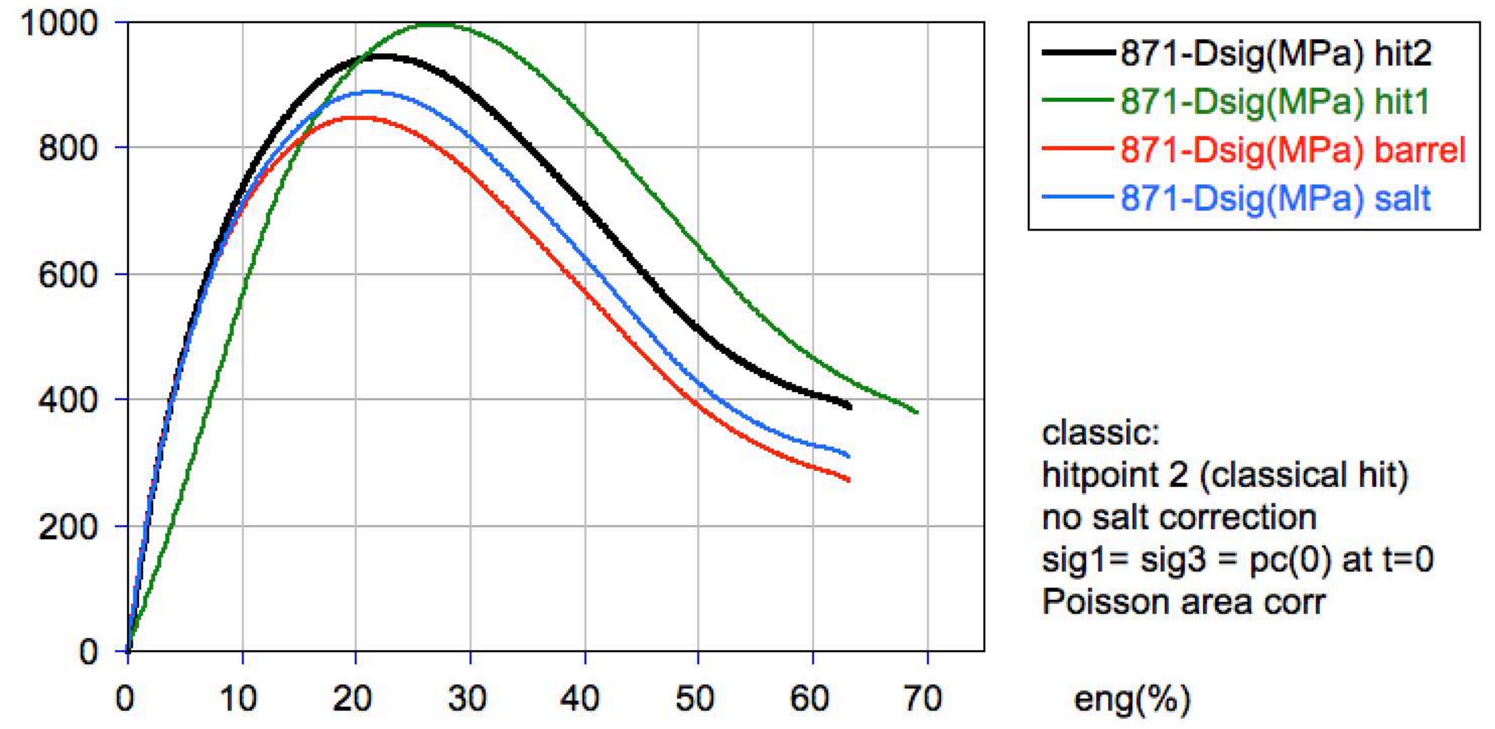
general shearing experiments



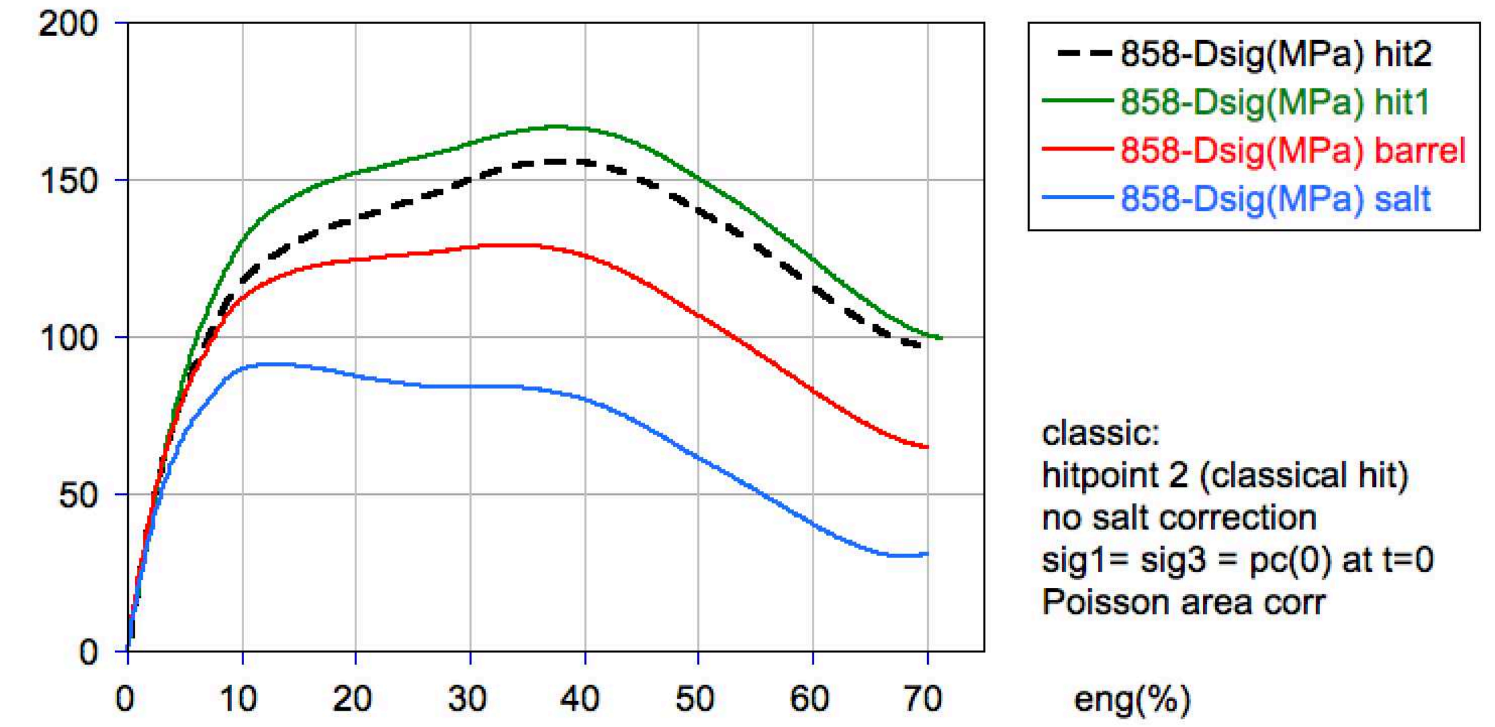
SHEAR CLASSIC OPTIONS:	denoted:
1 - Using (new) lead hitpoint	1
2 - No friction correction applied to force	0
3 - Salt correction: slope = 33.071 MPa/mm	2
4 - sig1(0)=sig3(0)=1/16*F/A(0)+15/16*pc(0)	2
5 - Area corr.: Modified ACF (delayed overlap)	2
6 - sig3(t) = sig3(t) + salt corr. (can be = 0)	2
7 - DeltaSIG = sig1(t)-sig3(t)	2
8 - Rewrite sig1(t) = sig3(t) + Dsig(t)	2

effect of selecting:
hitpoint 1
barrel area correction
salt correction



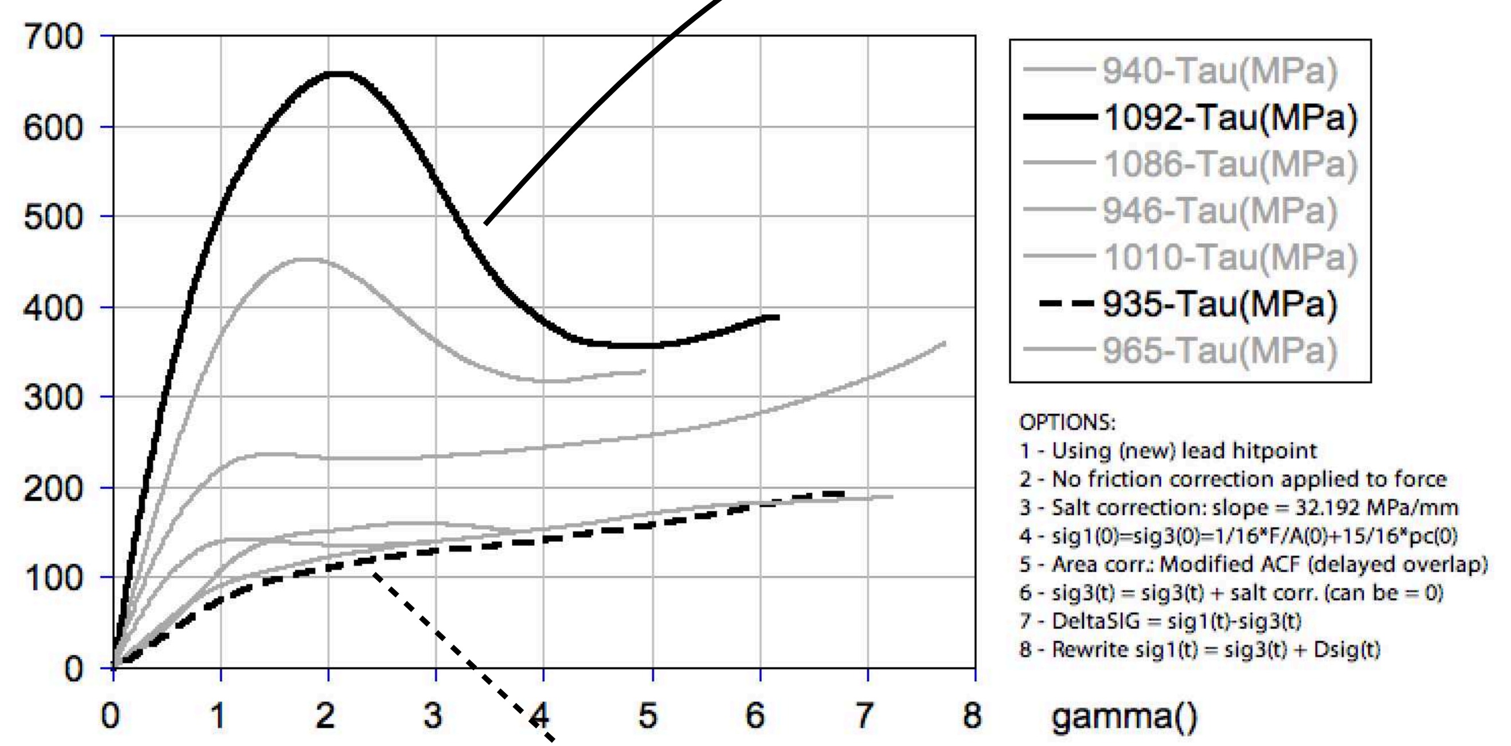


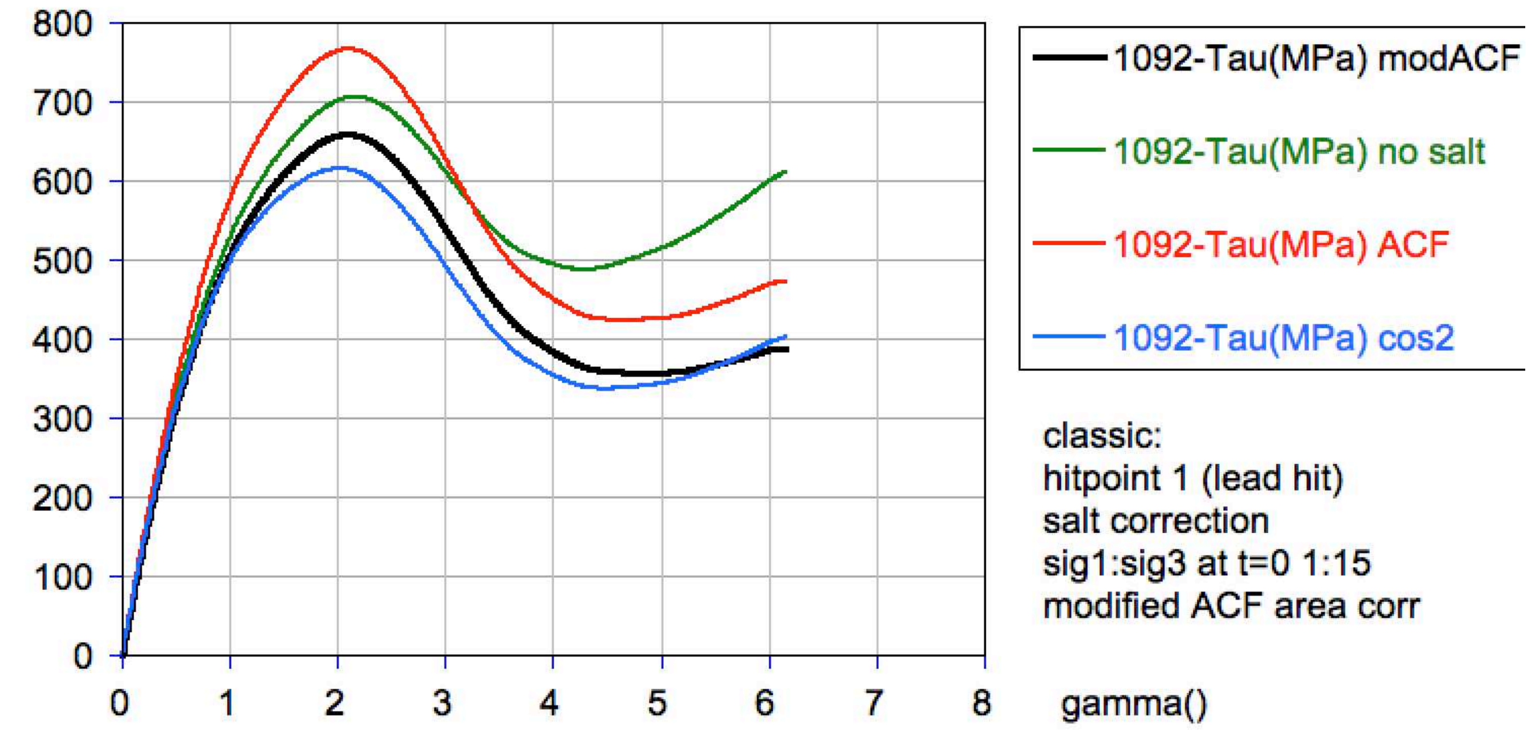
classic:
hitpoint 2 (classical hit)
no salt correction
sig1= sig3 = pc(0) at t=0
Poisson area corr



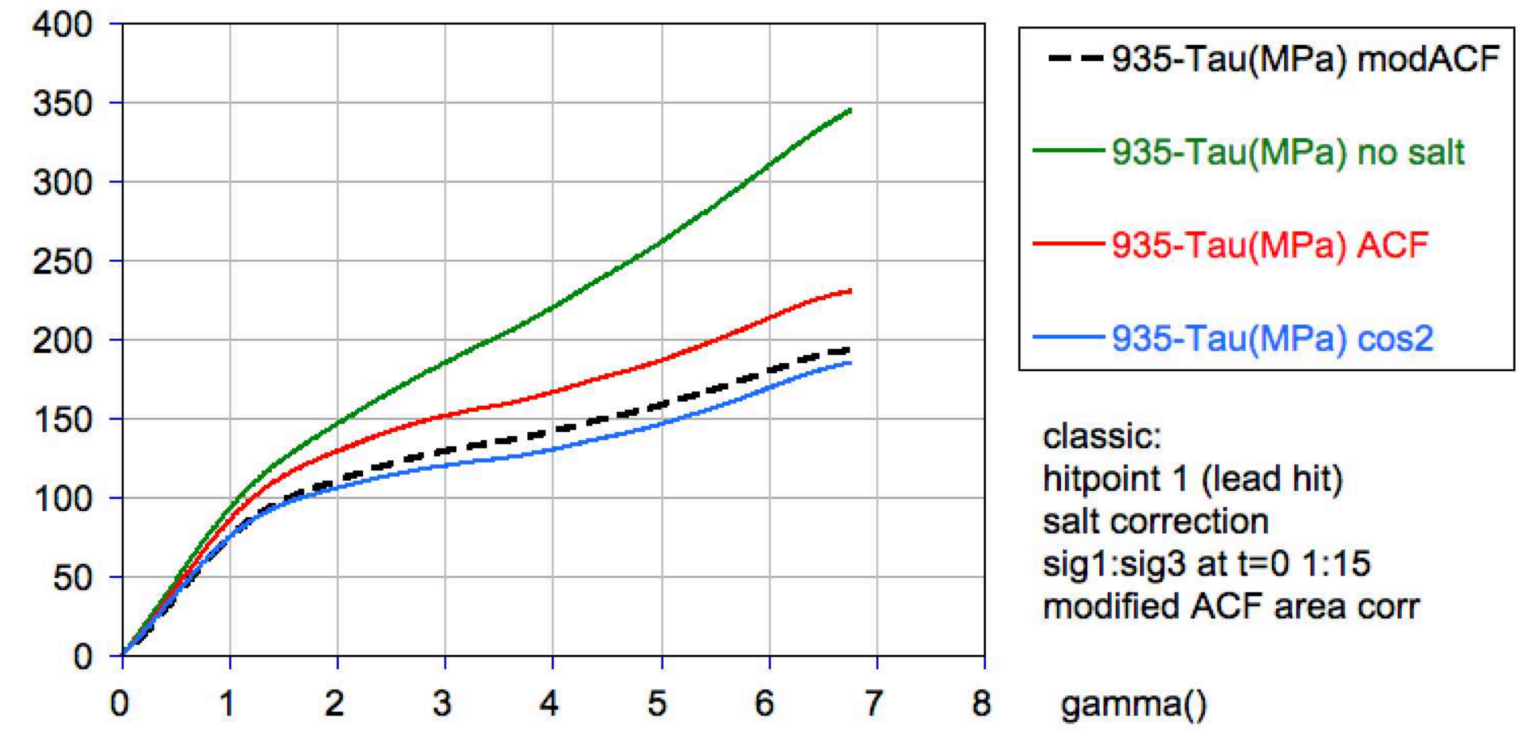
classic:
hitpoint 2 (classical hit)
no salt correction
sig1= sig3 = pc(0) at t=0
Poisson area corr

effect of selecting:
no salt correction
ACF area correction
cos^2 area correction





classic:
hitpoint 1 (lead hit)
salt correction
sig1:sig3 at t=0 1:15
modified ACF area corr

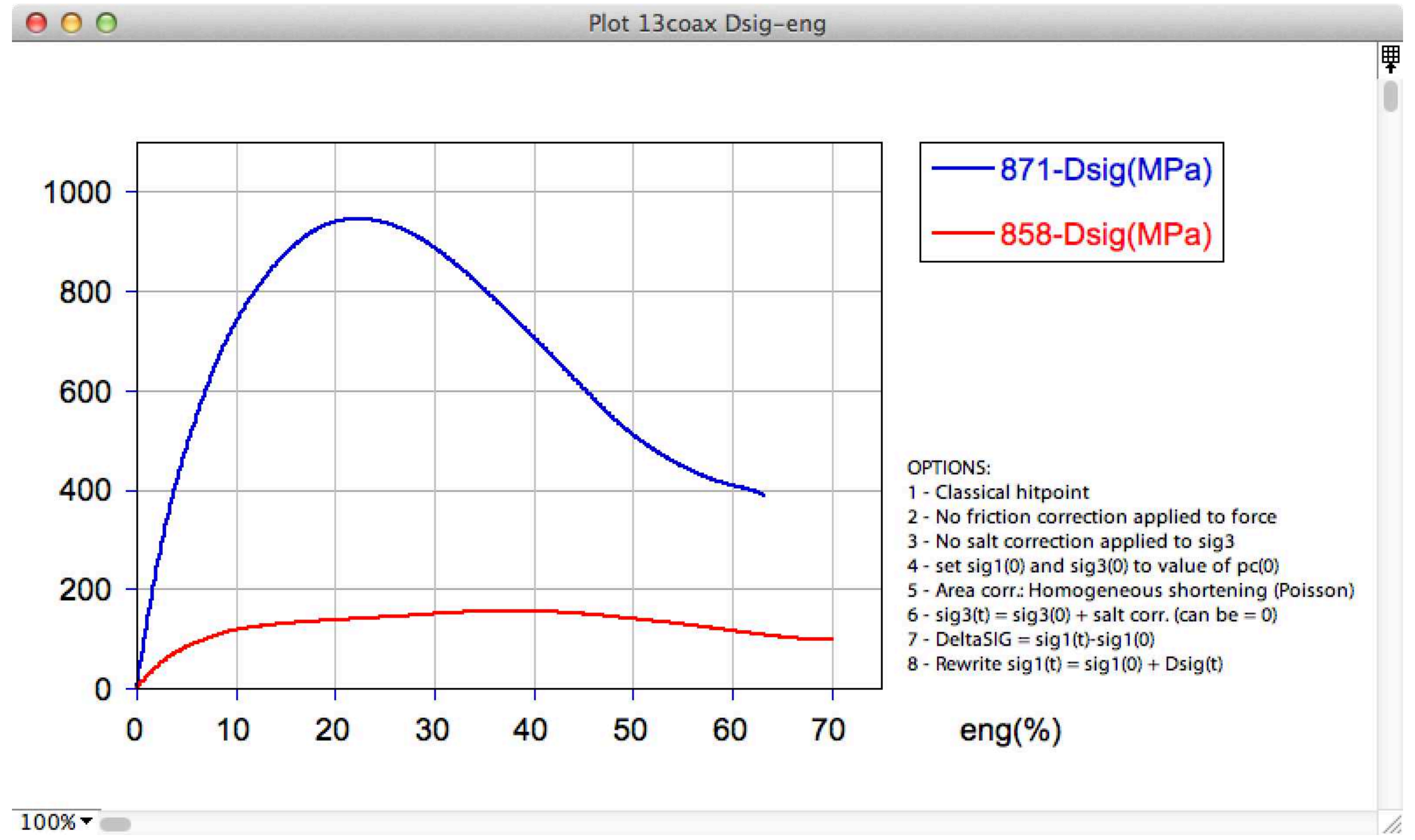


classic:
hitpoint 1 (lead hit)
salt correction
sig1:sig3 at t=0 1:15
modified ACF area corr

< *go to overview* >

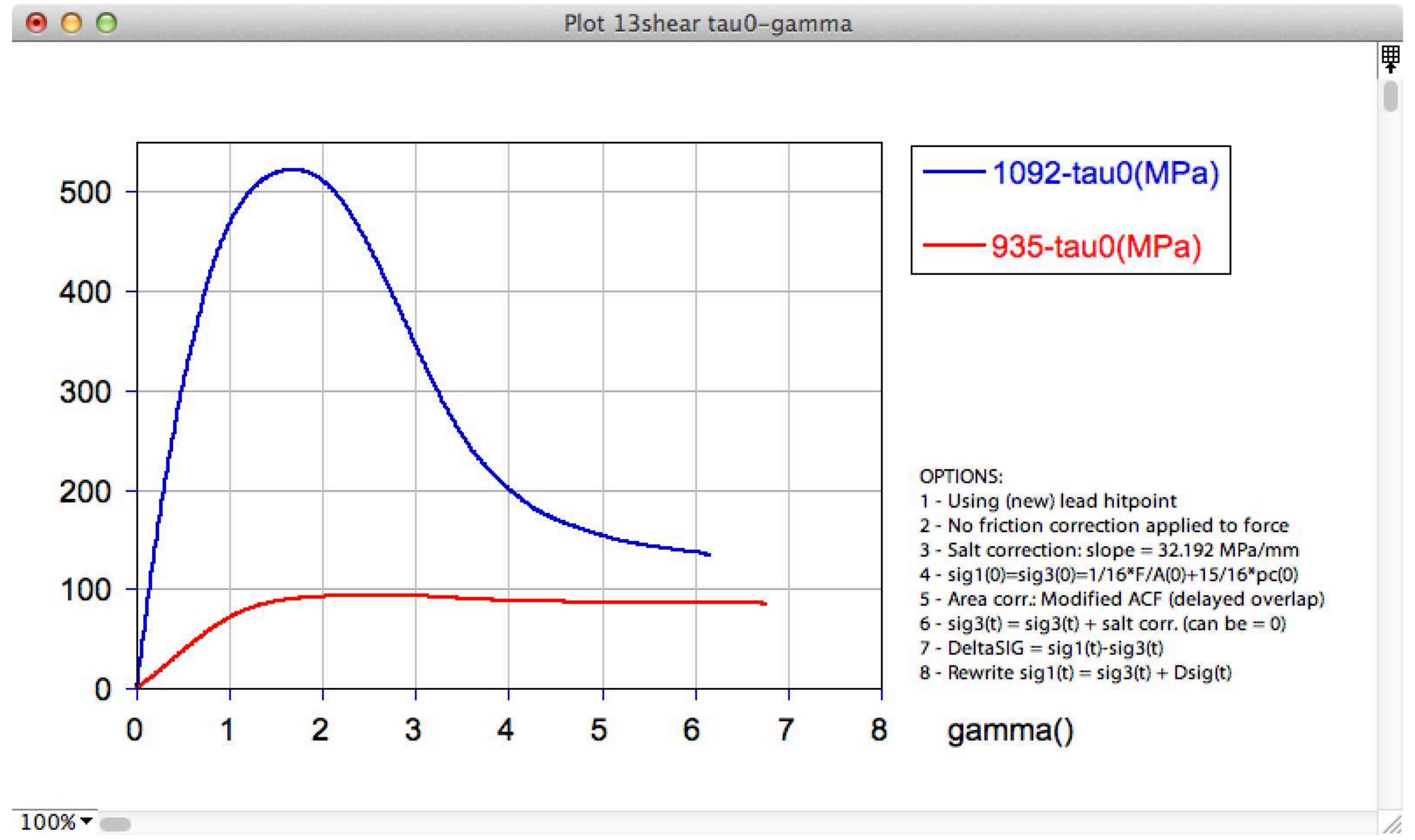
which 'strain' ?

engineering strain

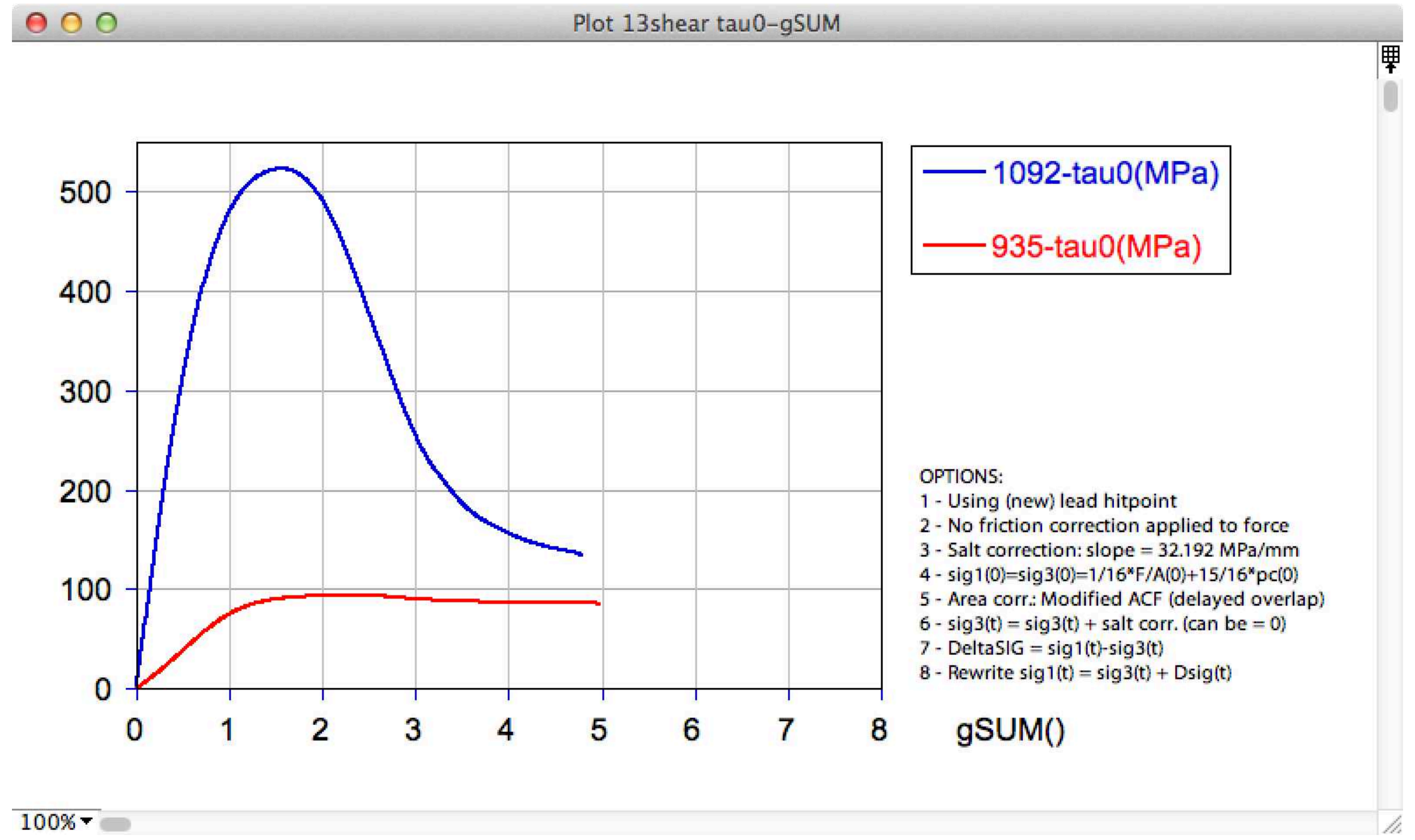


OPTIONS:
1 - Classical hitpoint
2 - No friction correction applied to force
3 - No salt correction applied to sig3
4 - set sig1(0) and sig3(0) to value of pc(0)
5 - Area corr.: Homogeneous shortening (Poisson)
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig1(0)
8 - Rewrite sig1(t) = sig1(0) + Dsig(t)

shear strain



OPTIONS:
1 - Using (new) lead hitpoint
2 - No friction correction applied to force
3 - Salt correction: slope = 32.192 MPa/mm
4 - sig1(0)=sig3(0)=1/16*F/A(0)+15/16*pc(0)
5 - Area corr.: Modified ACF (delayed overlap)
6 - sig3(t) = sig3(t) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig3(t)
8 - Rewrite sig1(t) = sig3(t) + Dsig(t)



OPTIONS:
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2 - No friction correction applied to force
3 - Salt correction: slope = 32.192 MPa/mm
4 - sig1(0)=sig3(0)=1/16*F/A(0)+15/16*pc(0)
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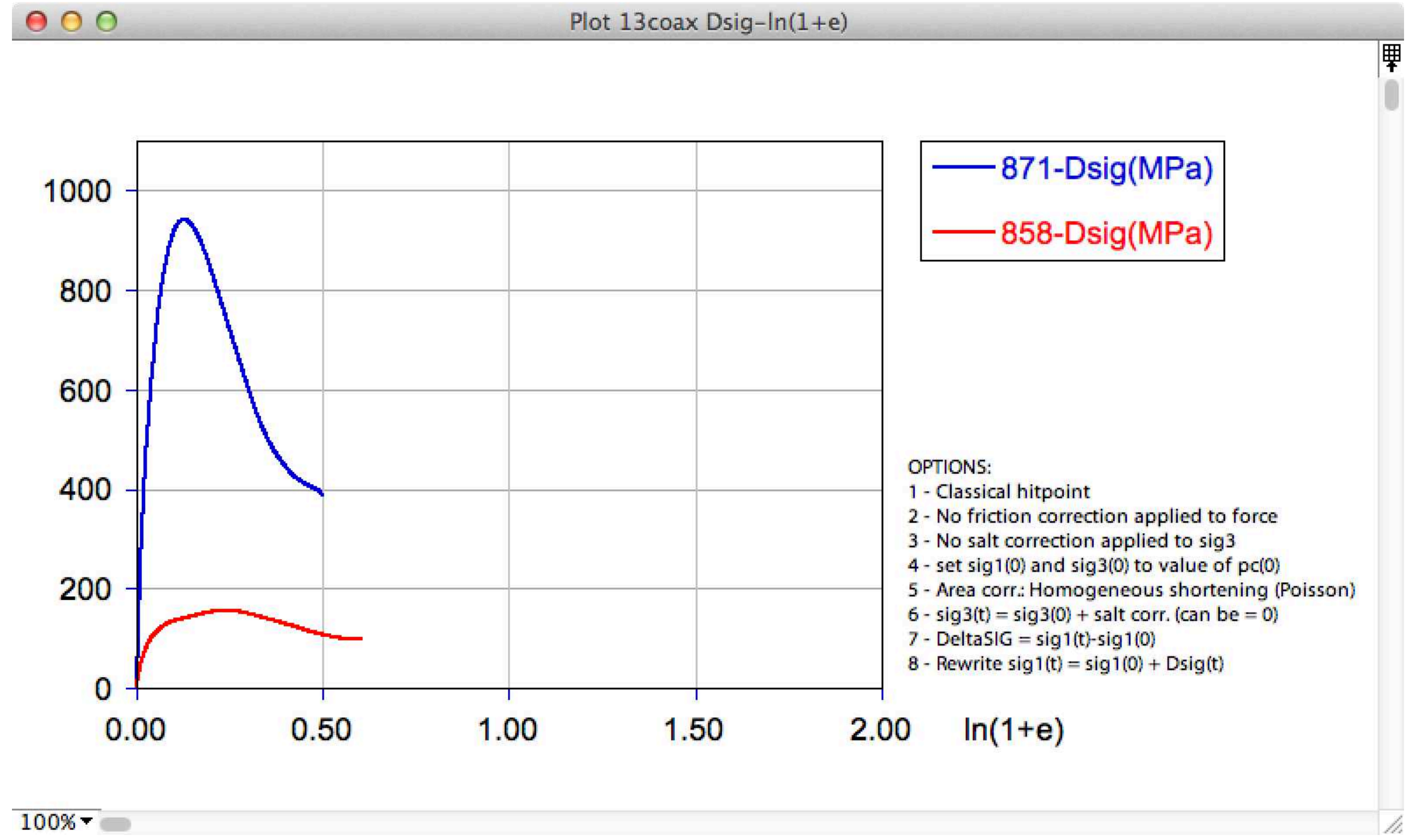
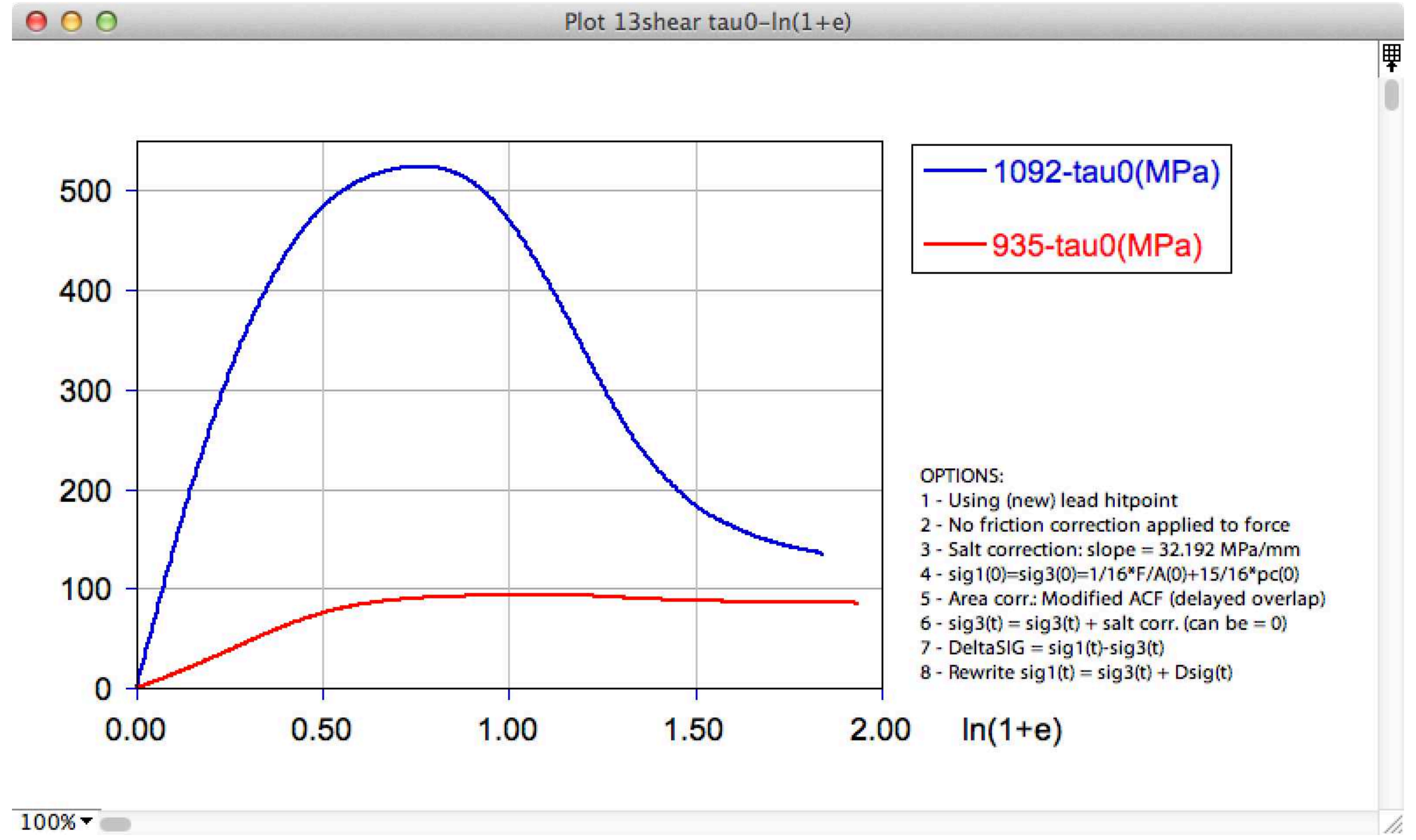
6 - sig3(t) = sig3(t) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig3(t)
8 - Rewrite sig1(t) = sig3(t) + Dsig(t)

natural strain



OPTIONS:
1 - Classical hitpoint
2 - No friction correction applied to force
3 - No salt correction applied to sig3
4 - set sig1(0) and sig3(0) to value of pc(0)
5 - Area corr.: Homogeneous shortening (Poisson)
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig1(0)
8 - Rewrite sig1(t) = sig1(0) + Dsig(t)

natural strain



OPTIONS:
1 - Using (new) lead hitpoint
2 - No friction correction applied to force
3 - Salt correction: slope = 32.192 MPa/mm
4 - sig1(0)=sig3(0)=1/16*F/A(0)+15/16*pc(0)
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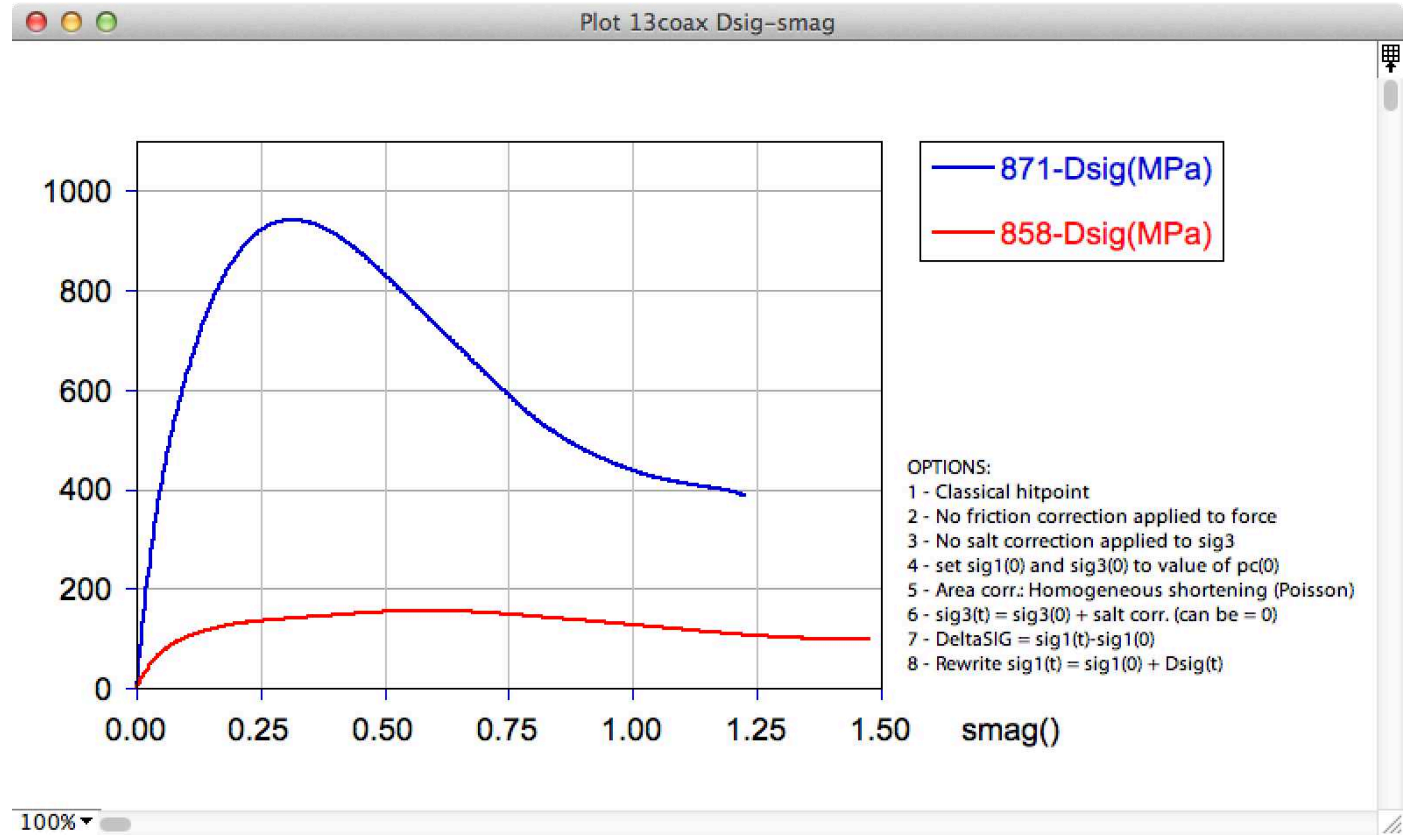
7 - DeltaSIG = sig1(t)-sig3(t)
8 - Rewrite sig1(t) = sig3(t) + Dsig(t)

strain magnitude



OPTIONS:
1 - Classical hitpoint
2 - No friction correction applied to force
3 - No salt correction applied to sig3
4 - set sig1(0) and sig3(0) to value of pc(0)
5 - Area corr.: Homogeneous shortening (Poisson)
6 - sig3(t) = sig3(0) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig1(0)
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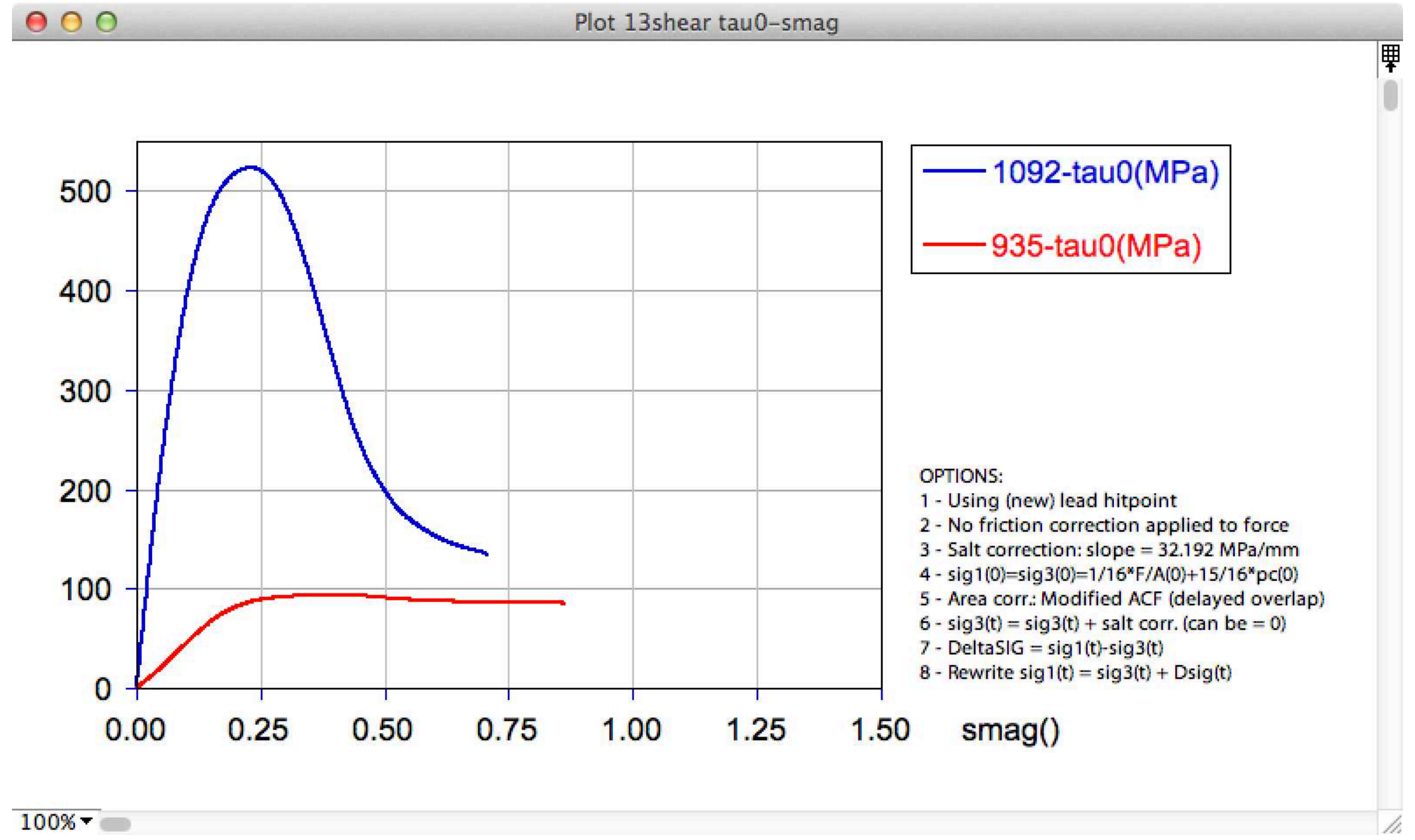
strain magnitude



OPTIONS:
1 - Using (new) lead hitpoint
2 - No friction correction applied to force
3 - Salt correction: slope = 32.192 MPa/mm
4 - sig1(0)=sig3(0)=1/16*F/A(0)+15/16*pc(0)
5 - Area corr.: Modified ACF (delayed overlap)
6 - sig3(t) = sig3(t) + salt corr. (can be = 0)
7 - DeltaSIG = sig1(t)-sig3(t)
8 - Rewrite sig1(t) = sig3(t) + Dsig(t)

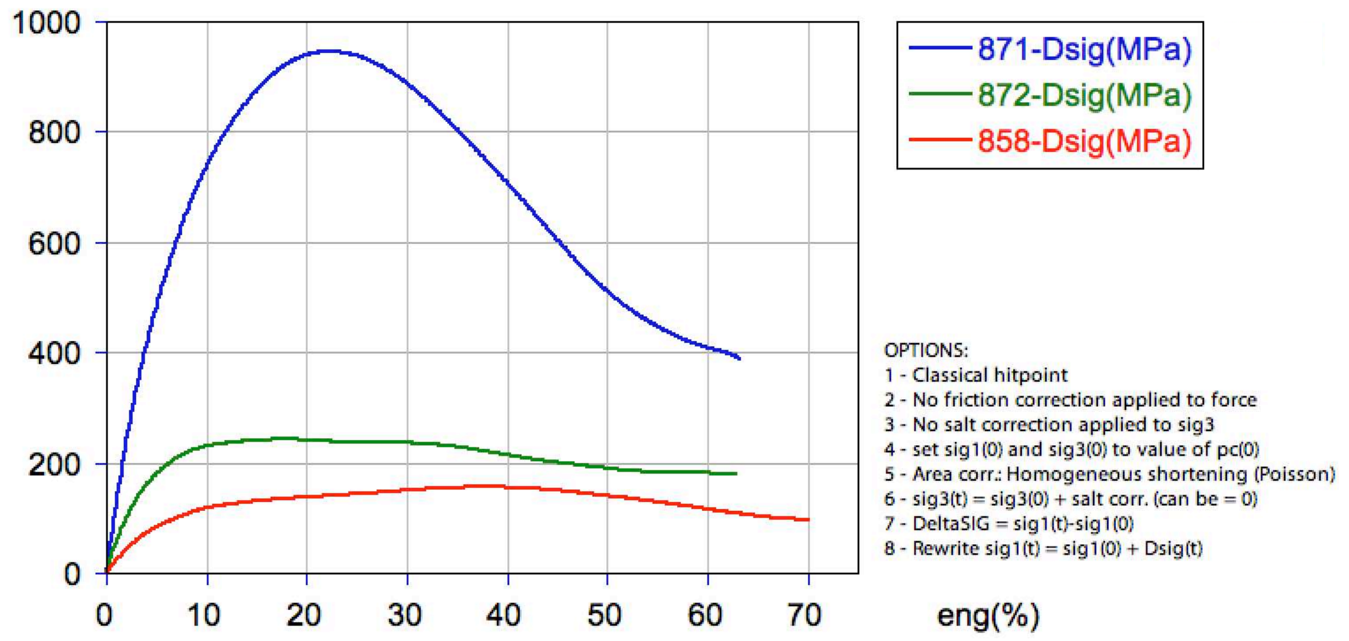
Changing the strain definition does not alter the calculated stress, but it severly changes the shape of the stress-strain curve.

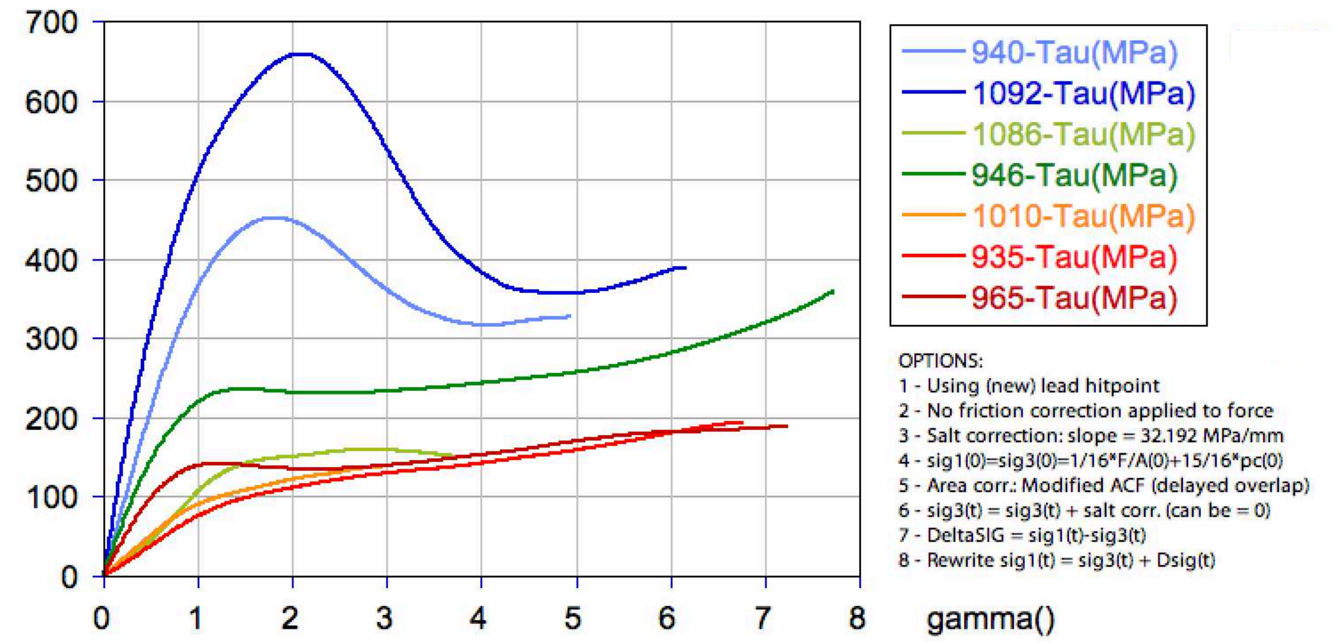
When comparing coaxial and general shearing data, the choice of the 'equivalent' strain is important.

When using natural strain, shear experiments accumulate more strain, when using the strain magnitude (derived from the octahedral shear strain), the coax experiements achieve higher strains...

< *go to overview* >

results !



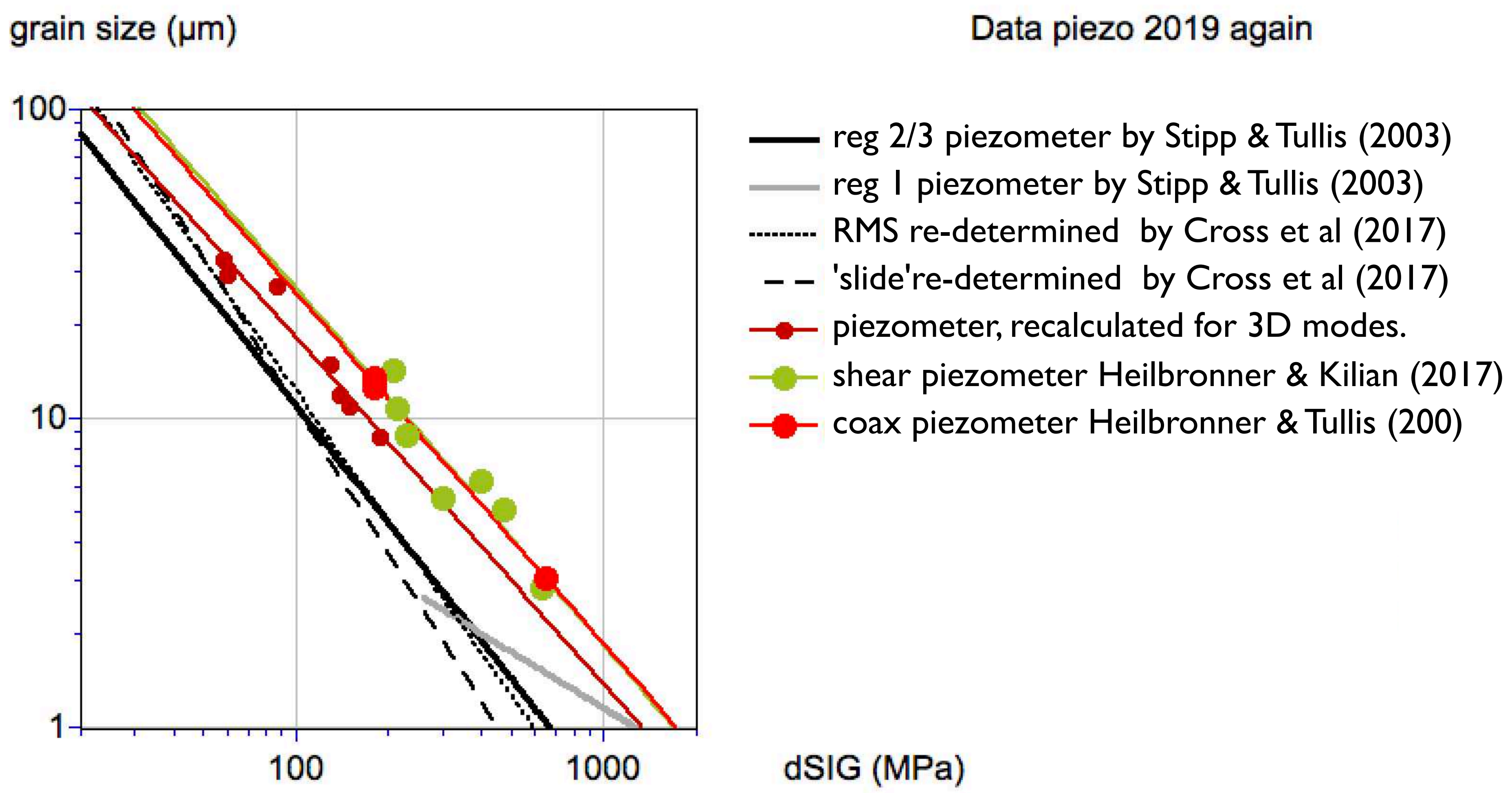


how to choose the flow stress ?

new run records	mode v(D) µm	Δσ (2017)	Δσ (2019)
1-w871			400
2-w872			240
3-w858			160
1a-w940	5.048	476	638
1b-w1092	3.843	628	712
2a-w1986	5.521	300	466
2b-w946	6.278	402	328
3a-w1010	8.752	230	286
3b-w935	14.182	206	274
3c-w965	10.714	214	274

scanning effort by Leif Tokle,
Brown Univertsity is
gratefully, acknowldedged

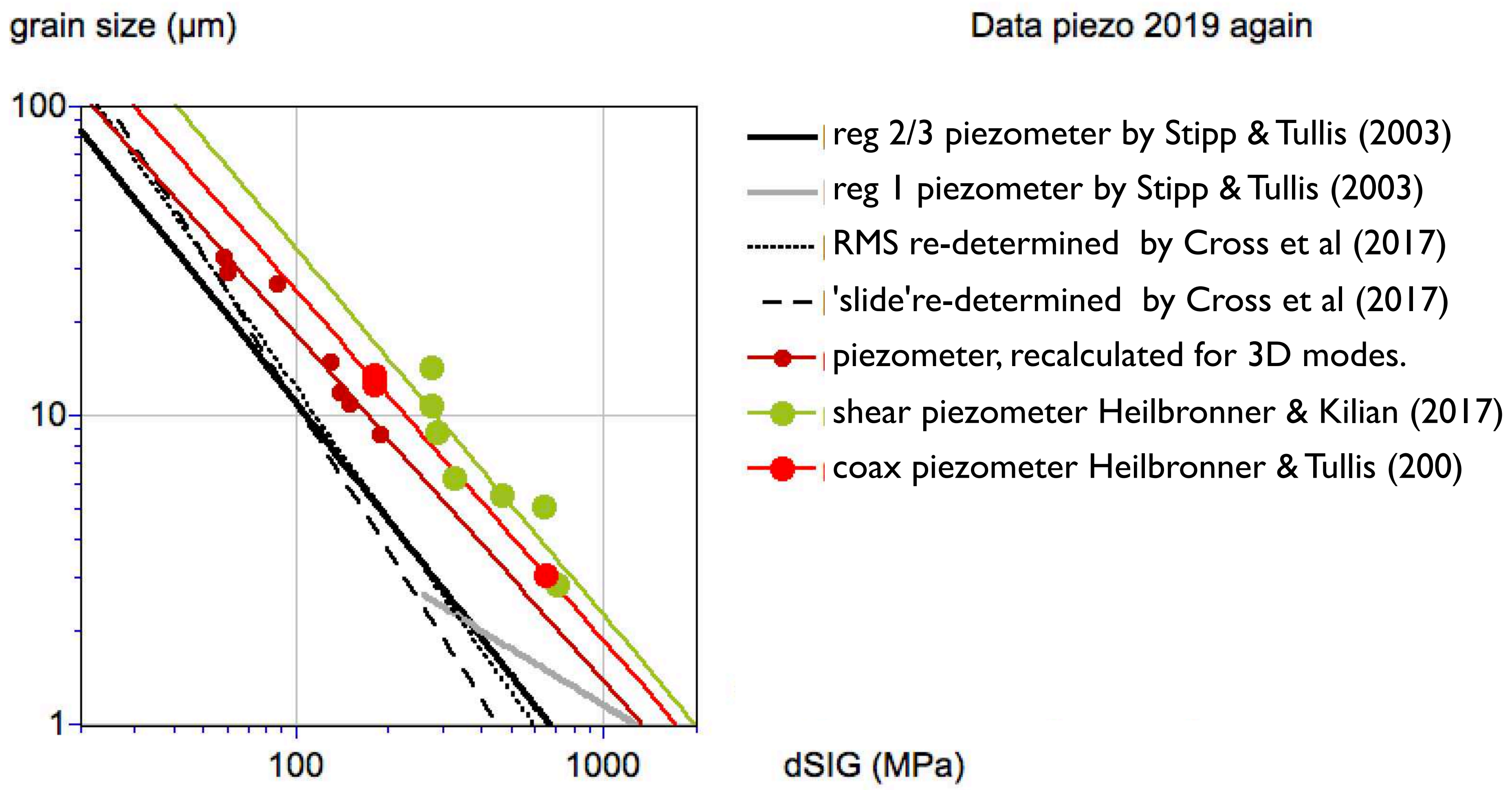
2019 coax SSA added



published gs data shear (2017)
+ new gs w871 and w858
+ published stresses (2017, 2002)

=> in solid medium coax = shear
=> coax stronger in solid than molten

2019 stresses recalculated



published gs data shear (2017)
+ new gs w871 and w858
+ stresses from run record
+ recalculated for standard coax and standard shear

=> shear even stronger !
=> coax solidmedium same as molten

< *go to overview*