putting rock properties in their place

– meshing orientation imaging with grain shape and size distribution

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physical properties – at each pixel

$$A_{phase}/A_{total} = V_{phase}/V_{total}$$

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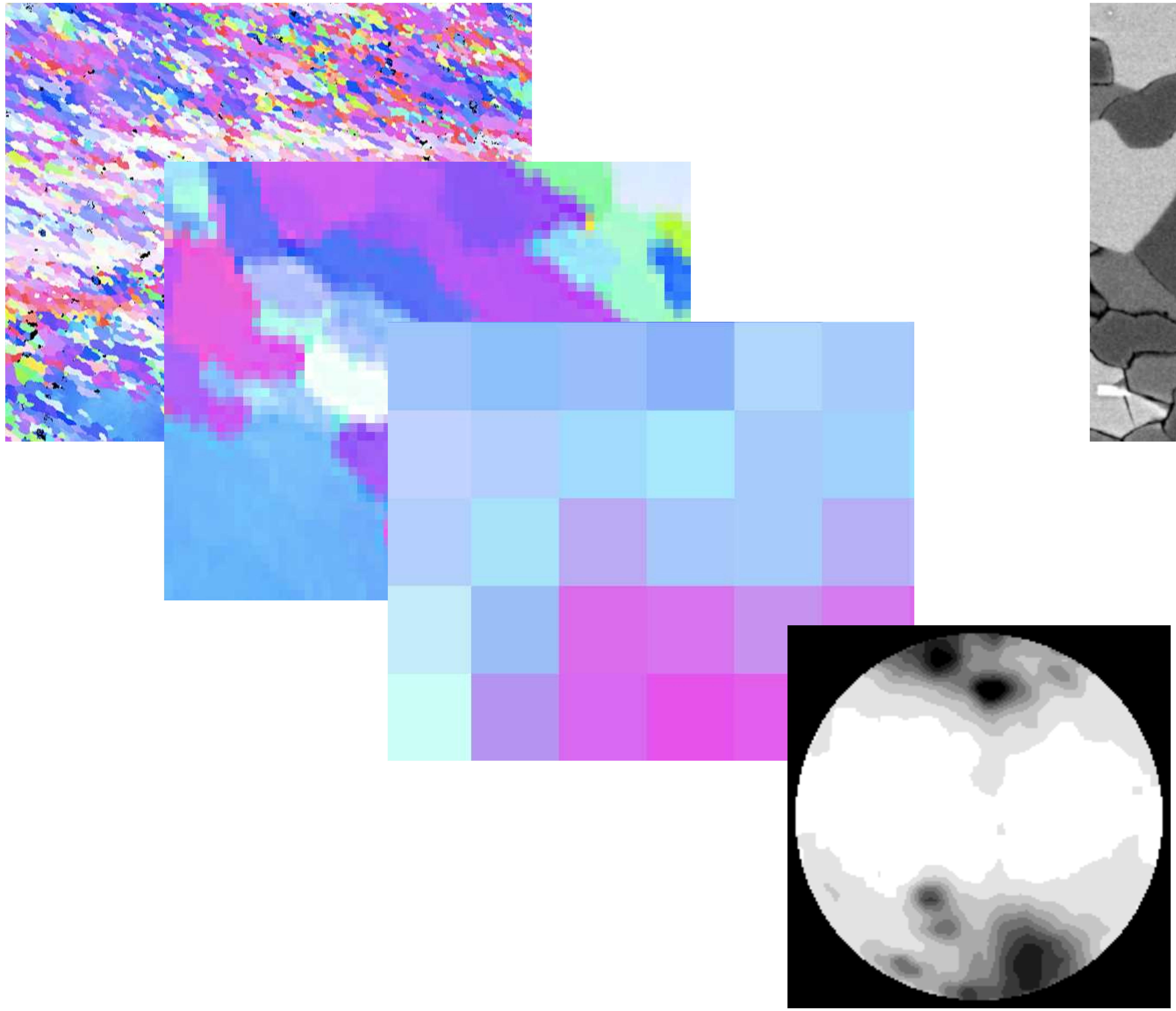
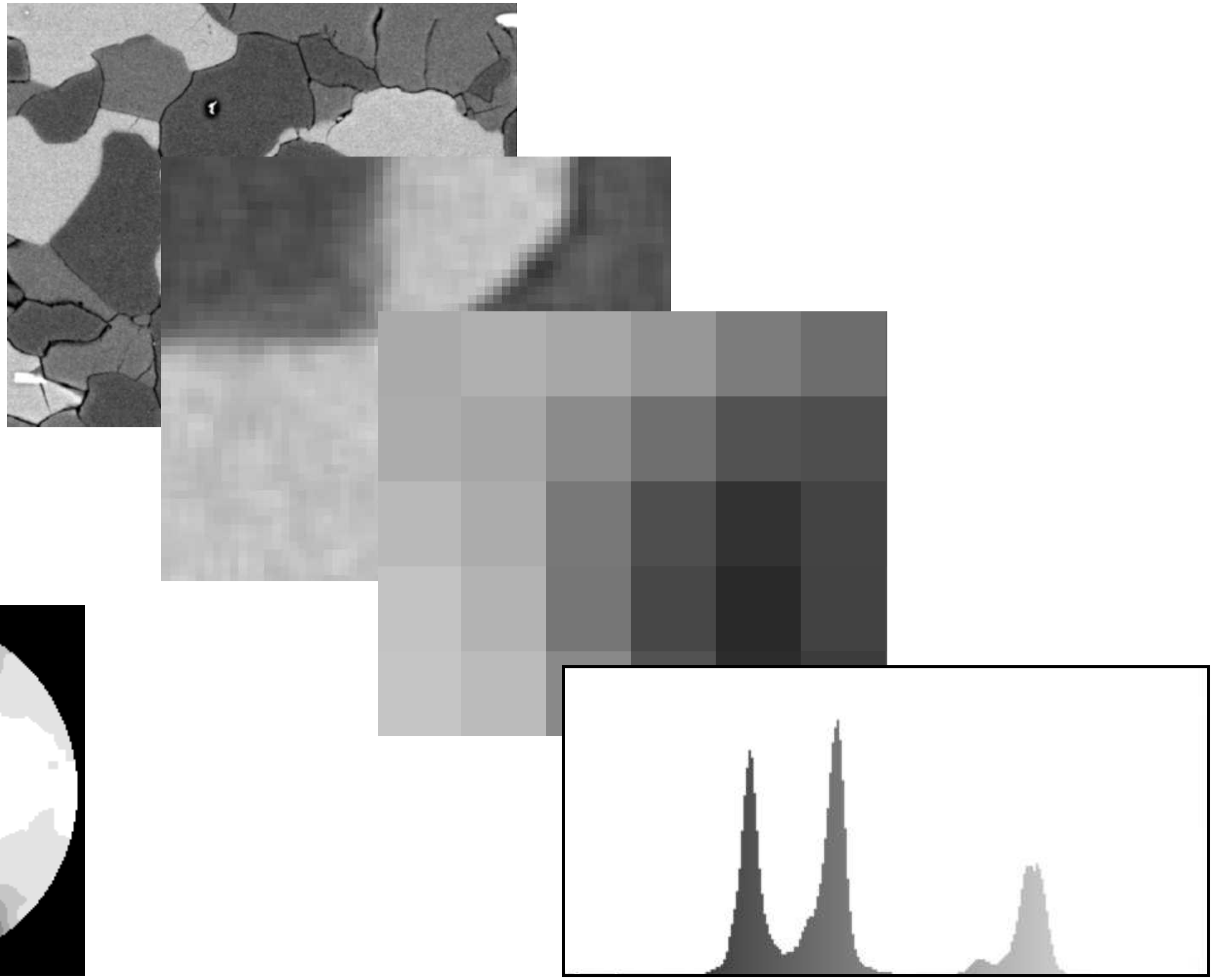
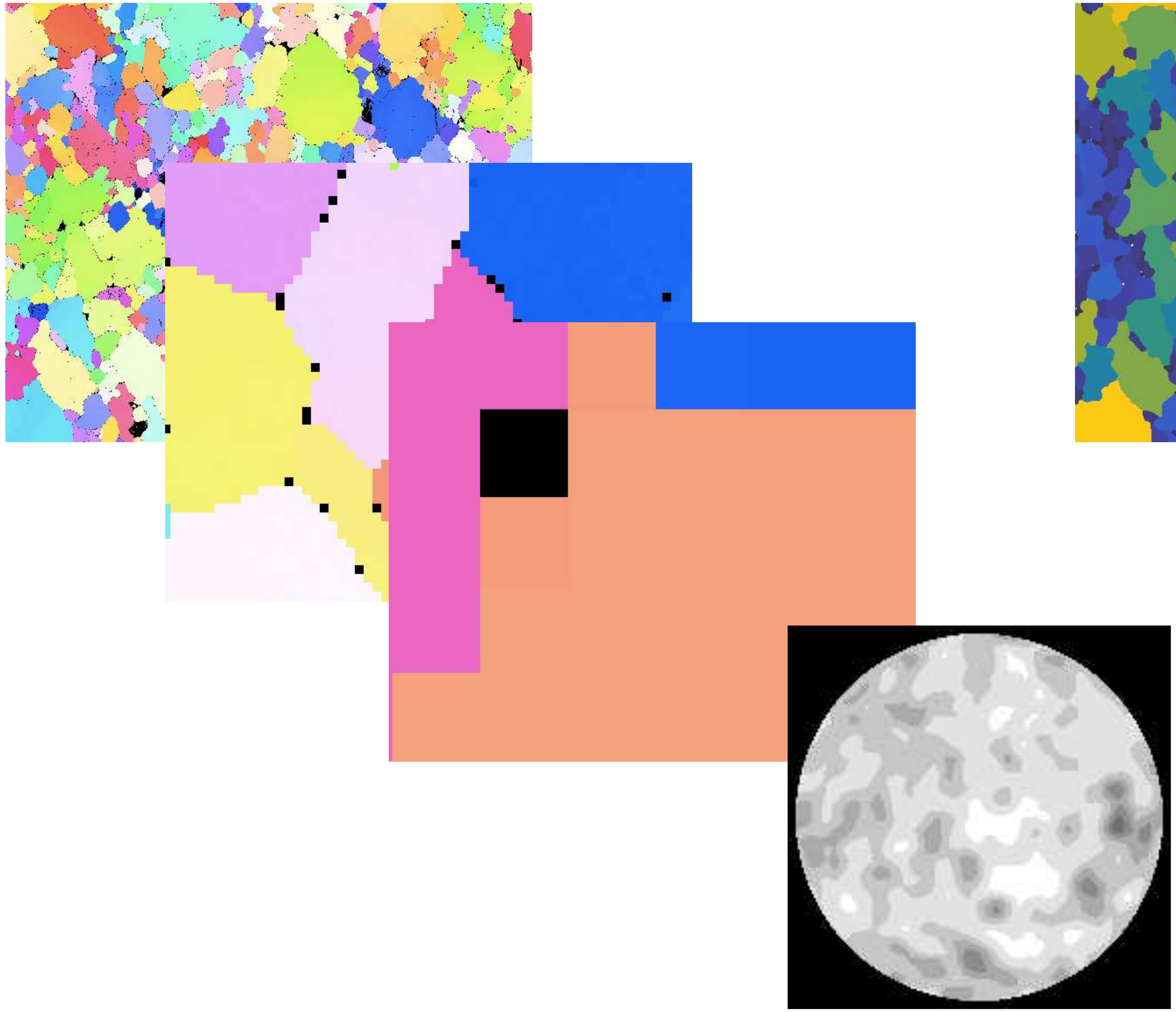


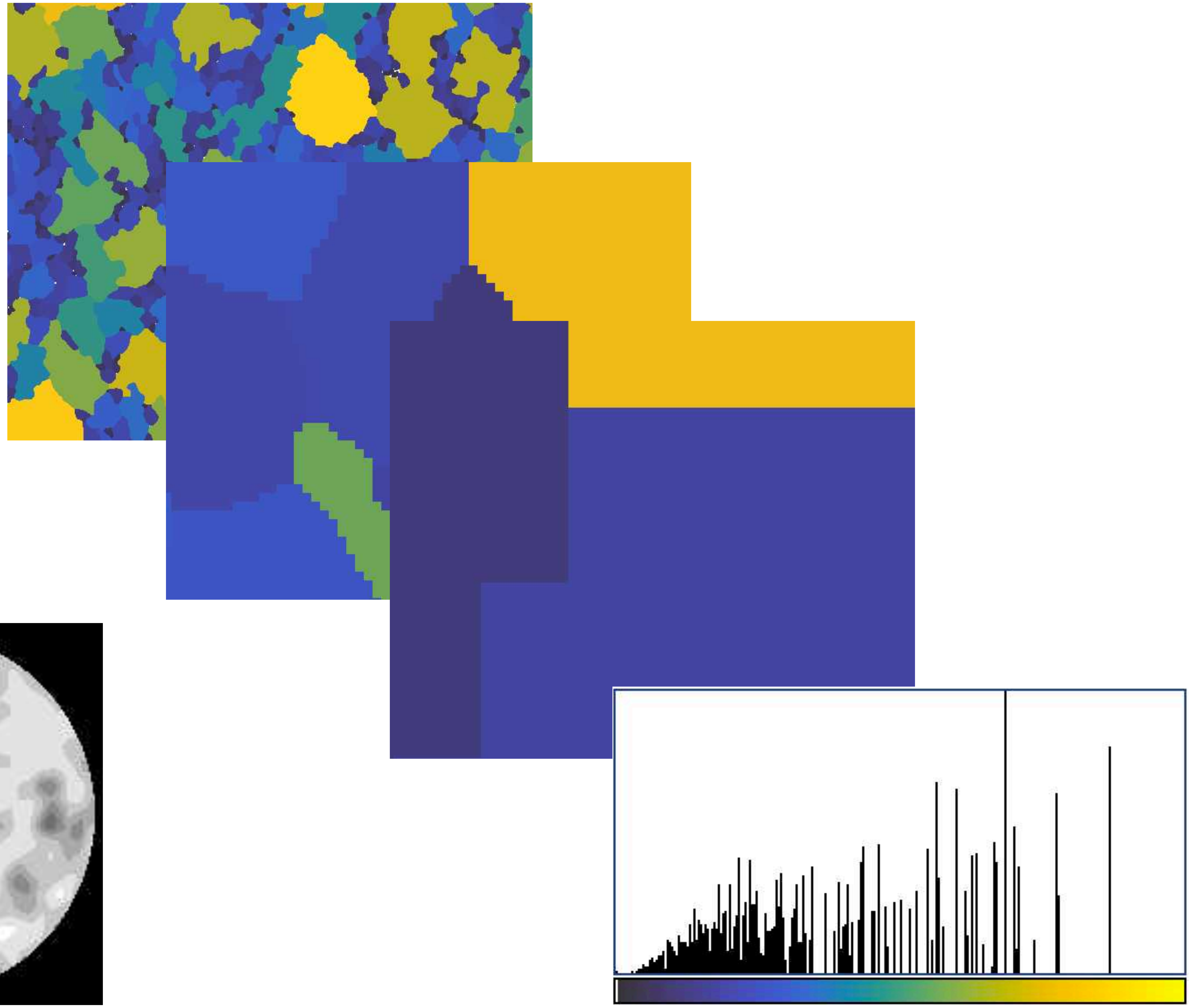


properties of pixels – properties of grains

$A_{phase}/A_{total} = V_{phase}/V_{total}$

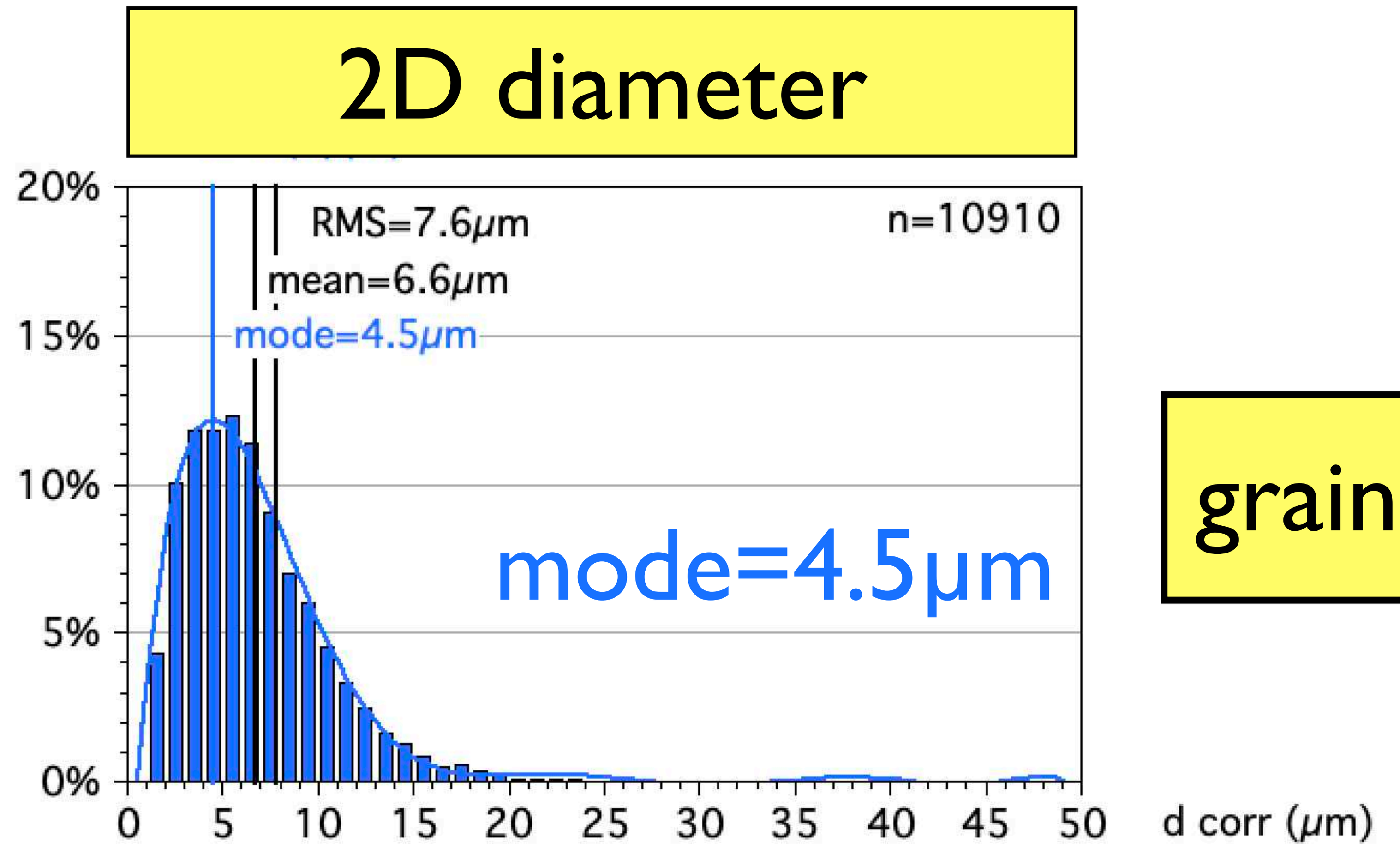
$A_{grainsize}/A_{total} \neq V_{grainsize}/V_{total}$



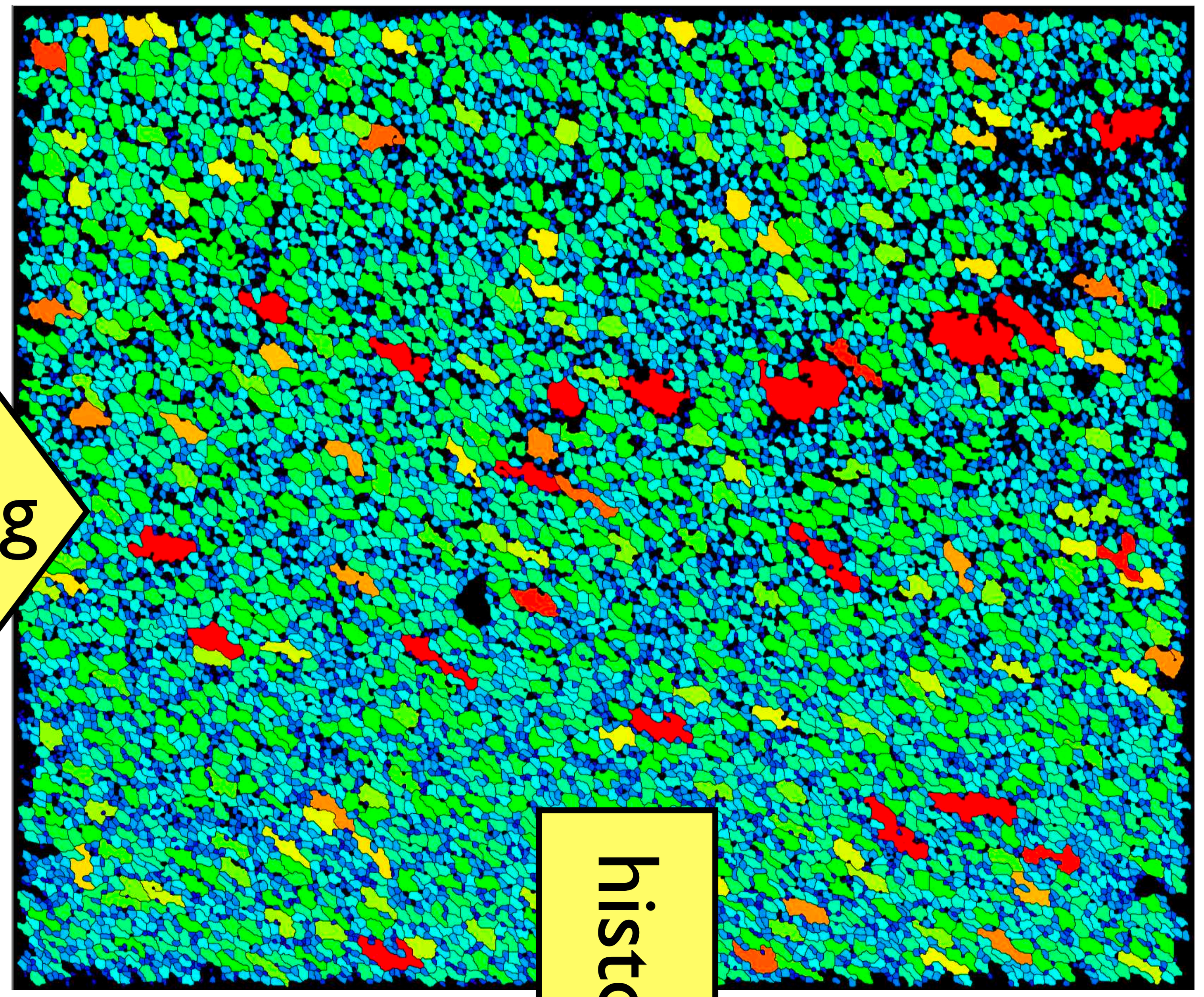


my mission on earth ... 2D sections → 3D grains

segmentation

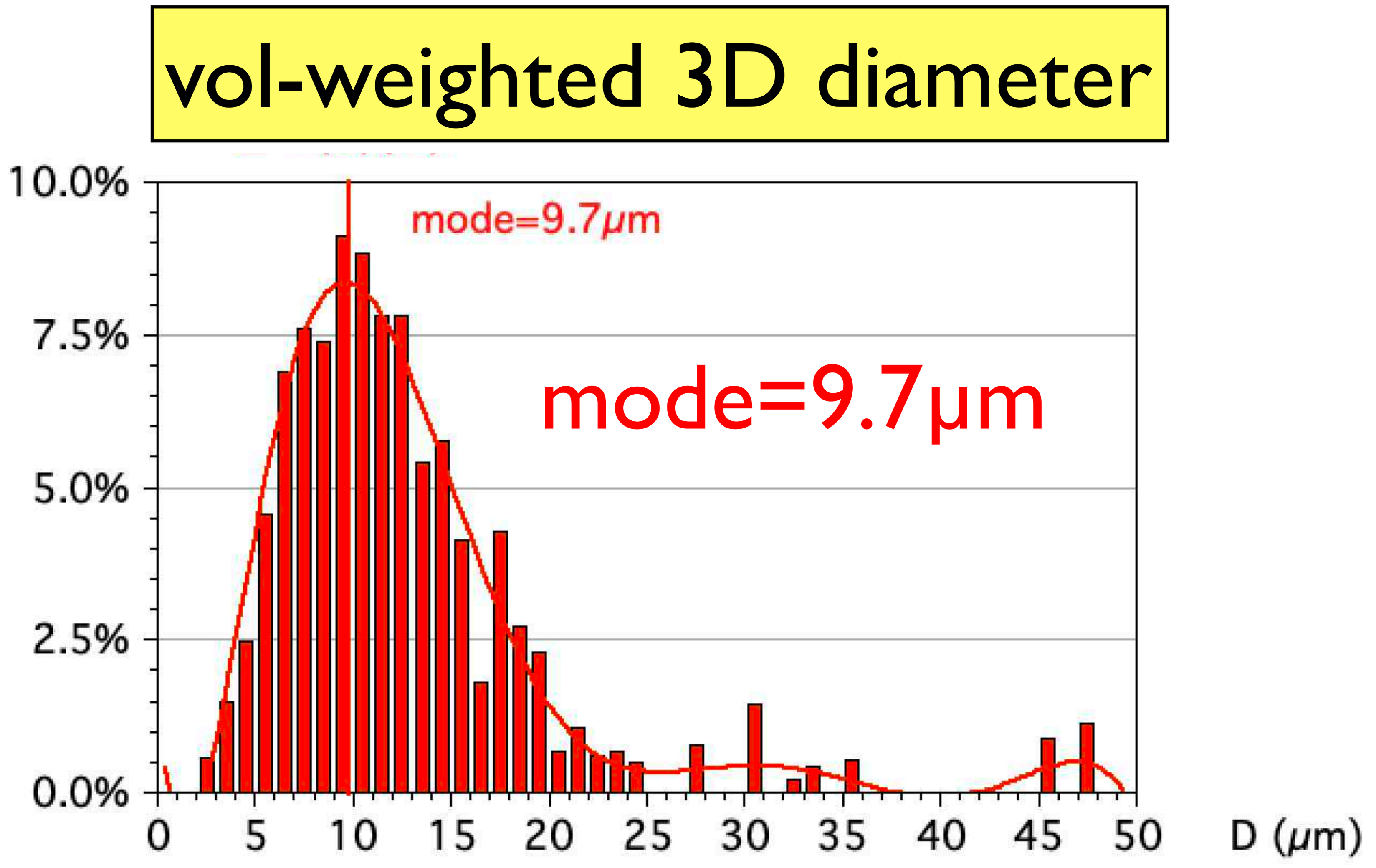


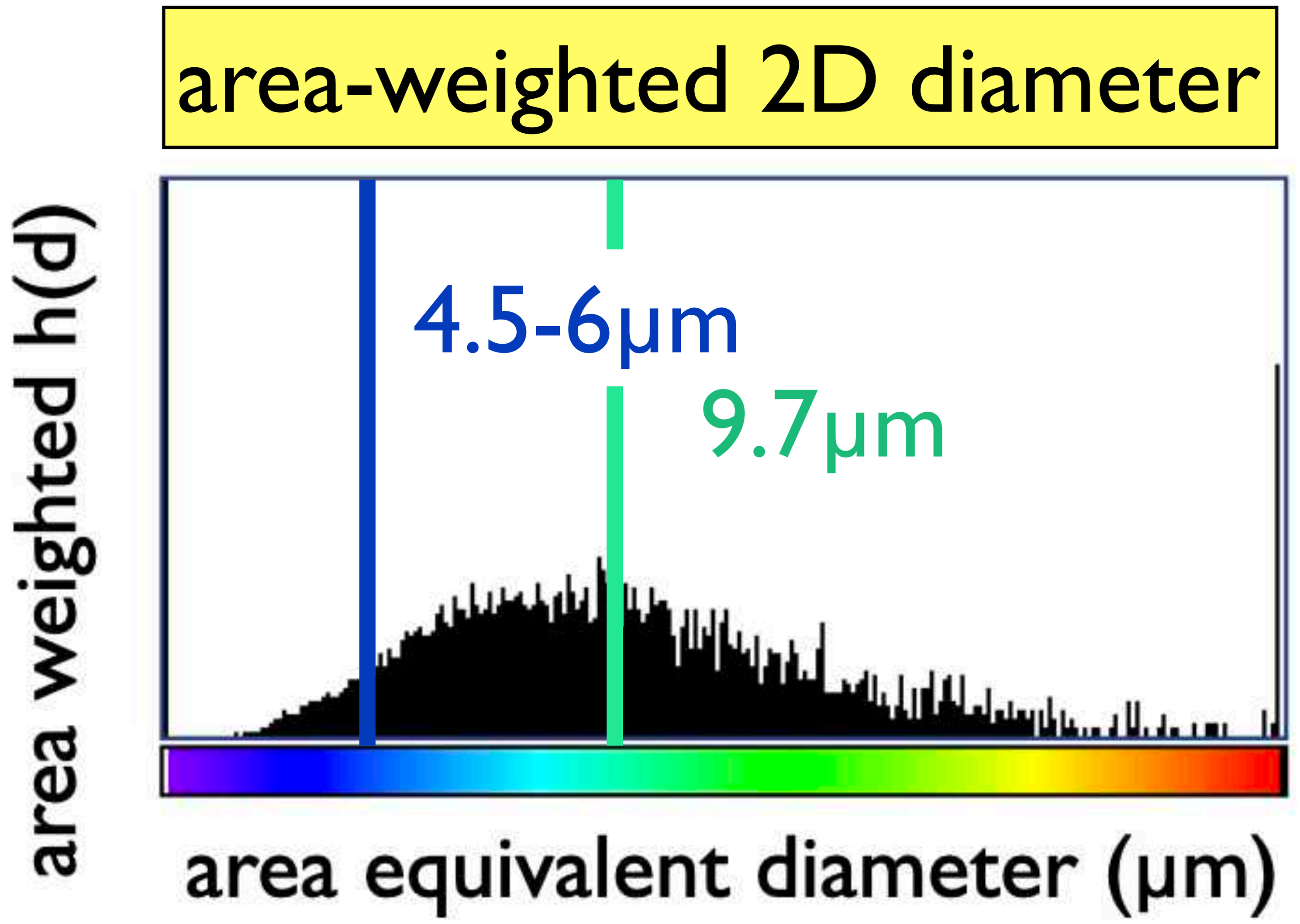
grain size mapping



stripstar

histogram

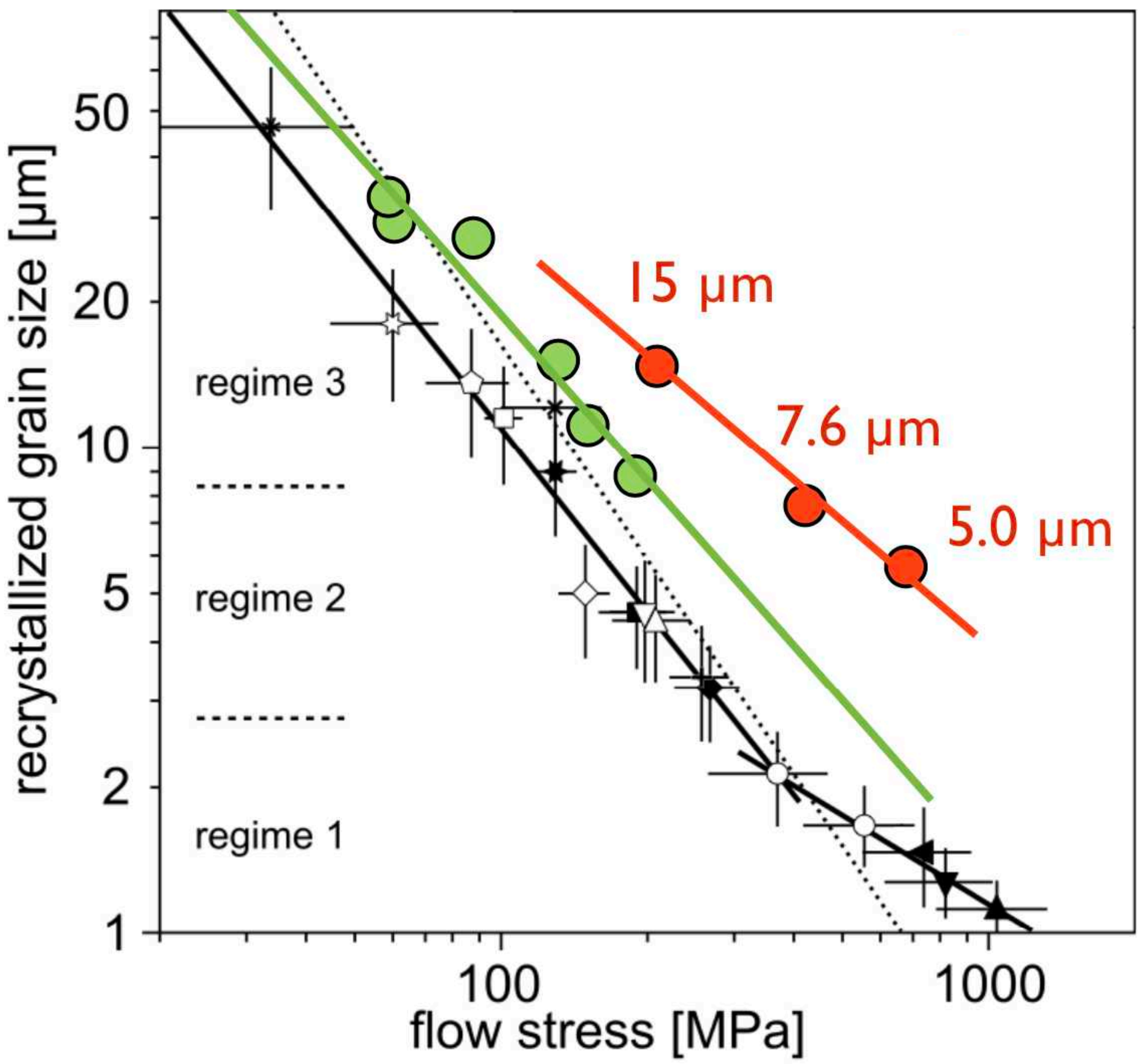




area-weighting of 2D diameters (grainsize mapping) confirms visually that the dominant grain size ≠ the numerical mean (or RMS) of h(d) where to start ?

... the piezometer ...?

EGU 2016 – surprise surprise !!



RMS h(d)
d = diameter of 2D sections
— Stipp & Tullis 2003
······· Twiss 1977
mode vol%(D)
D = diameter of 3D grains
— Stipp & Tullis 2003
recalculated from EBSD maps

coaxial experiments
molten salt assembly

mode vol%(D)
D = diameter of 3D grains
— shear 'piezometer'

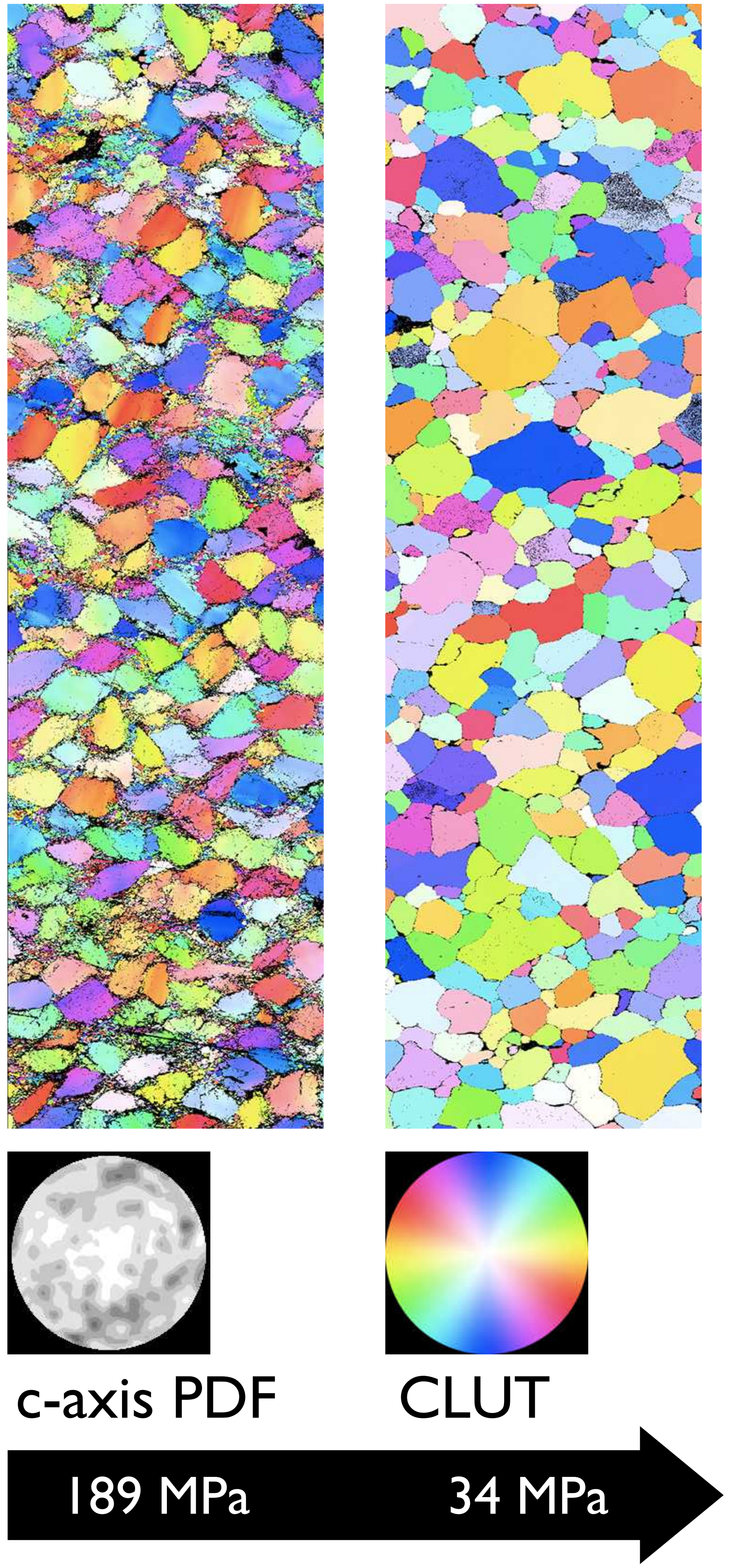
shearing experiments
solid confining medium

questions:
- is BHQ stronger in shear compared to coaxial deformation ?!
  i.e., piezometer not valid for shearing deformation?
- is determination of $\Delta\sigma$ from shearing experiments incorrect?

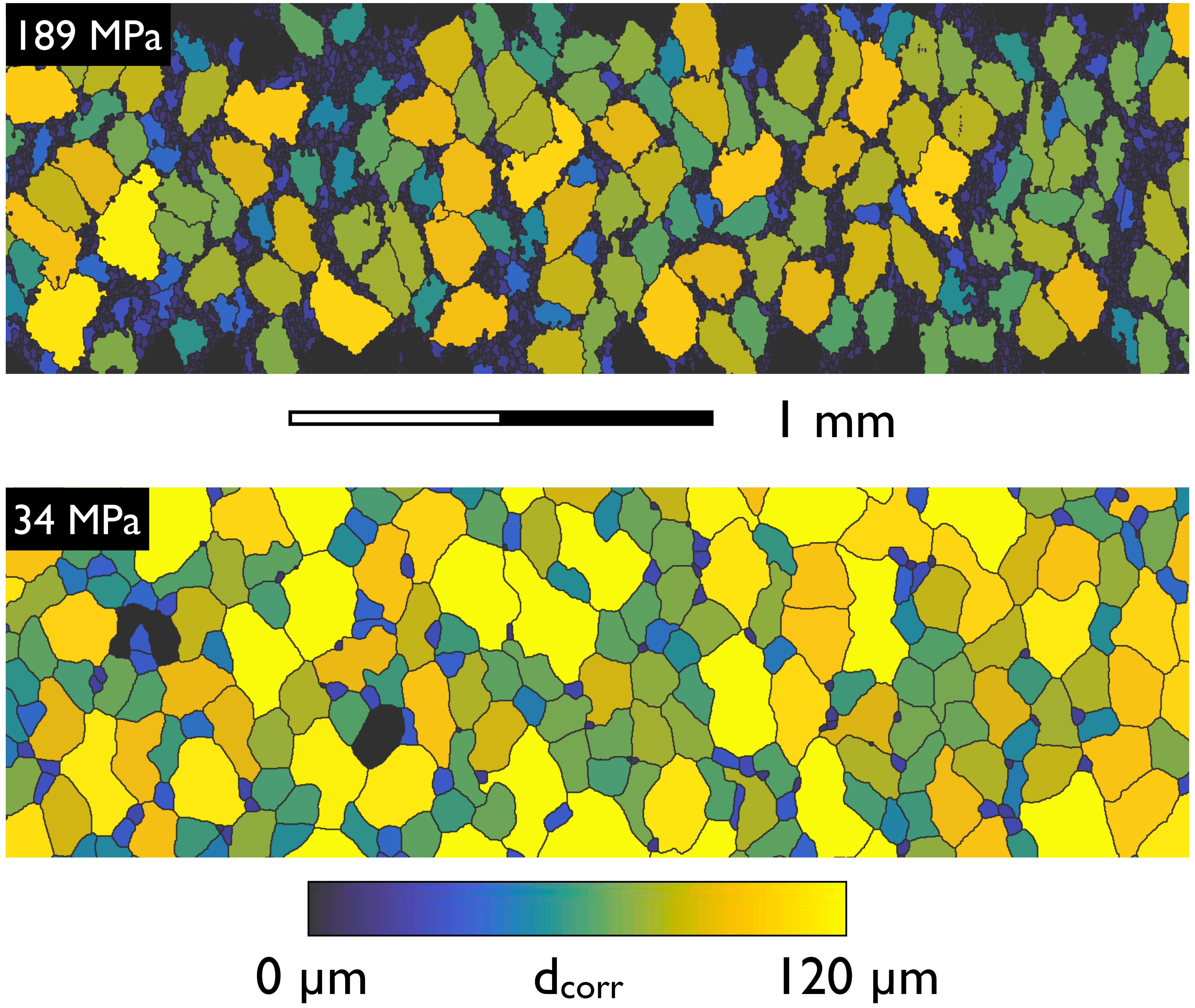
EBSD→CIP orientation images of piezometer experiments

grain boundaries → diameters → grain size maps

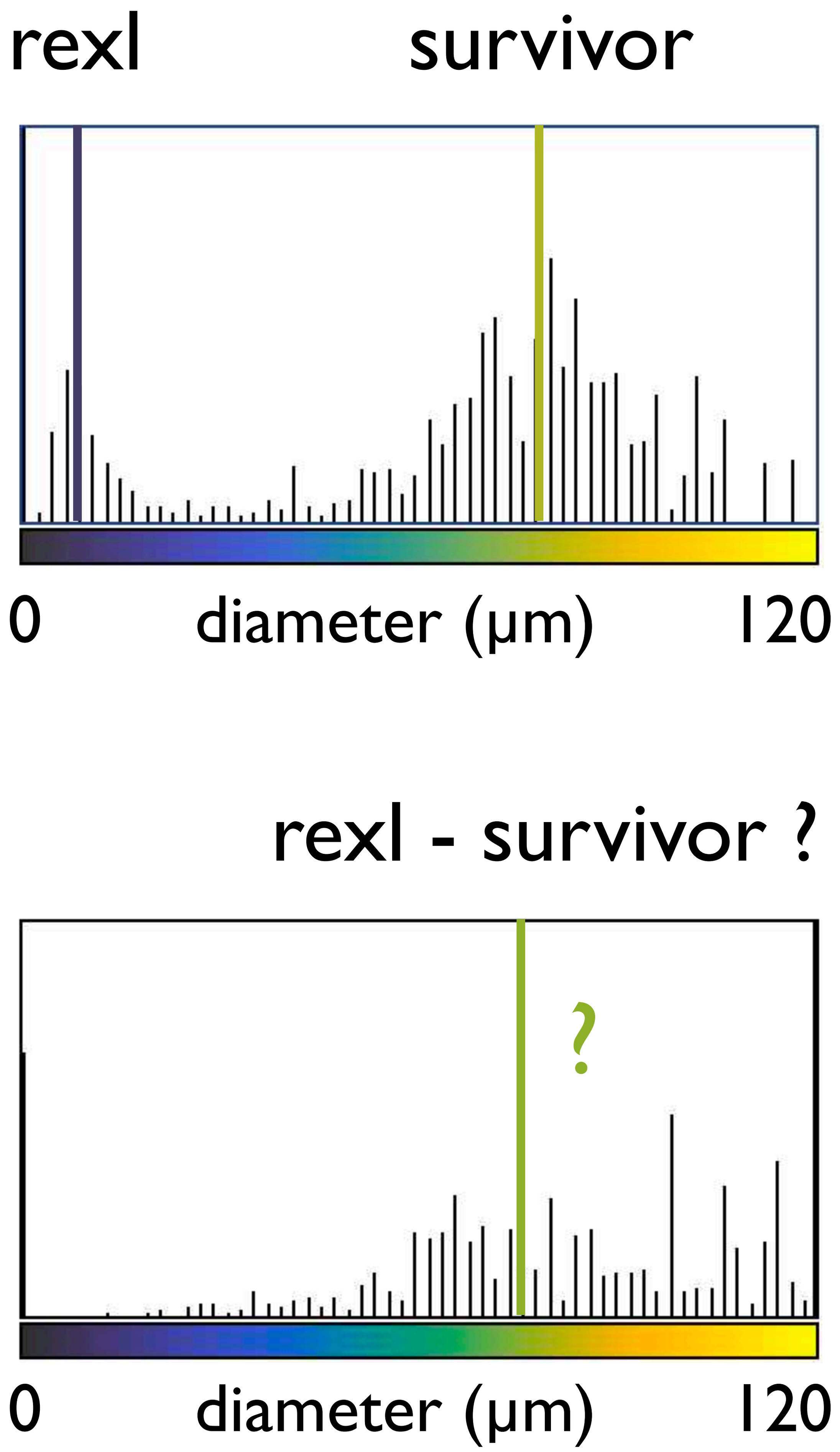
c-axis orientation images



grain size maps



area-weighted histograms



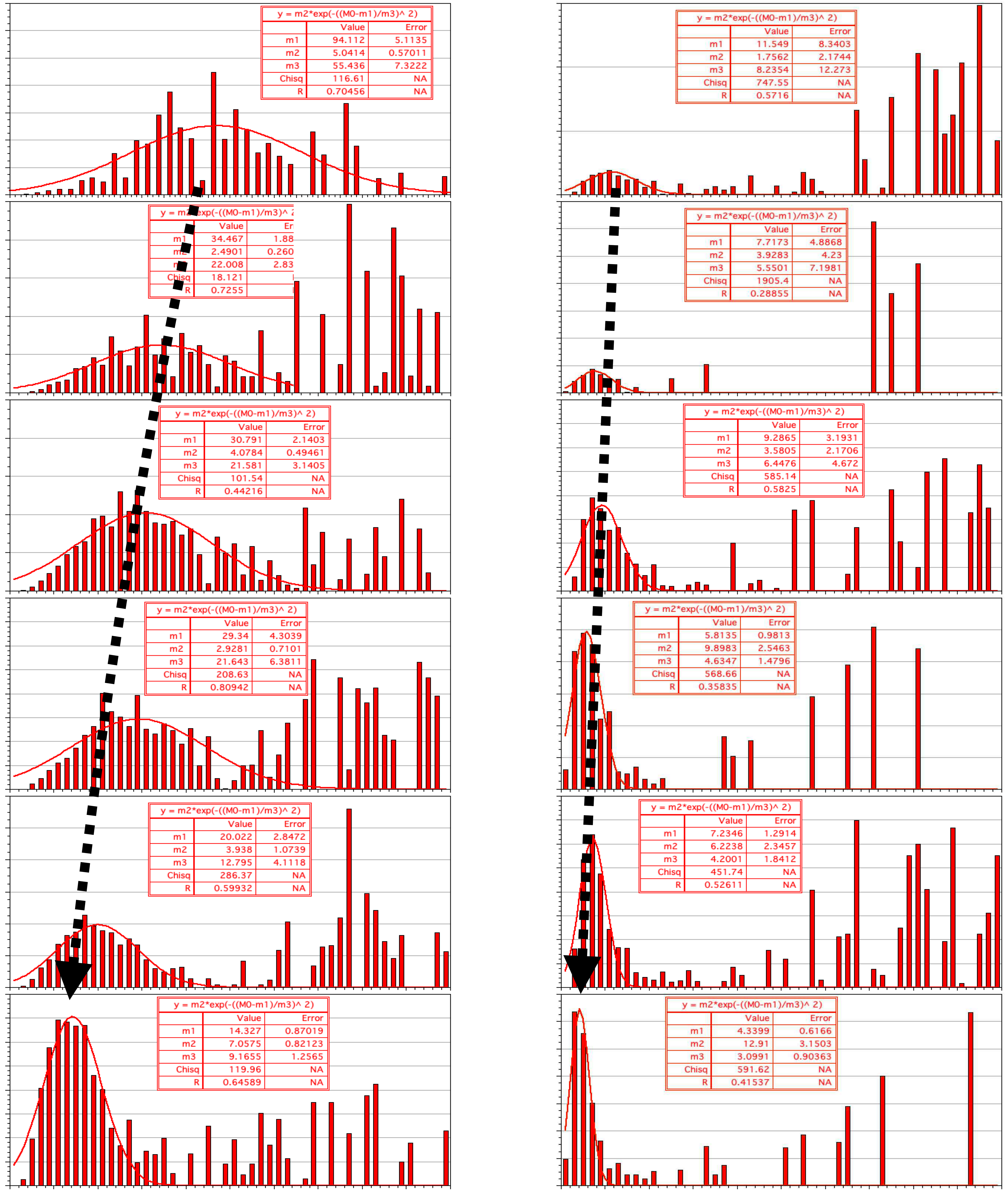
area-weighted of diameters of 2Dsections ≠ diameters of 3D grains !!

optional excursion: harping on the RMS

Kidder et al. 2016 use GOS to identify rexl grains

recrystallized grains have to be selected from h(d) before calculating RMS (→ bias)
stripstar (2D→3D) converts full h(d) to h(D) and volume weighted v(D)
the significant grain size is derived from the mode of v(D) and is independent of the range of h(d)

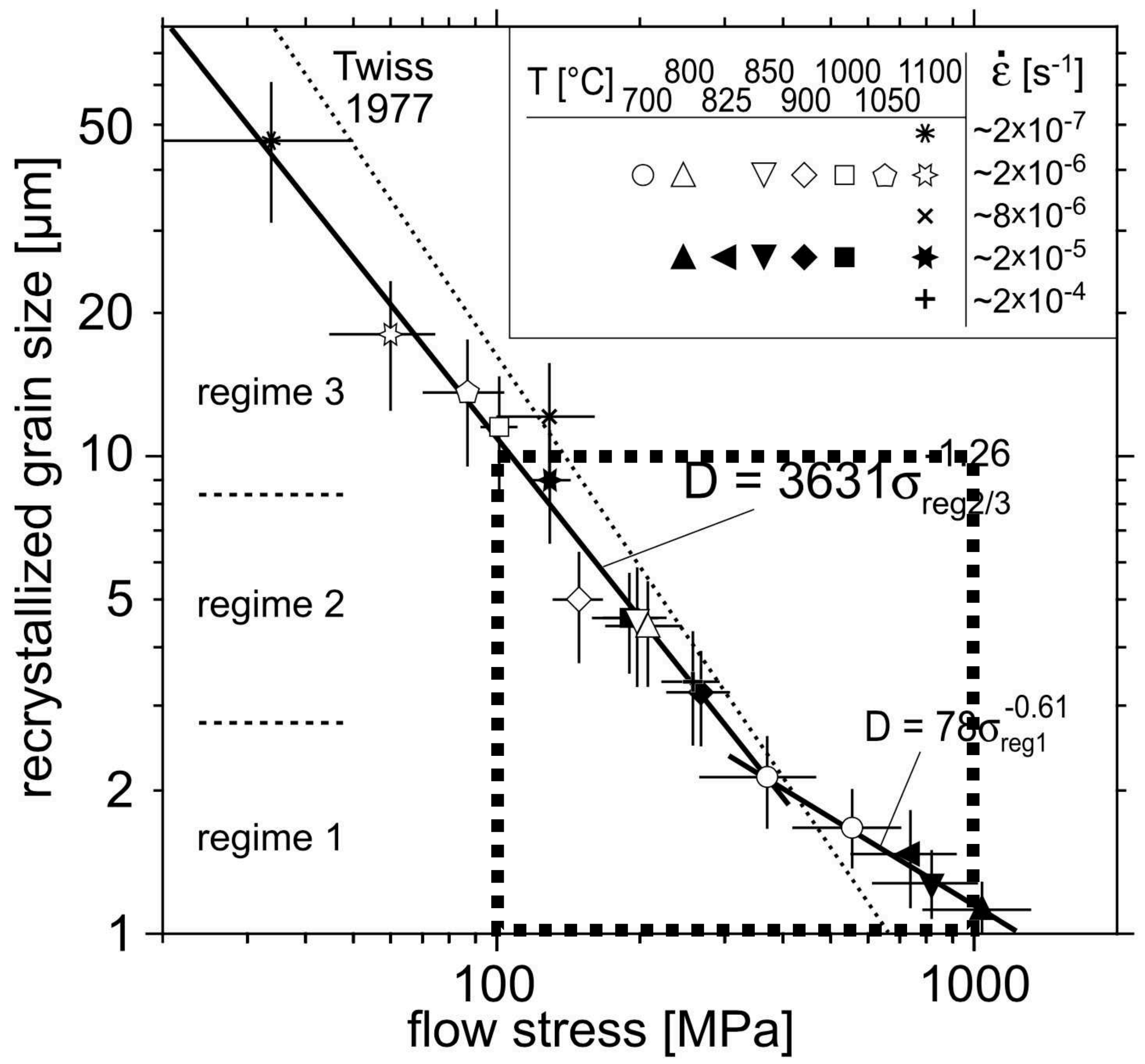
new EBSD piezo v(D) Gauss fit

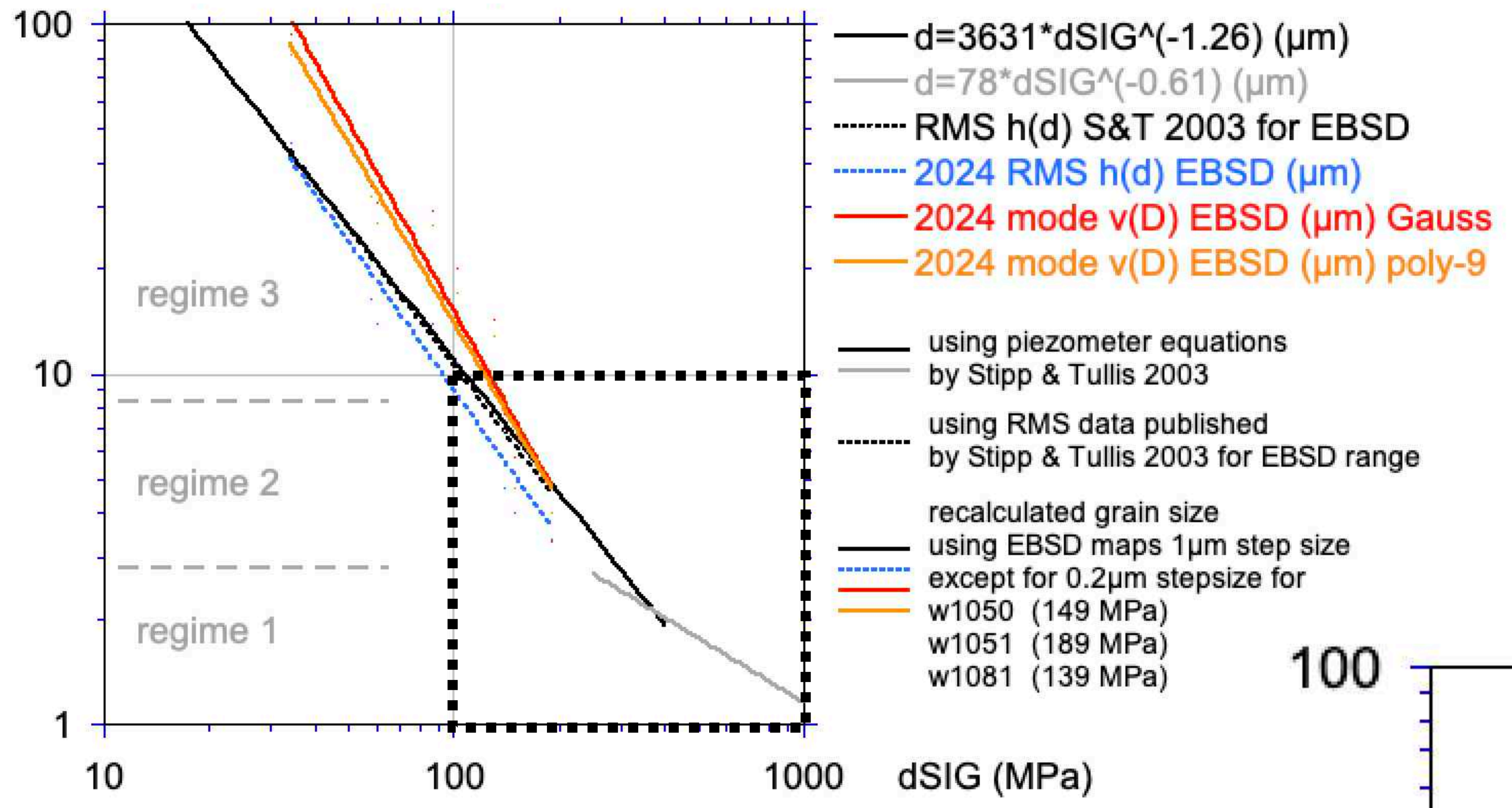


Δσ

	(MPa)	D (μm)
w1126-m2	34	94.1
w1143-m2	58	34.5
w1066-m2	60	30.8
w1025-m2	87	29.3
w1024-m10	102	20.0
w1029-m3	130	14.3
w1081-m4	139	11.5
w1081-m5	139	7.7
w1050-m6	149	5.8
w1050-m5	149	9.3
w1051-m6	189	3.3
w1051-m4	189	7.2

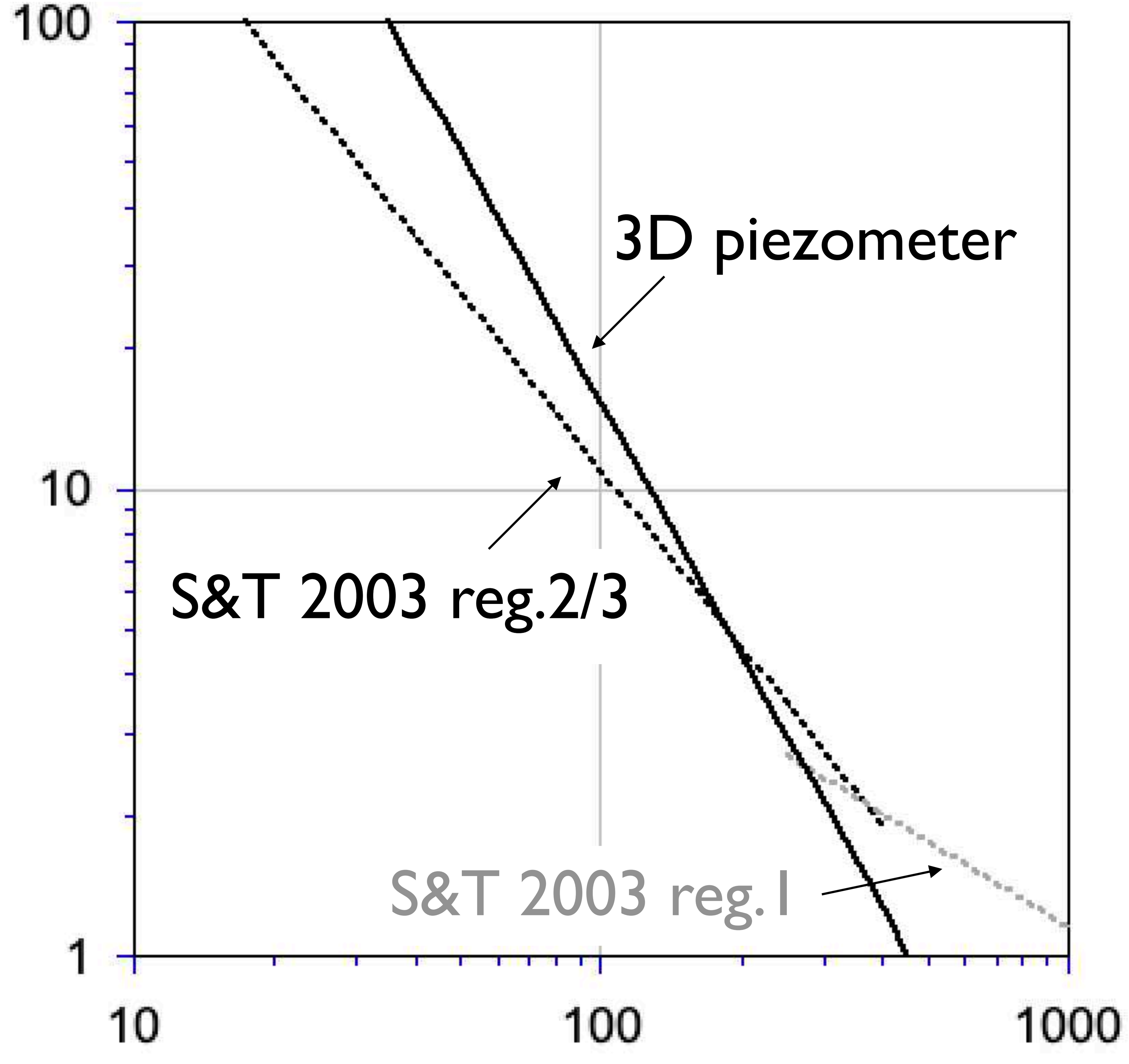
derive '3D piezometer'





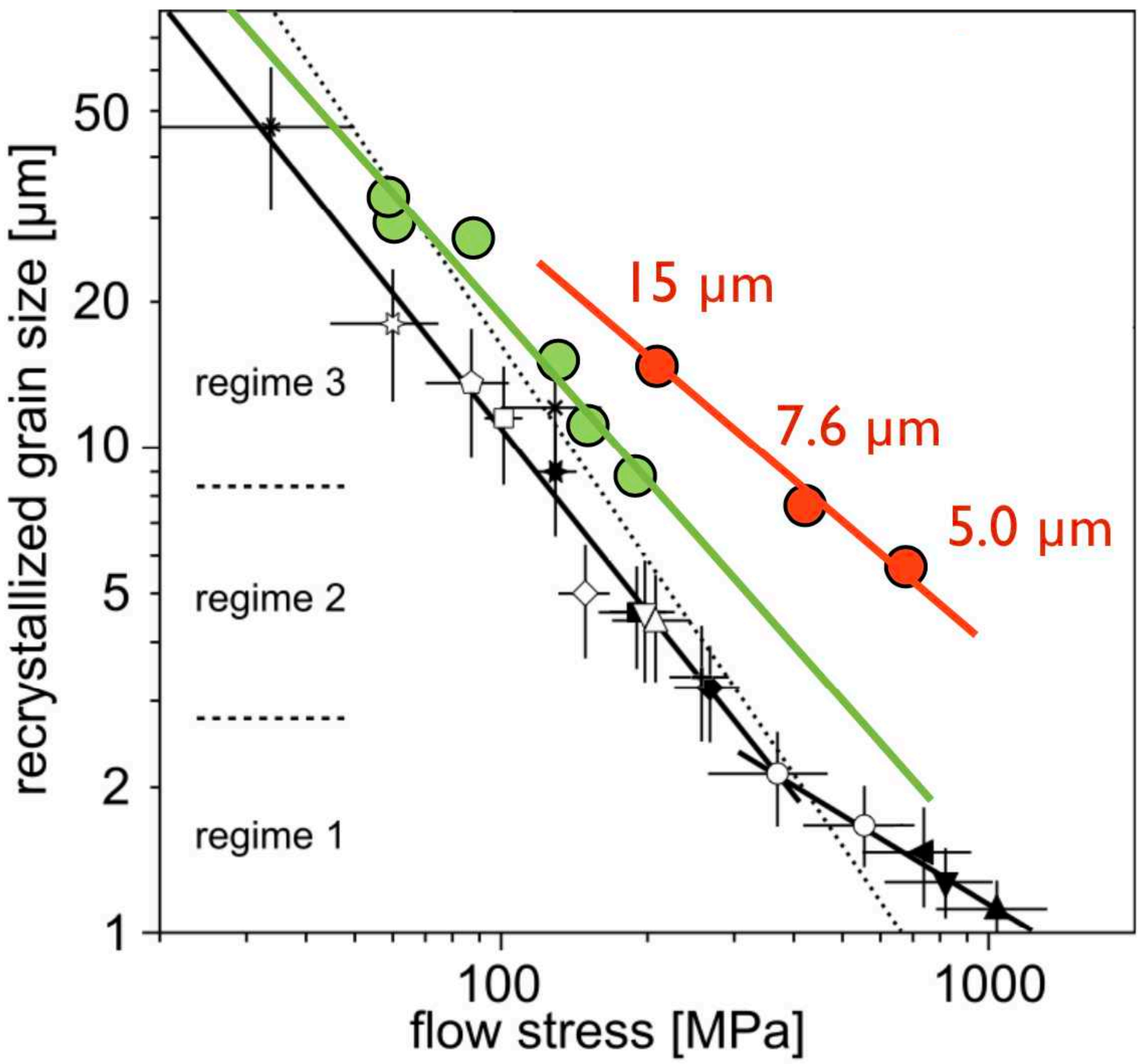
$$d = 3631 \cdot \Delta\sigma^{(-1.26)}$$
$$d = 78 \cdot \Delta\sigma^{(-0.61)}$$
$$D = 58060 \cdot \Delta\sigma^{(1.79)}$$

background for upcoming slides



back to experimental data

EGU 2016 – should we really have been surprised ??



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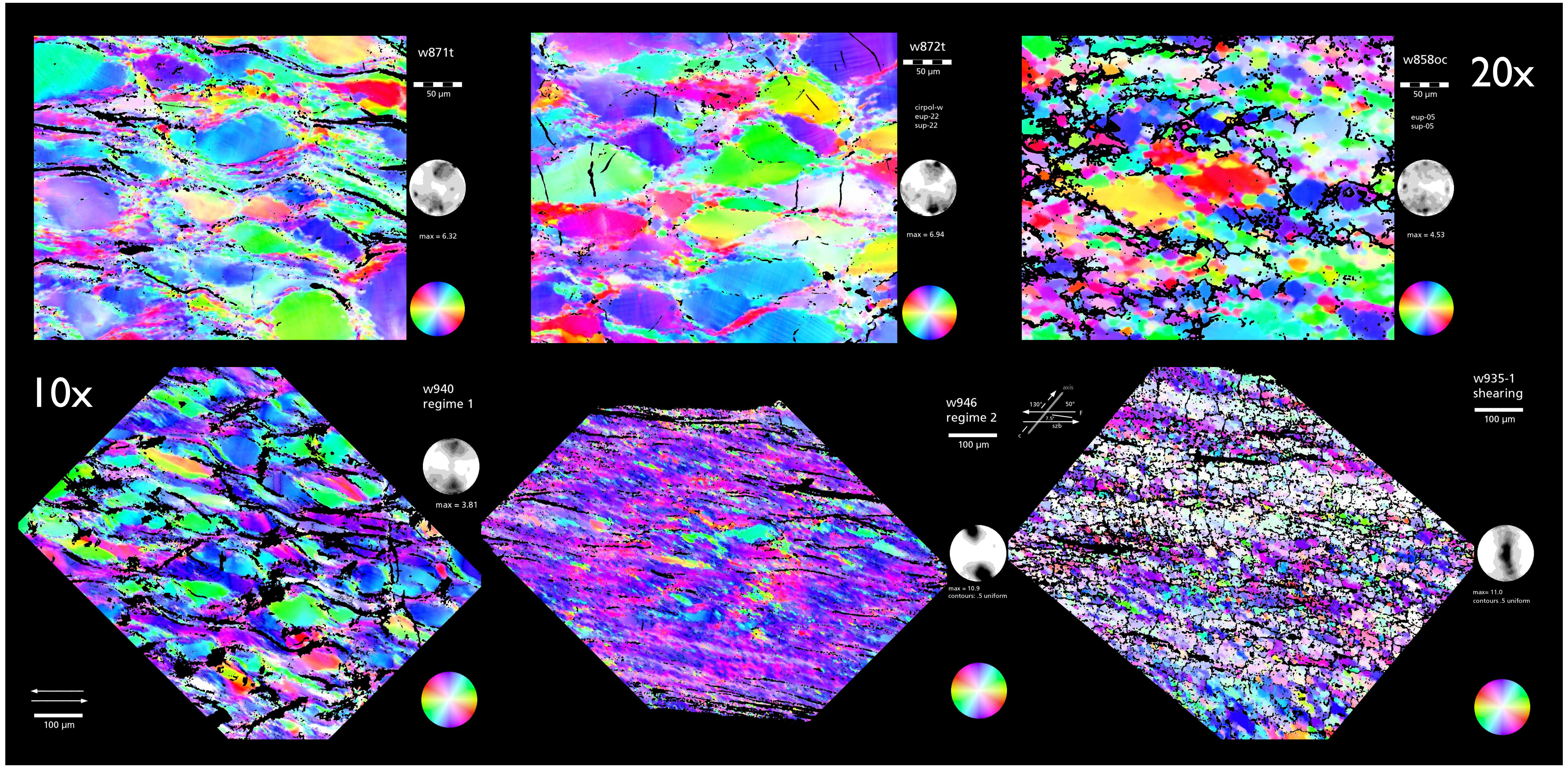
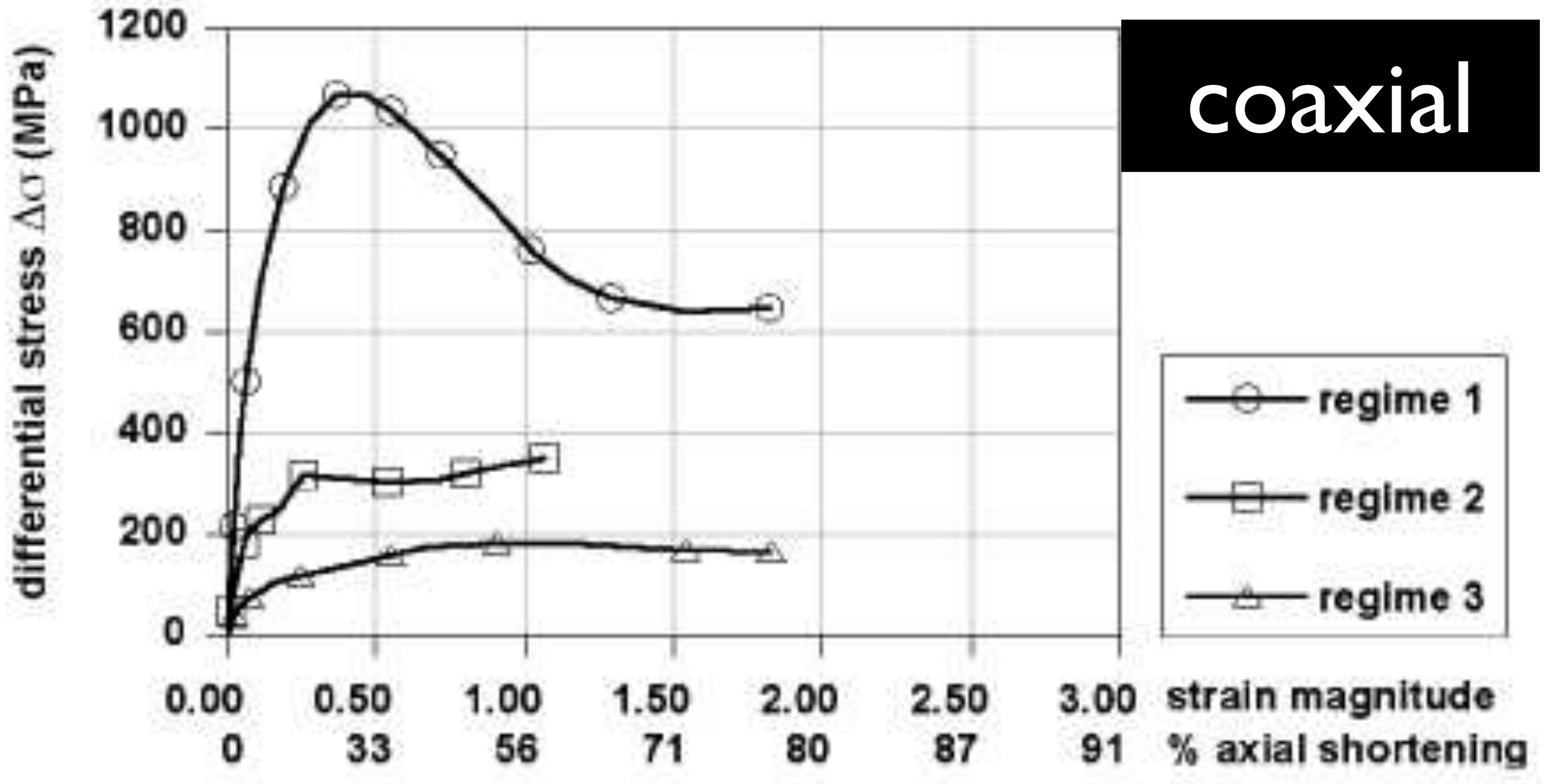
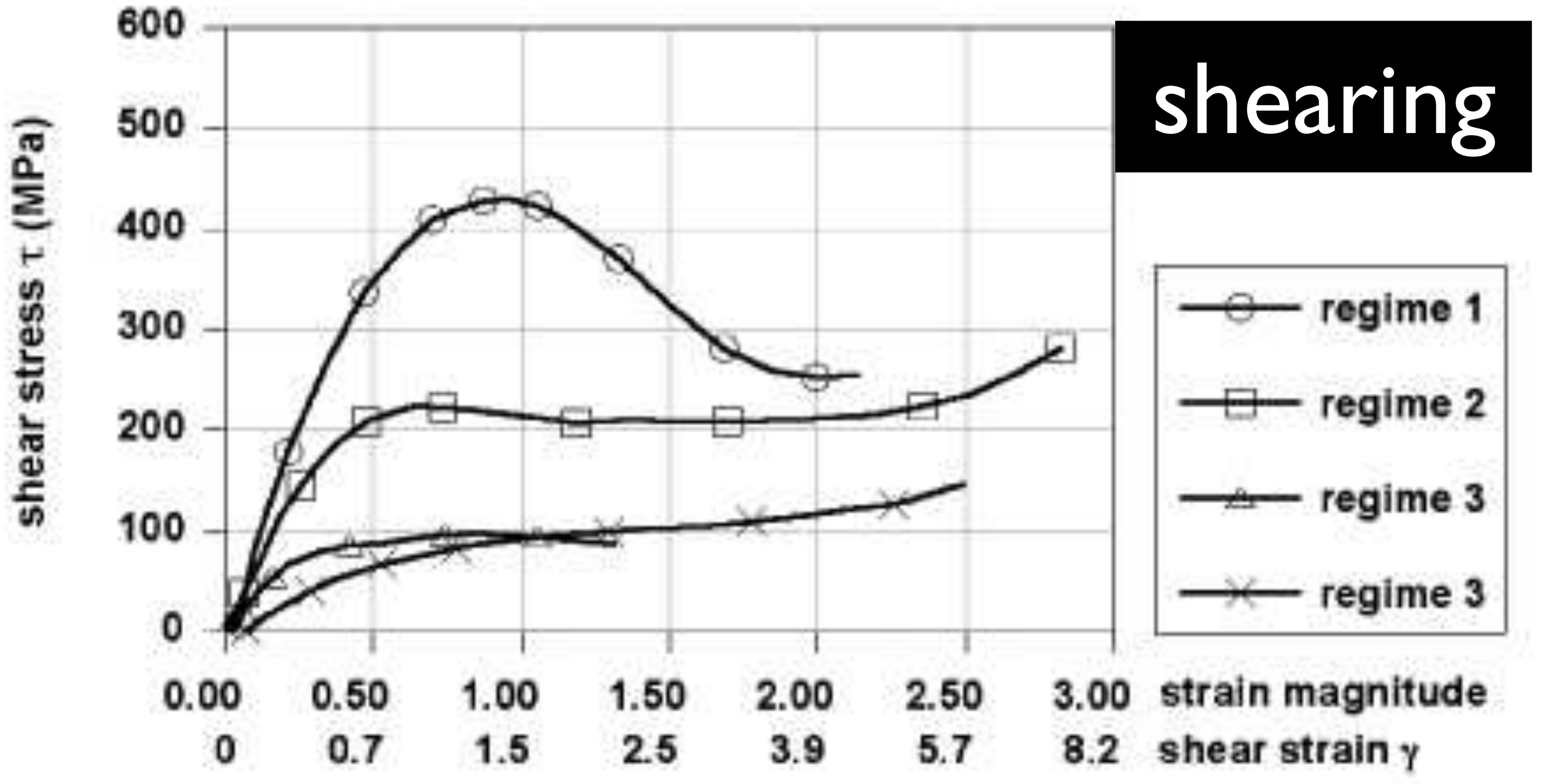
what we could have noted in 2002 ...

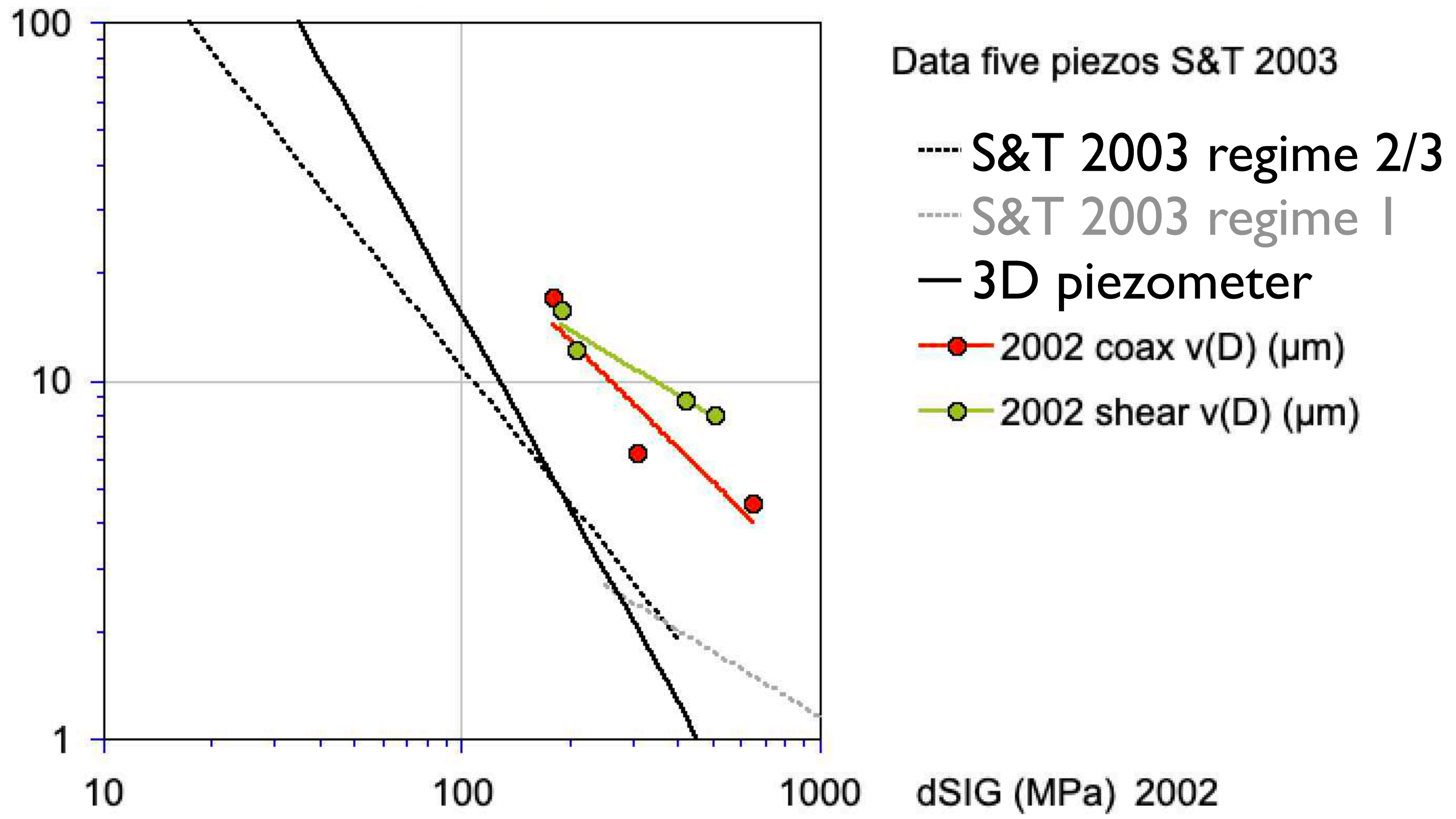




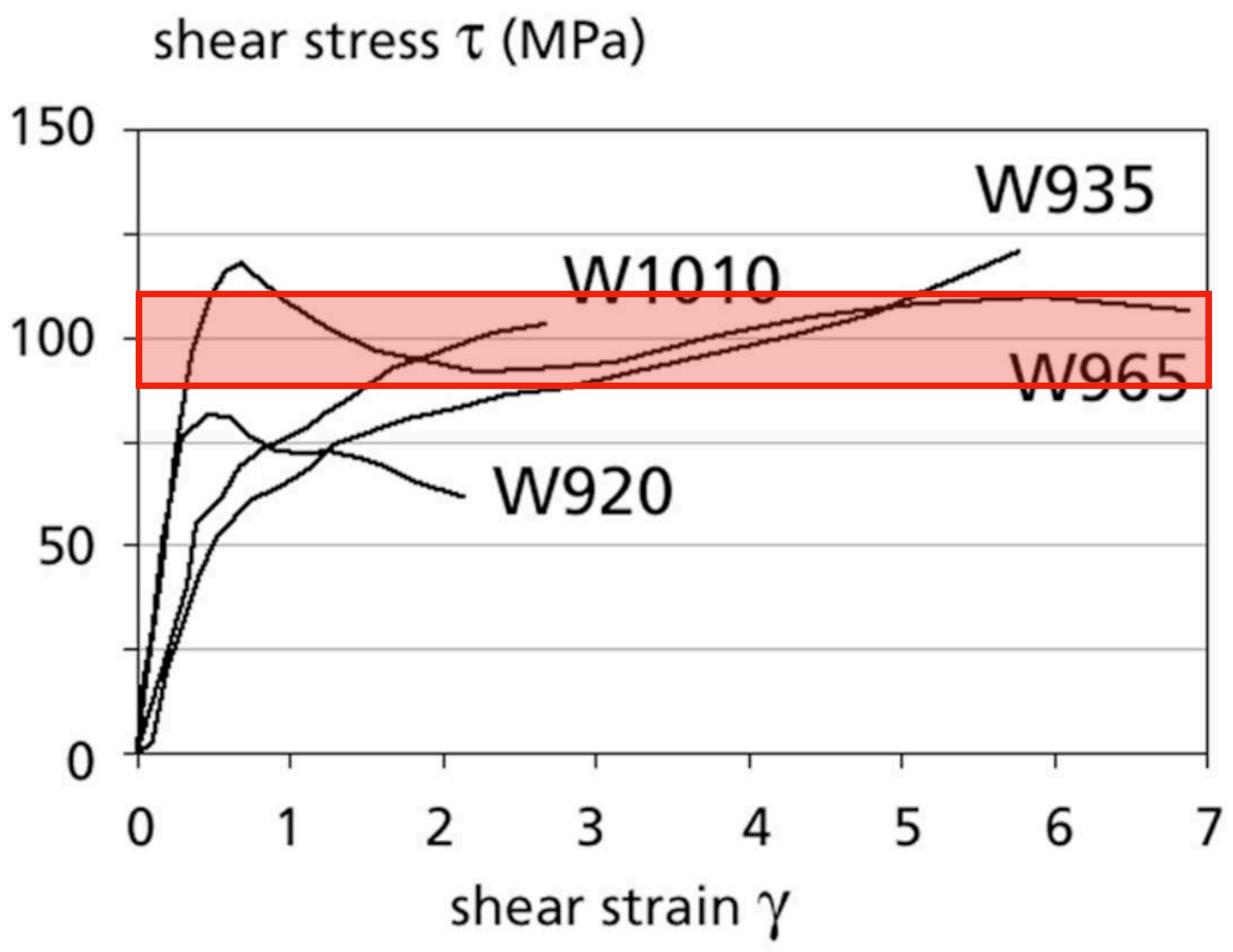


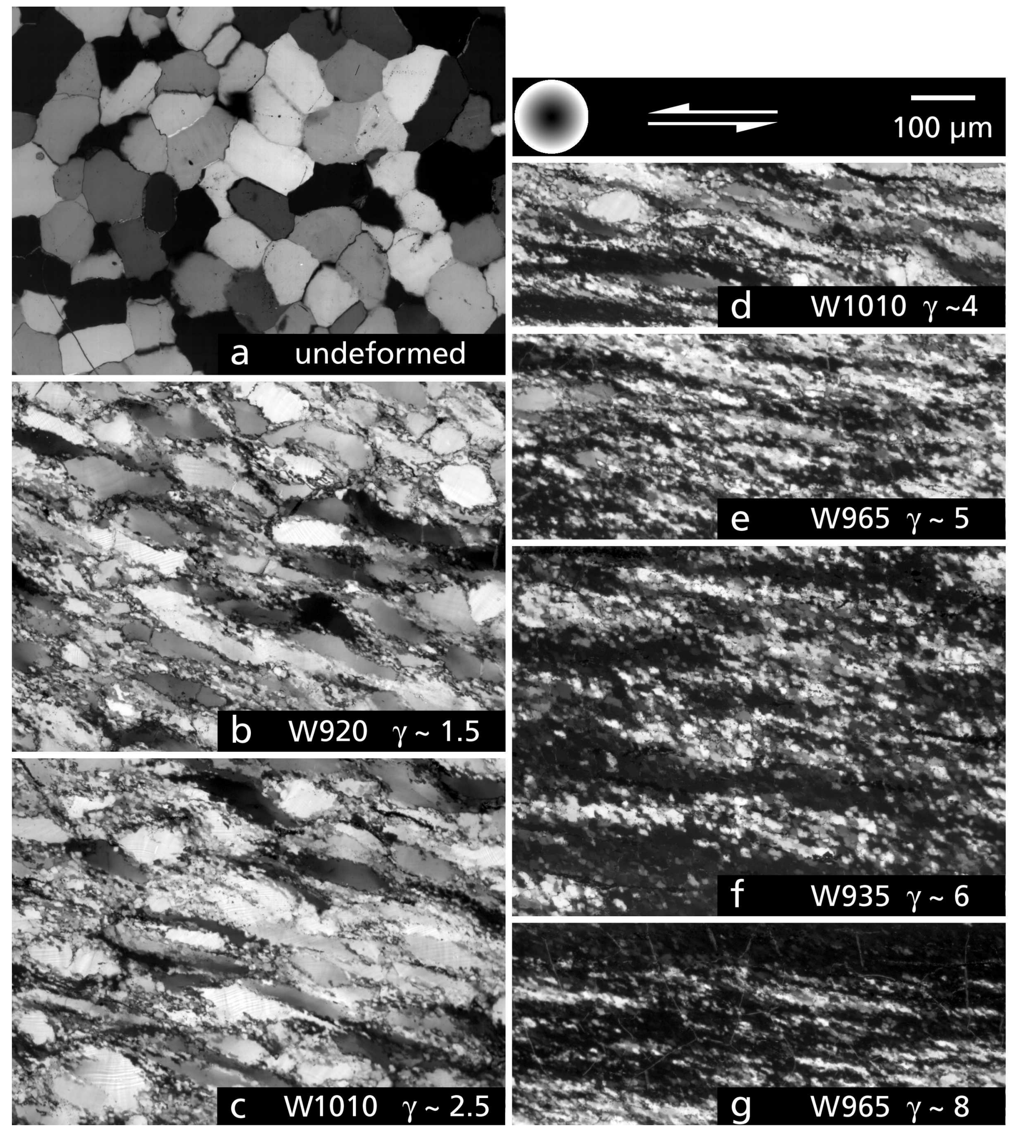
should have seen:
τ (Δσ/2) of shearing experiments
≈ Δσ of coaxial experiments
should have guessed:
shearing exp. reg.3→1 show lower
Δσ-gradient than coaxial exp.

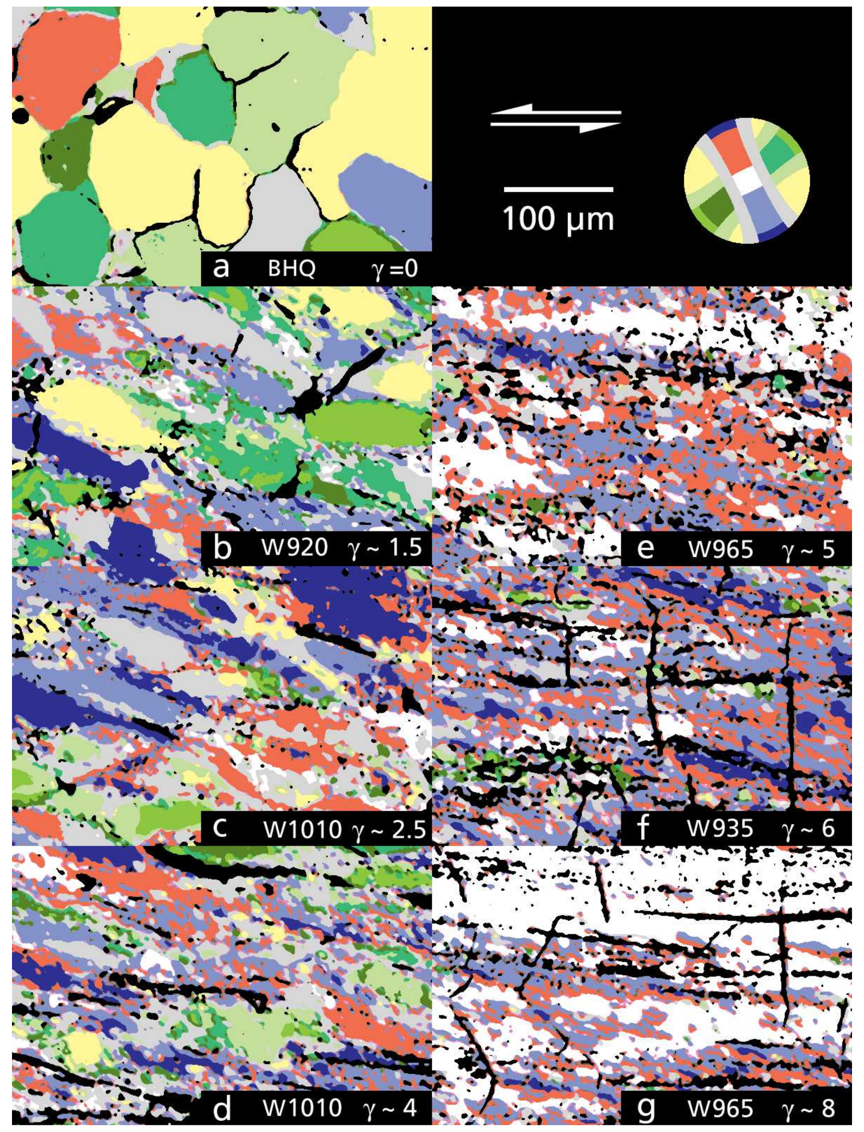
regime	coaxial Δσ (MPa)	shearing Δσ (MPa)
1	650	510
2	310	420
3	180	210

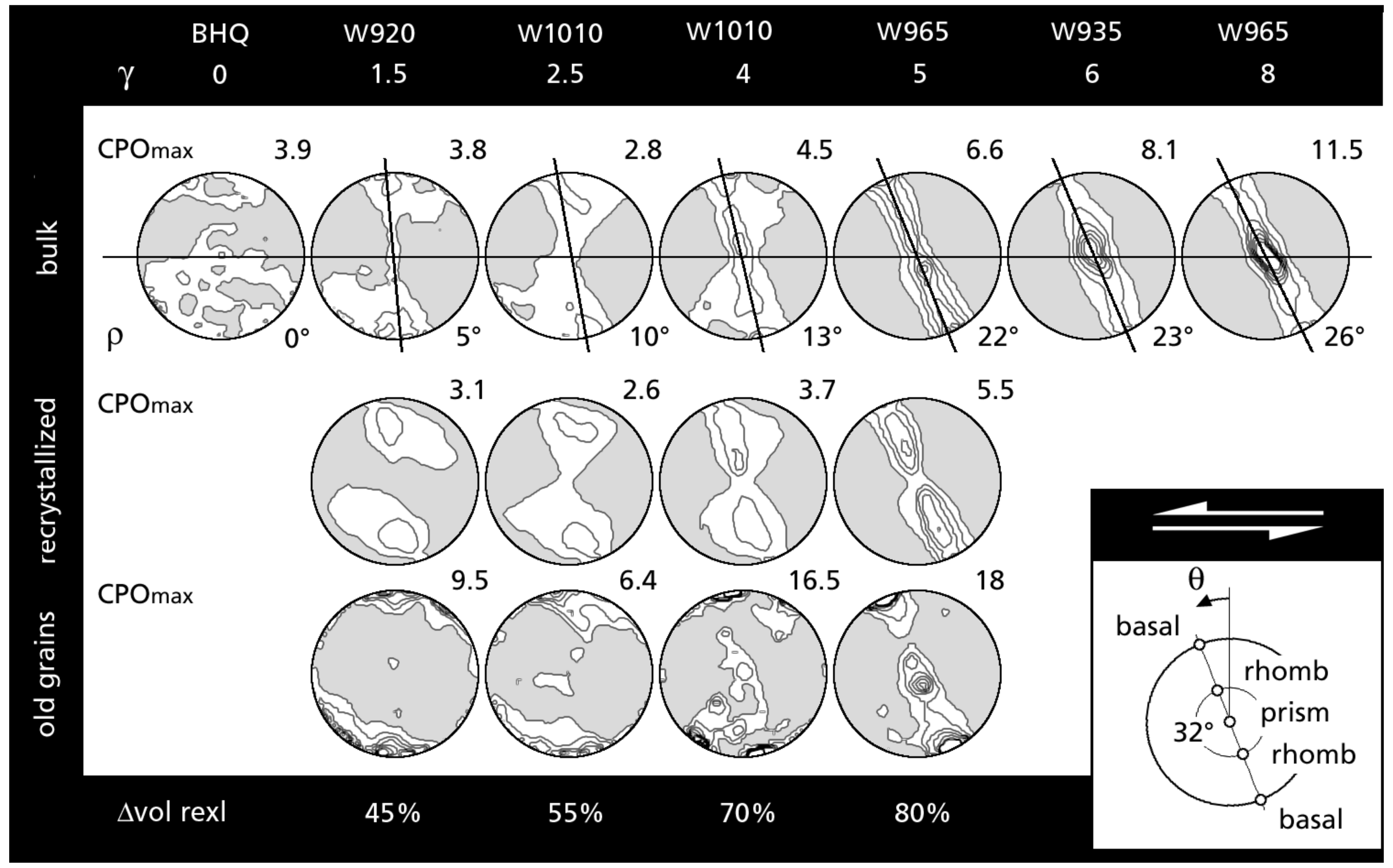


what we could have learned in 2006 ...









recrystallized grain size on average is ~17μm	~~corresponding shear stress 71 MPa~~

$\Delta\sigma_{piezo}$ = 71 MPa

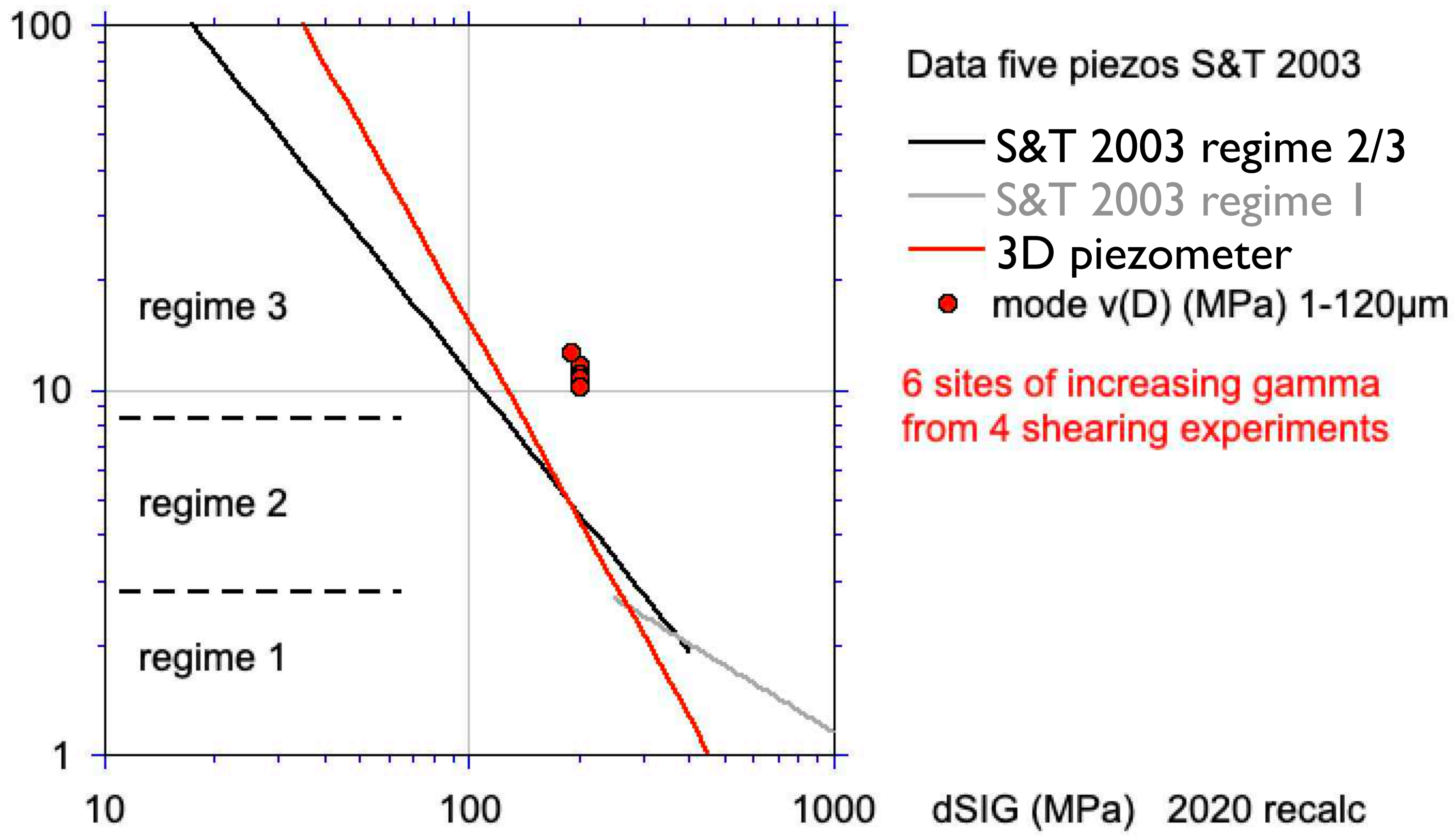
$\Longrightarrow \tau_{piezo}$ = 35 MPa

average measured shear stress was 100 MPa

$\Delta\sigma_{meas} \approx$ 200 MPa

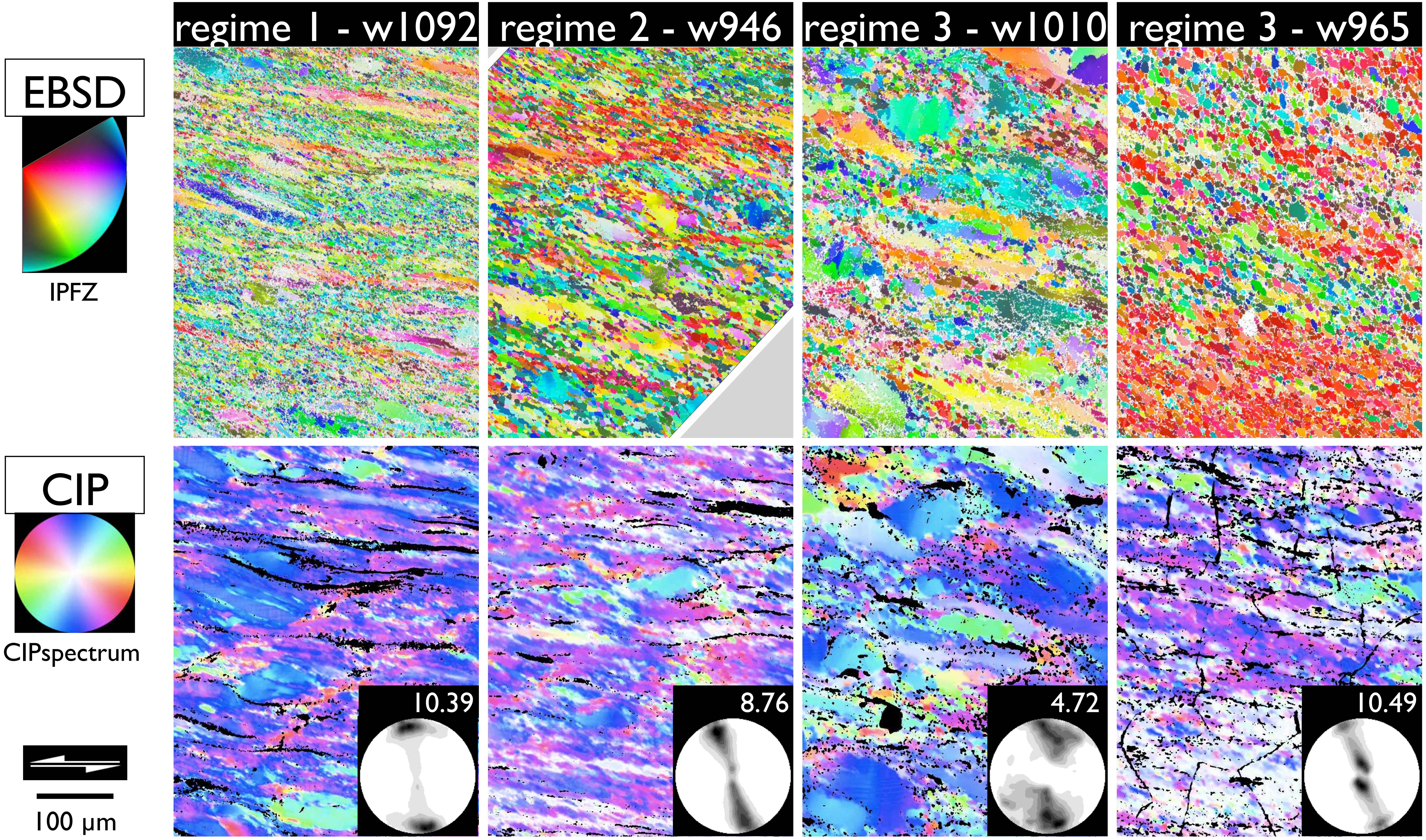
$\Longleftarrow \tau_{meas} \approx$ 100 MPa

- the difference between stress values is <u>not</u> "reasonable"

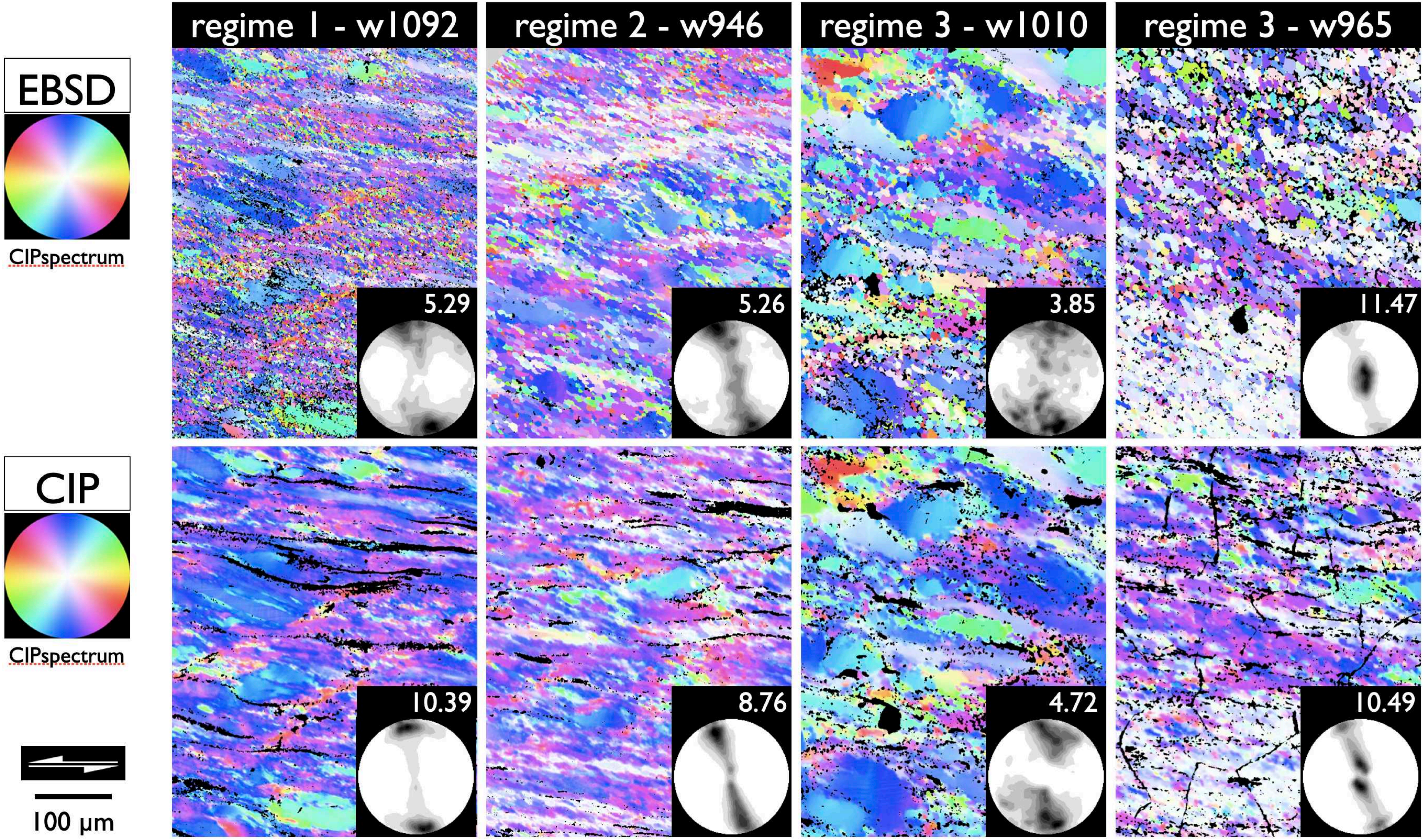


- solid medium shear samples are significantly stronger than molten salt coaxial samples !!

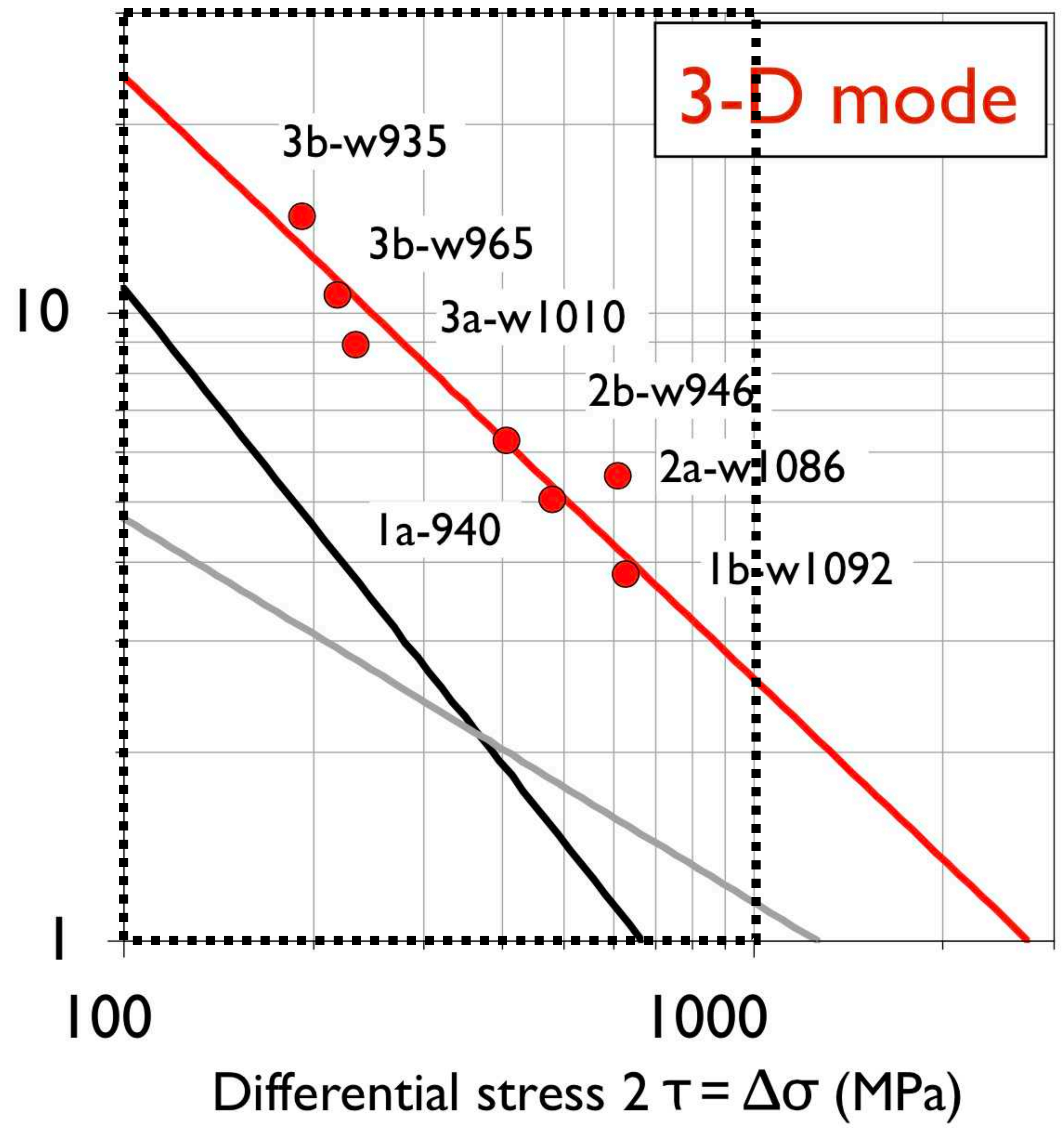
2017 old sample at high resolution

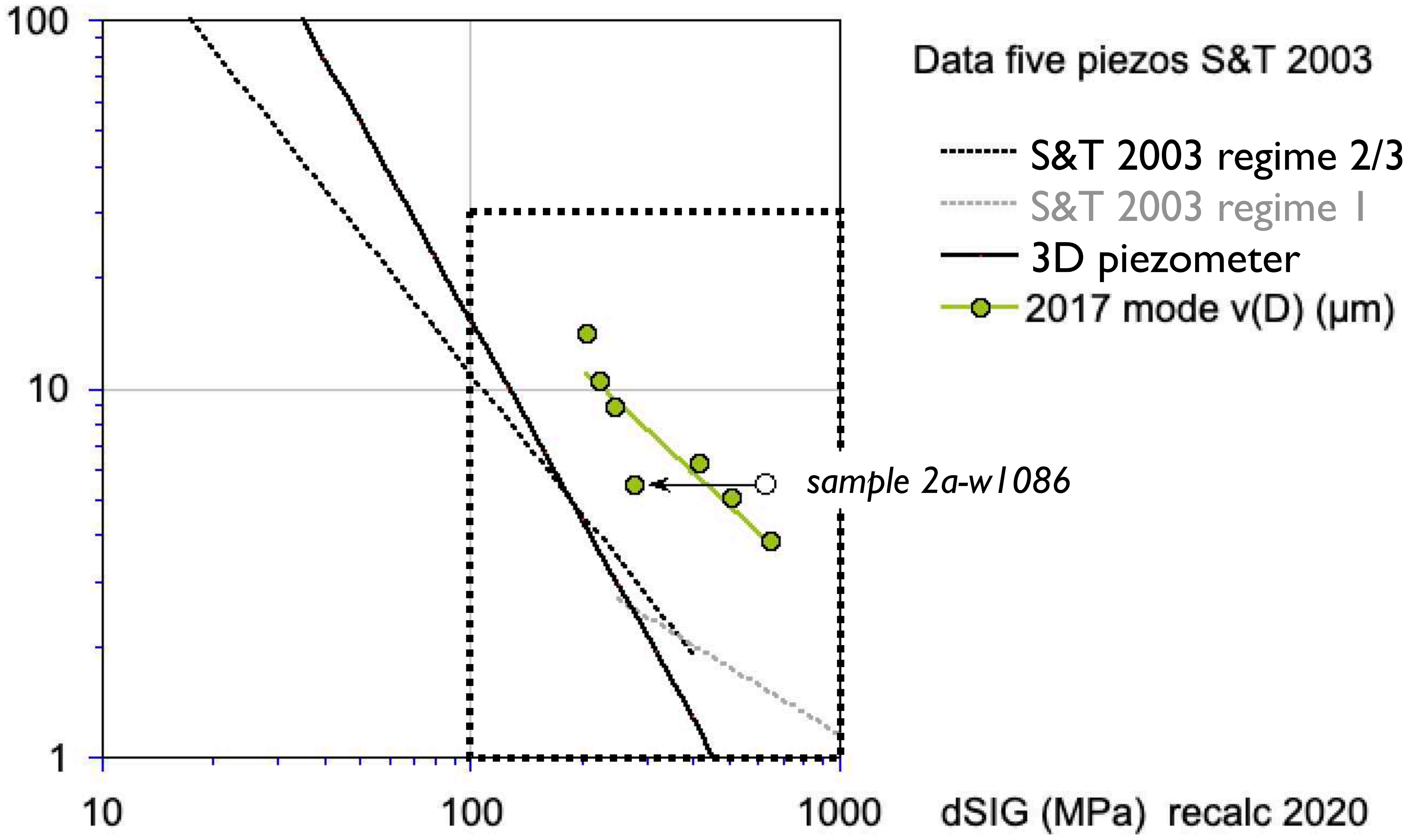


CIP maps from EBSD



run records redone – Δσ recalculated

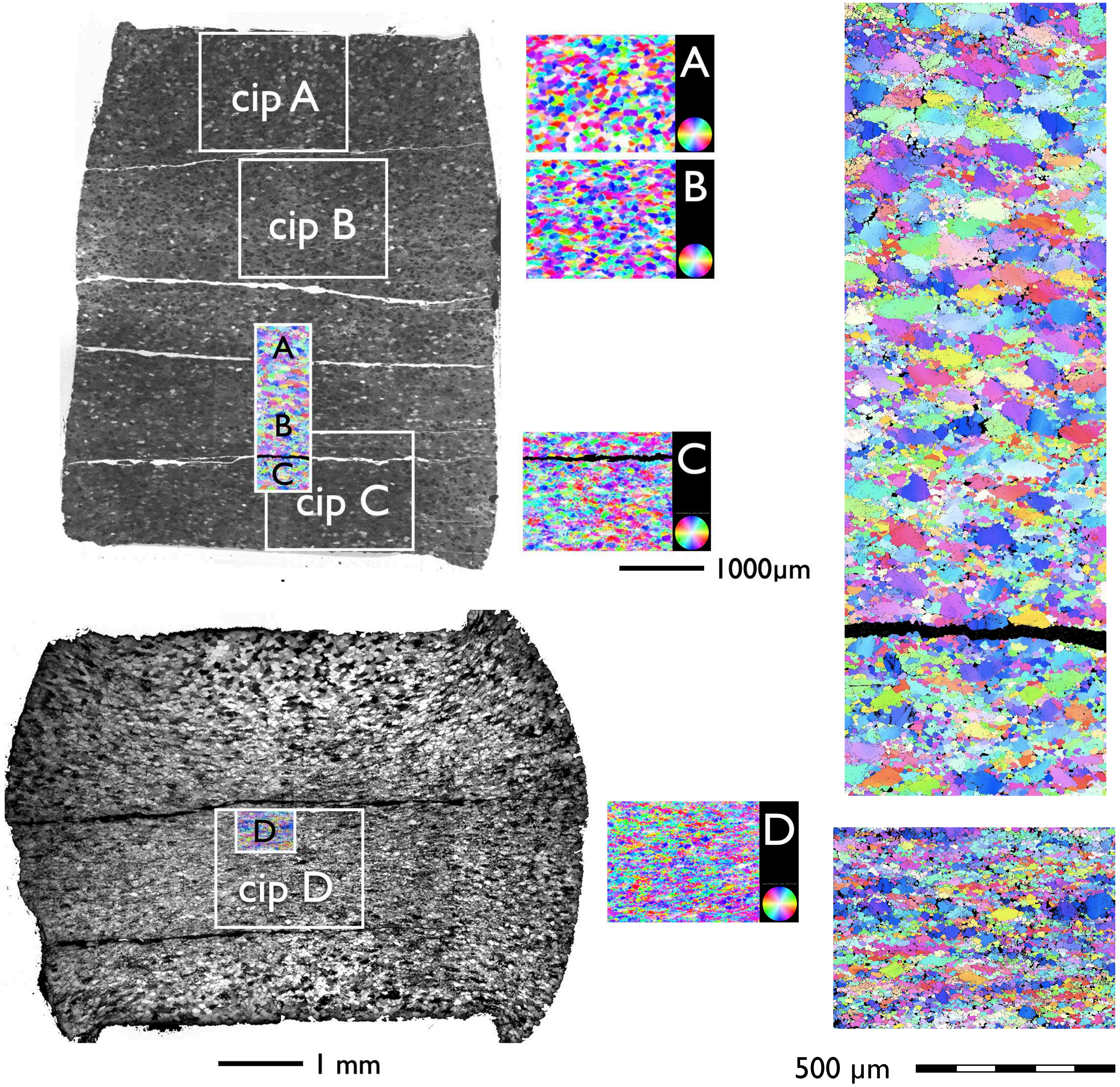




2020 recalculated Δσ yield similar result
except for sample 2a-w1086 (wrong run record)

should we worry about spatial resolution?

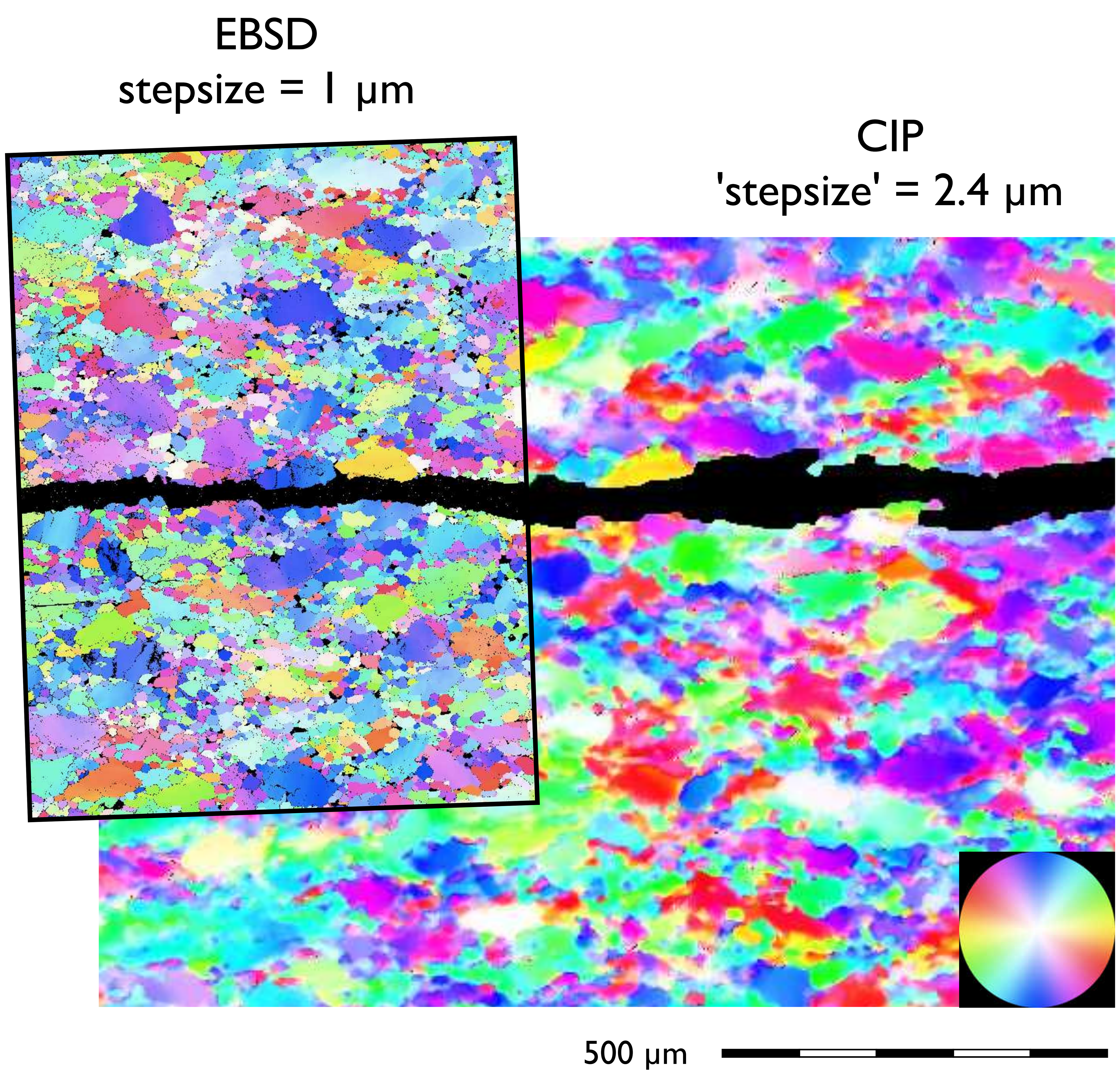
sometimes lucky EBSD map of previous CIP



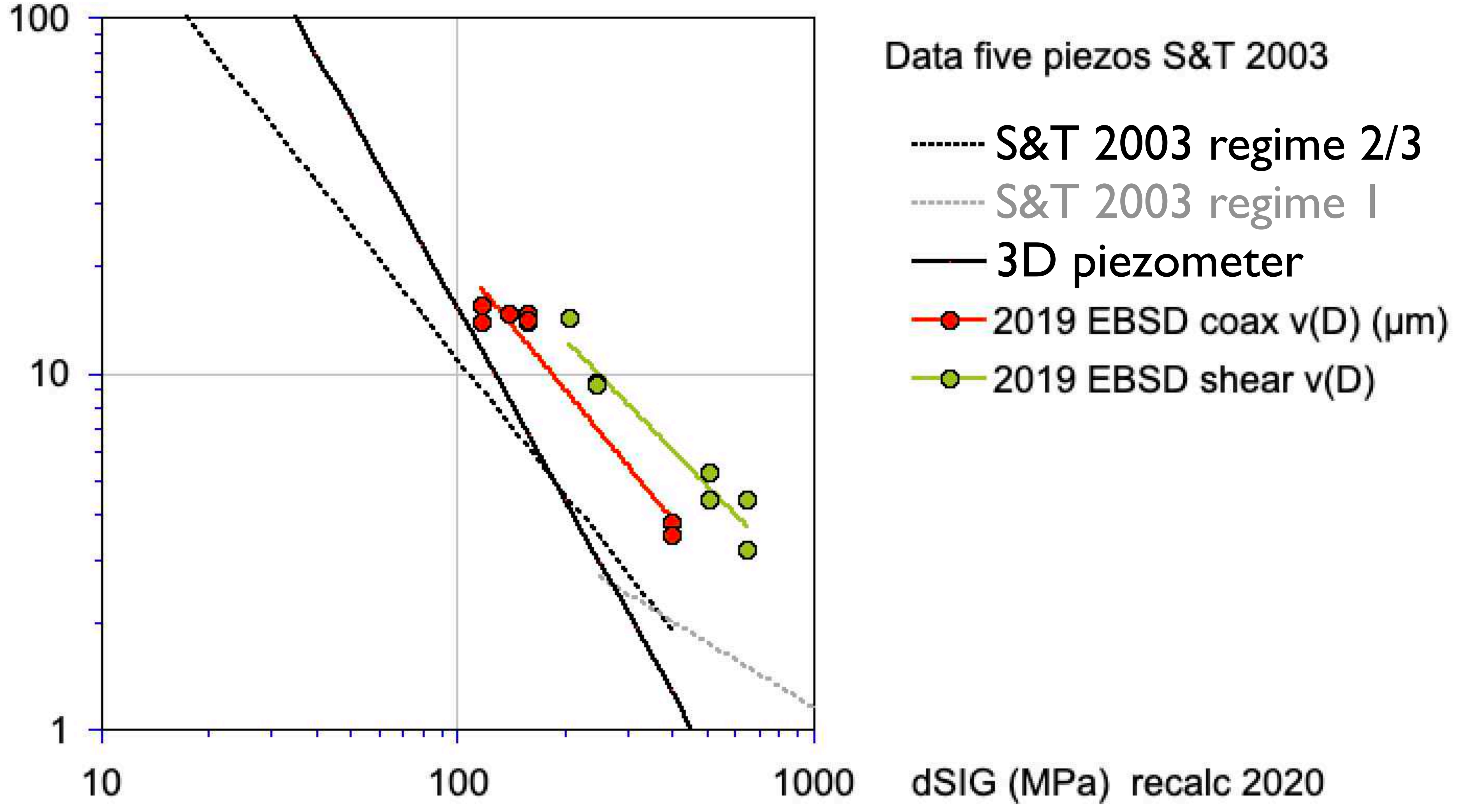
method	stepsize (µm)	3D grain size (µm) site C	siteD
CIP	2.64	18	19
EBSD	0.5	16	15

high resolution decreses grain size
⟹ steeper piezometer

coaxial and shear at EBSD resolution



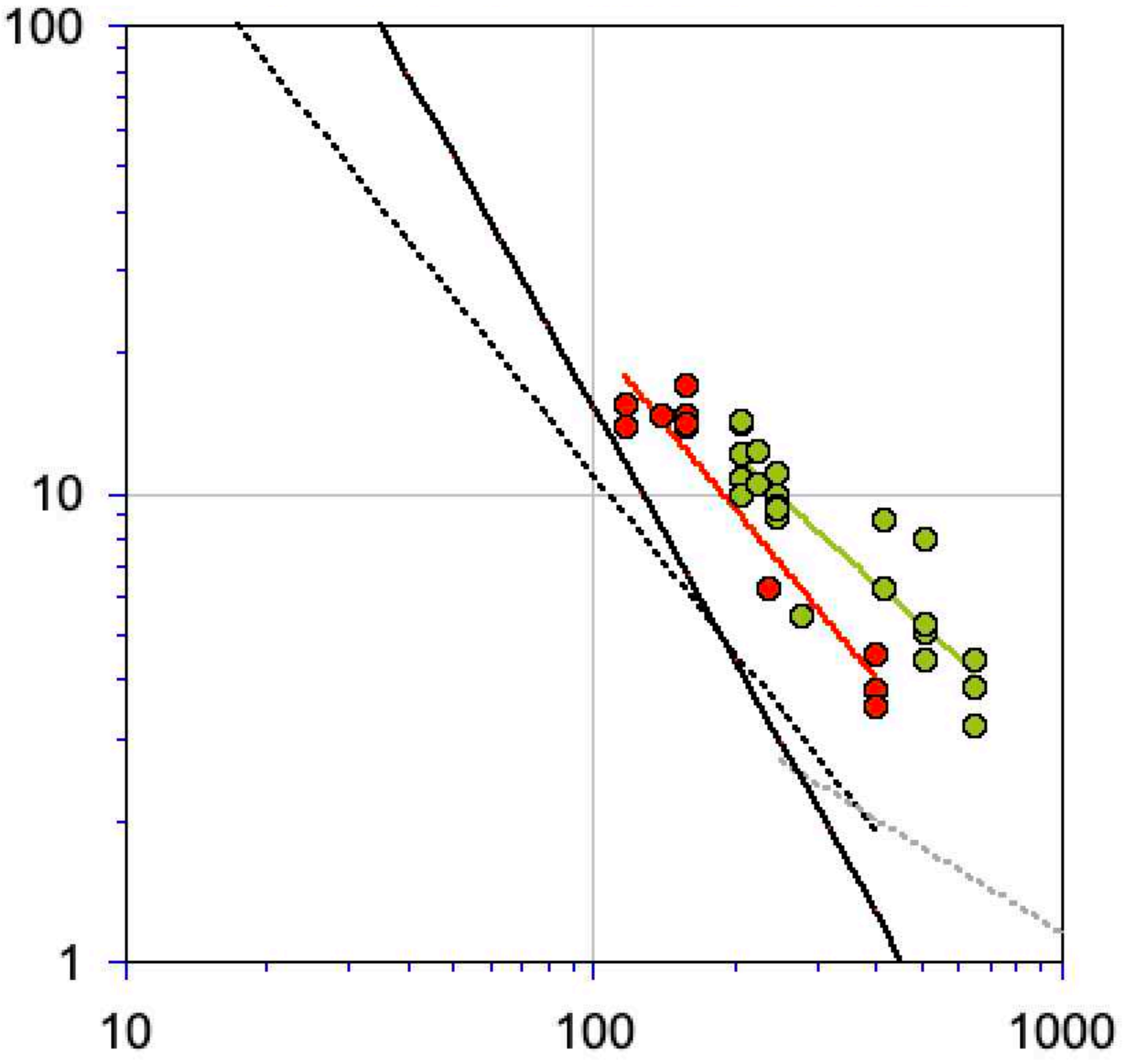
high resolution data only



high resolution: two piezometers
one each (coaxial and shearing) for all regimes

putting it alltogether

all best data



$d = 3631 \cdot \Delta\sigma^{(-1.26)}$

$d = 78 \cdot \Delta\sigma^{(-0.61)}$

$D = 58060 \cdot \Delta\sigma^{(1.79)}$

$D_{axial} = 5529 \cdot \Delta\sigma^{(-1.21)}$

$D_{shear} = 1435 \cdot \Delta\sigma^{(-0.90)}$

axial (solid medium) ≈ 2x S&D (MSC) piezometer
shear (solid medium) ≈ 2x axial piezometer

so what does it mean, Holger ?

... often enough I was more fascinated by the mere fact that I could quantify microstructures, shapes, distributions, correlations... and grain size, ...

... and often it was Holger who pointed out to me why any of that may actually be interesting

we tried early to get our daughter
interested in rocks – no luck !

maybe a better chance with the next generation ?