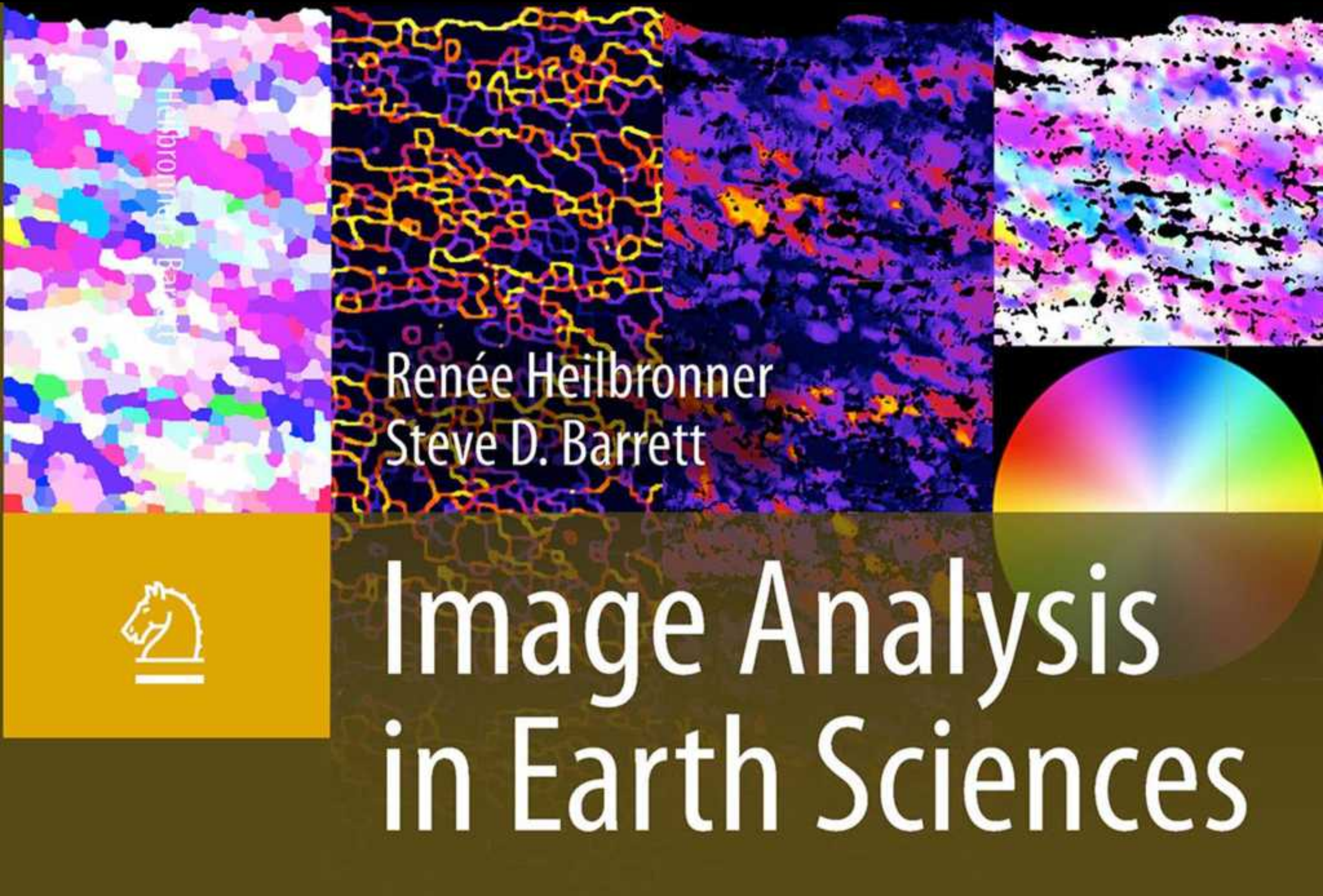
DRT 2015 Aachen, September 9-11, 2015



25 minutes stroll through the book...

... by way of two examples

1. Black Hills Quartzite revisited
   with Jan Tullis

2. Work in progress:
   The microstructure of 70:30 olivine-orthopyroxene mixtures
   experimentally deformed at 1200°C
   with Miki Tasaka

and a take-home message
and an announcement
and ... somebody has to turn off the microphone

the publication

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, B10202, doi:10.1029/2005JB004194, 2006

Click Here for Full Article

Evolution of c axis pole figures and grain size during dynamic recrystallization: Results from experimentally sheared quartzite

Renée Heilbronner[1] and Jan Tullis[2]

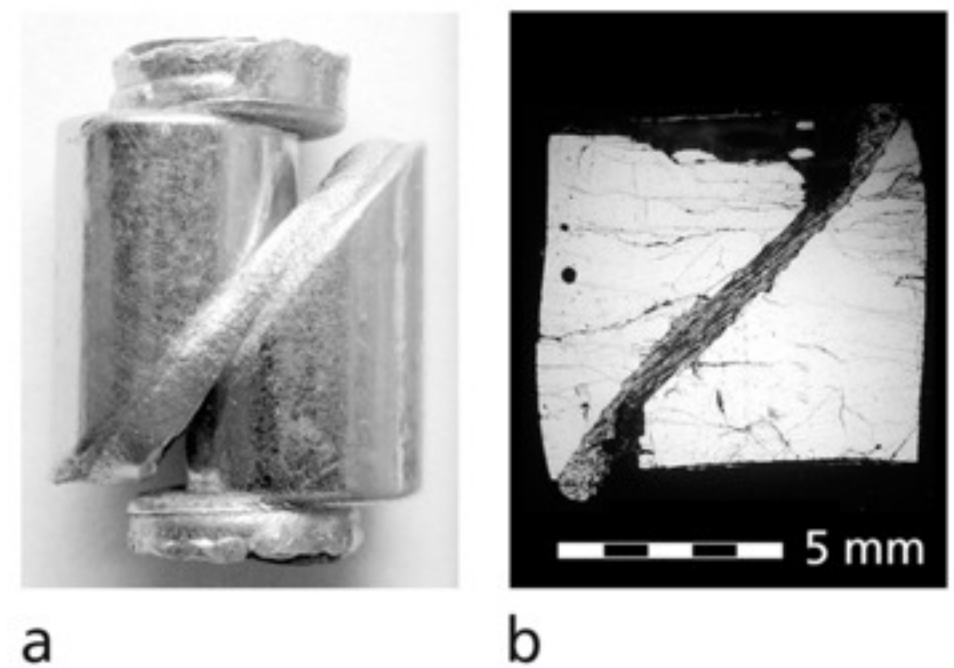


Figure 1. Geometry of experimentally sheared Black Hills quartzite samples. (a) Jacketed sample after general shear deformation: BHQ sheared between 45° precut Brazil quartz pistons (total undeformed length ≈ 15 mm, diameter = 6.3 mm), which are able to slide horizontally relative to the upper and lower ZrO_2 pistons. (b) Thin section of sheared BHQ sample and Brazil quartz pistons under circularly polarized light. Horizontal cracks in the pistons result from unloading.

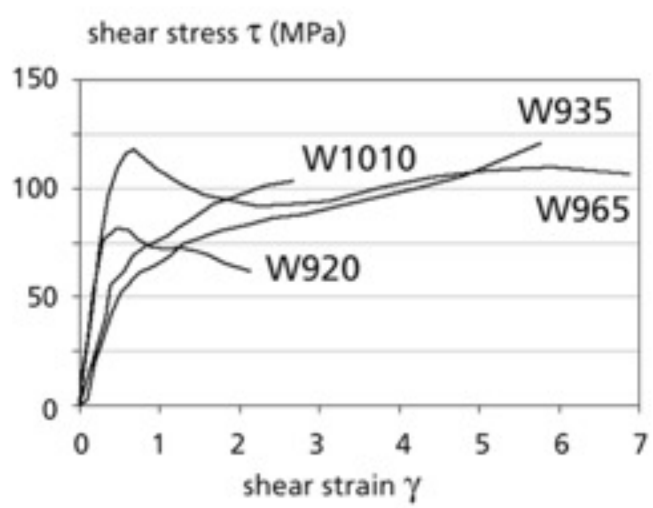
results

experimental conditions:

$T = 915°C$
$p_c = 1.5$ GPa
$\dot{\gamma} = 2 \cdot 10^{-5}\ s^{-1}$

(~ regime 3)

shear stresses:

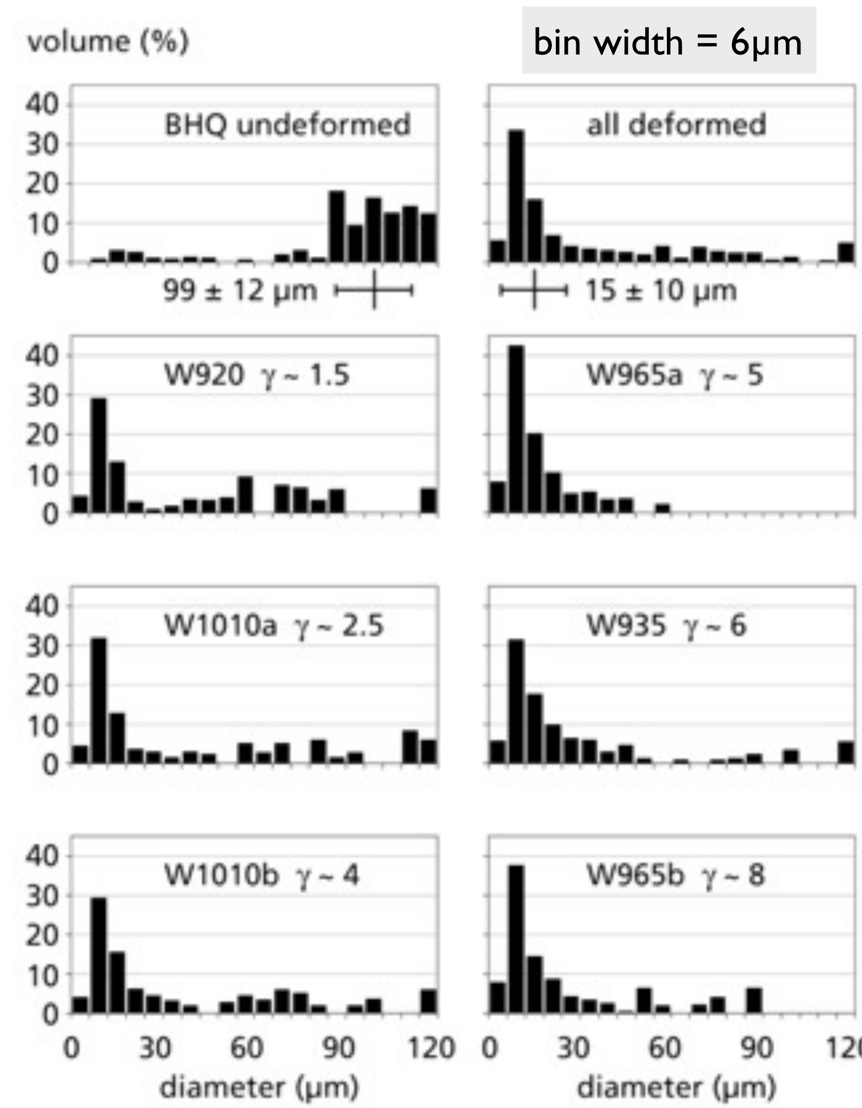


$\tau \approx 100$ MPa
$\Delta\sigma \approx 200$ MPa

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

(Heilbronner & Tullis, JGR, 2006)

3D grain size:



mode of recrystallized grain size (3D):
$D \approx 12$ μm

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.

why go back ?

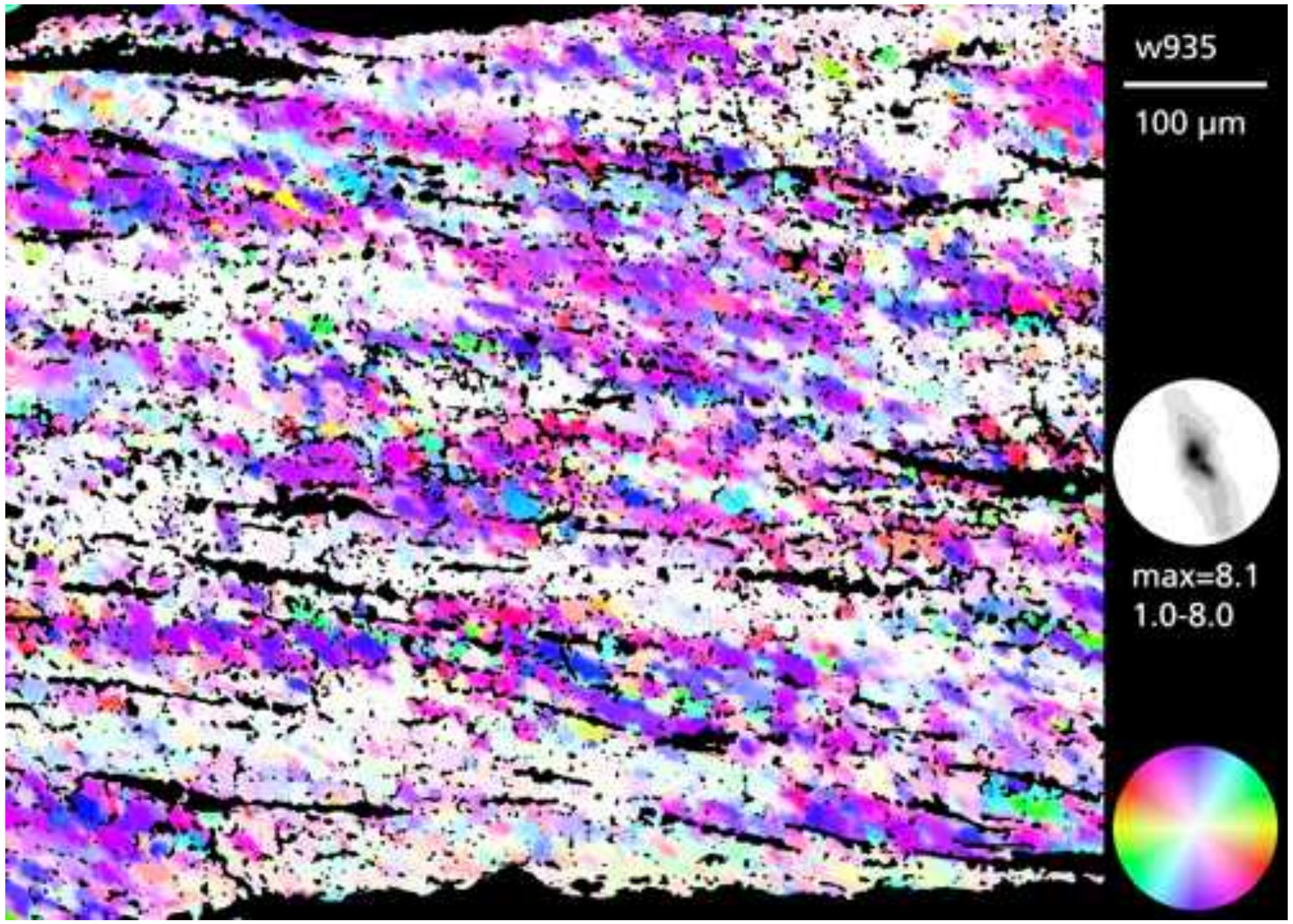
motivation:

re-measure CIP grain size using EBSD
analyze Betti's quartz - coesite experiments @ high resolution
verify Stipp & Tullis piezometer

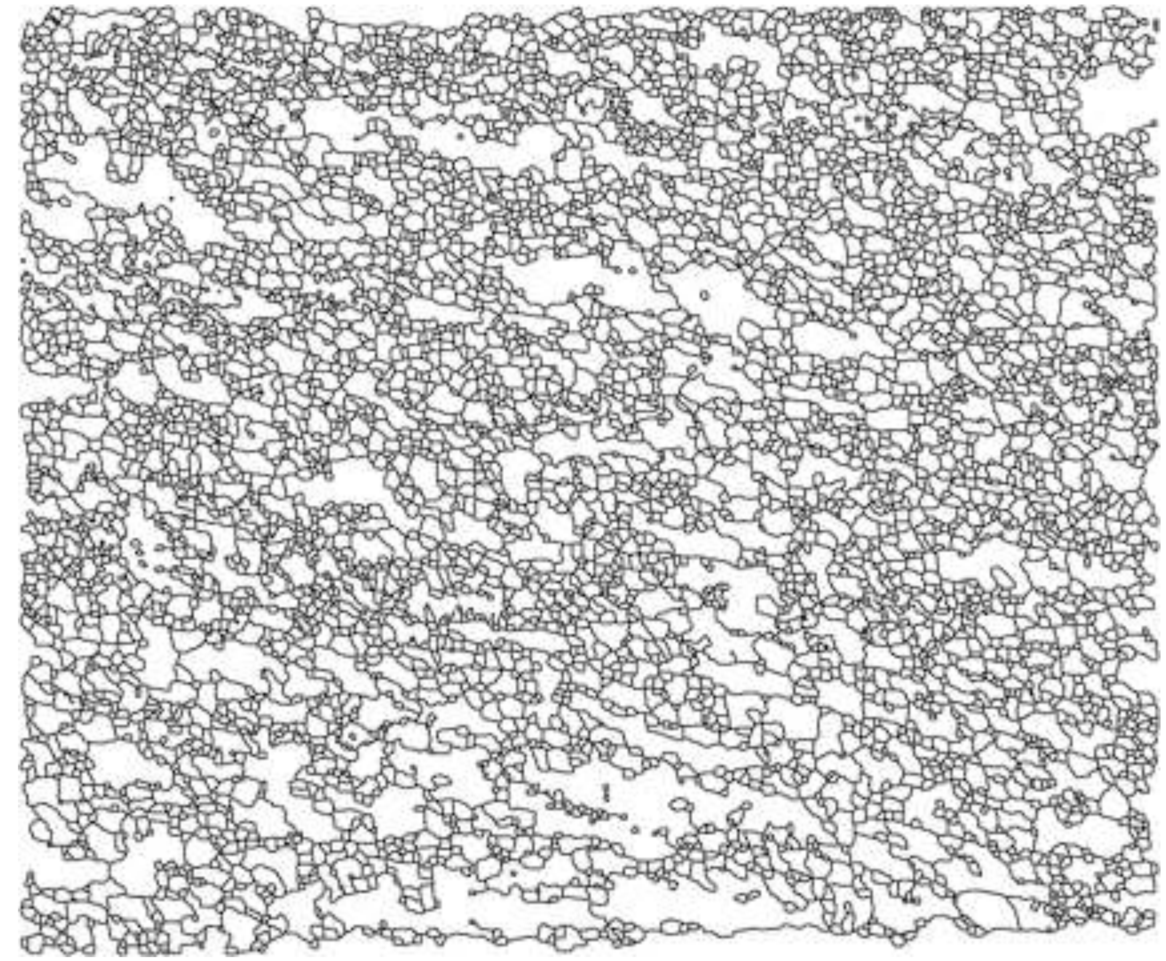
step 1: CIP vs EBSD grain size - rewrite STRIPSTAR
step 2: decide on "the mean grain size"
step 3: test piezometer
step 4: .... see Betti's poster and PhD

⇒ *reculer pour mieux sauter*

light microscopy - CIP



w935 c-axis orientation image (COI)

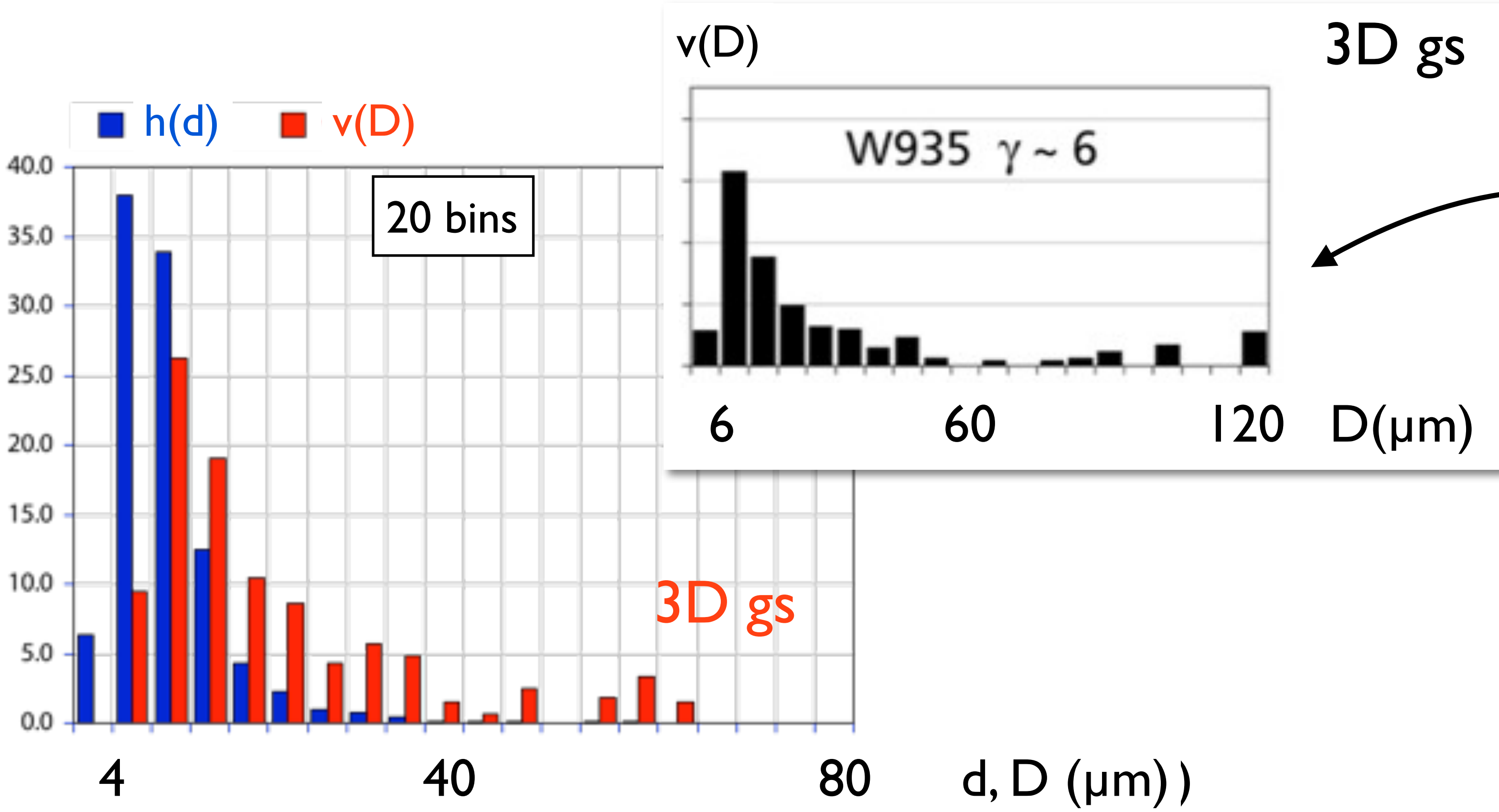


w 935 grain boundary map

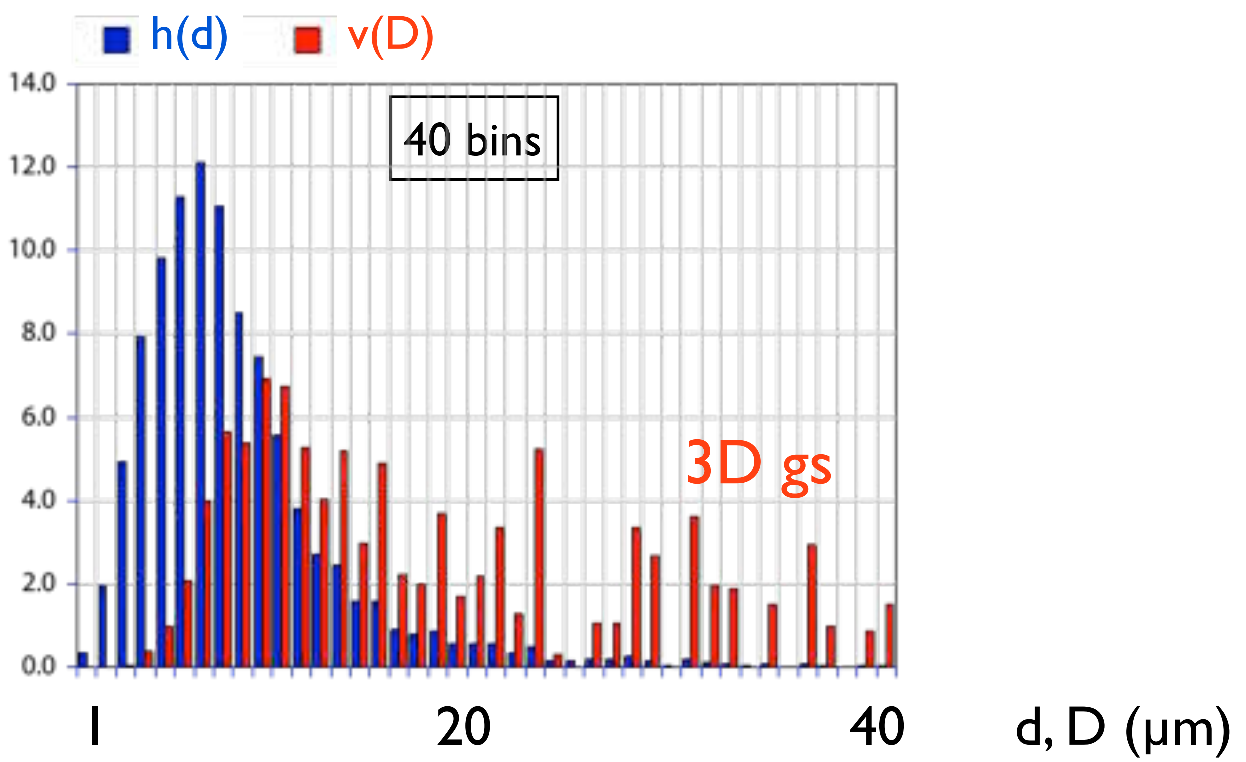
for segmentation, see many chapters in:
Heilbronner & Barrett, Springer (2014)

⇒ *segmentation is a pain*

CIP grain size at higher resolution



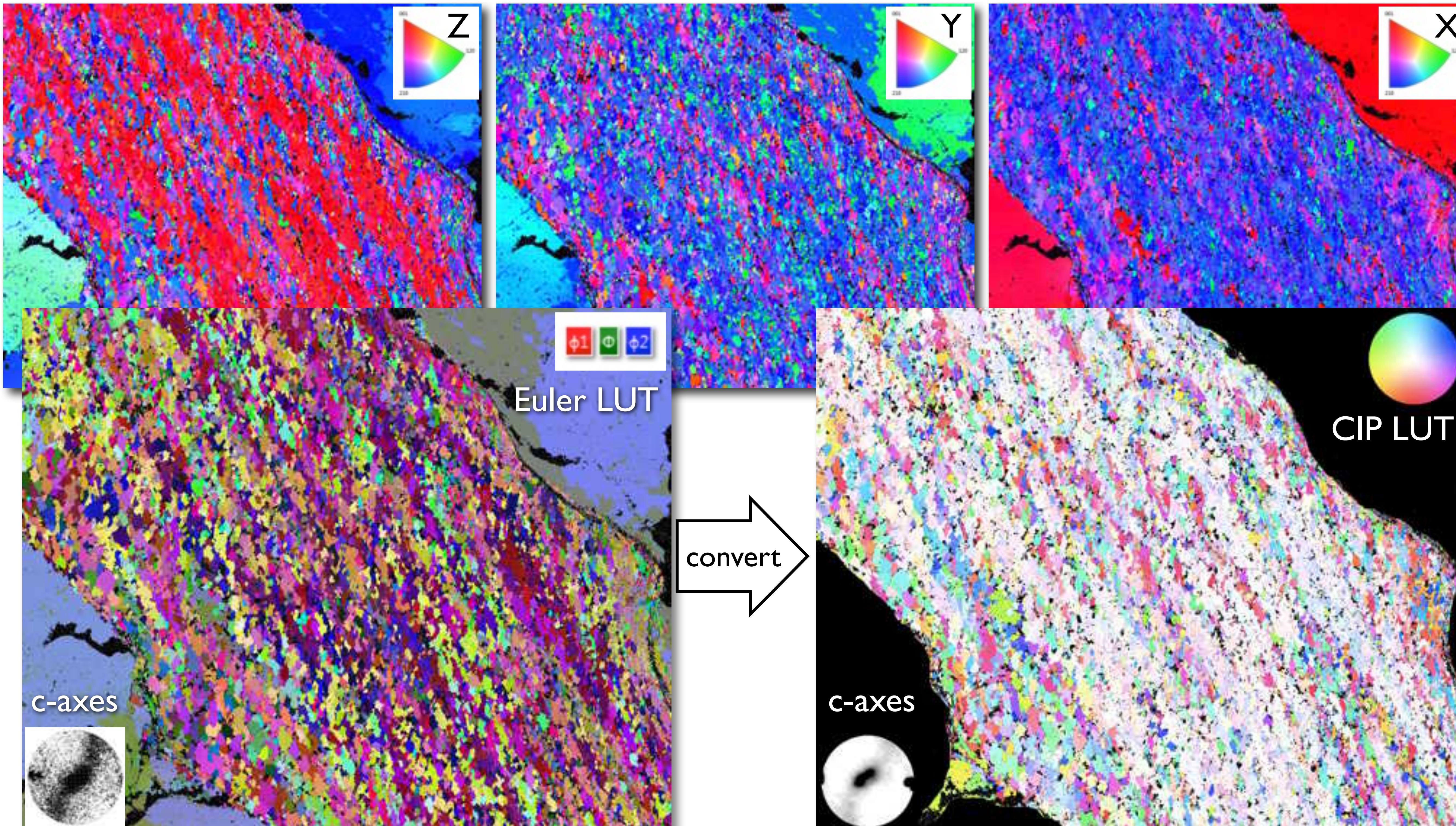
	d(µm)	D(µm³)
Mode		bin(6-12)
Mode	bin(4-8)	bin(8-12)



	d(µm)	D(µm³)
Mean	9.7	
RMS	11.4	
Mode	bin(6-7)	bin(9-10)

⇒ *new STRIPSTAR = improvement*

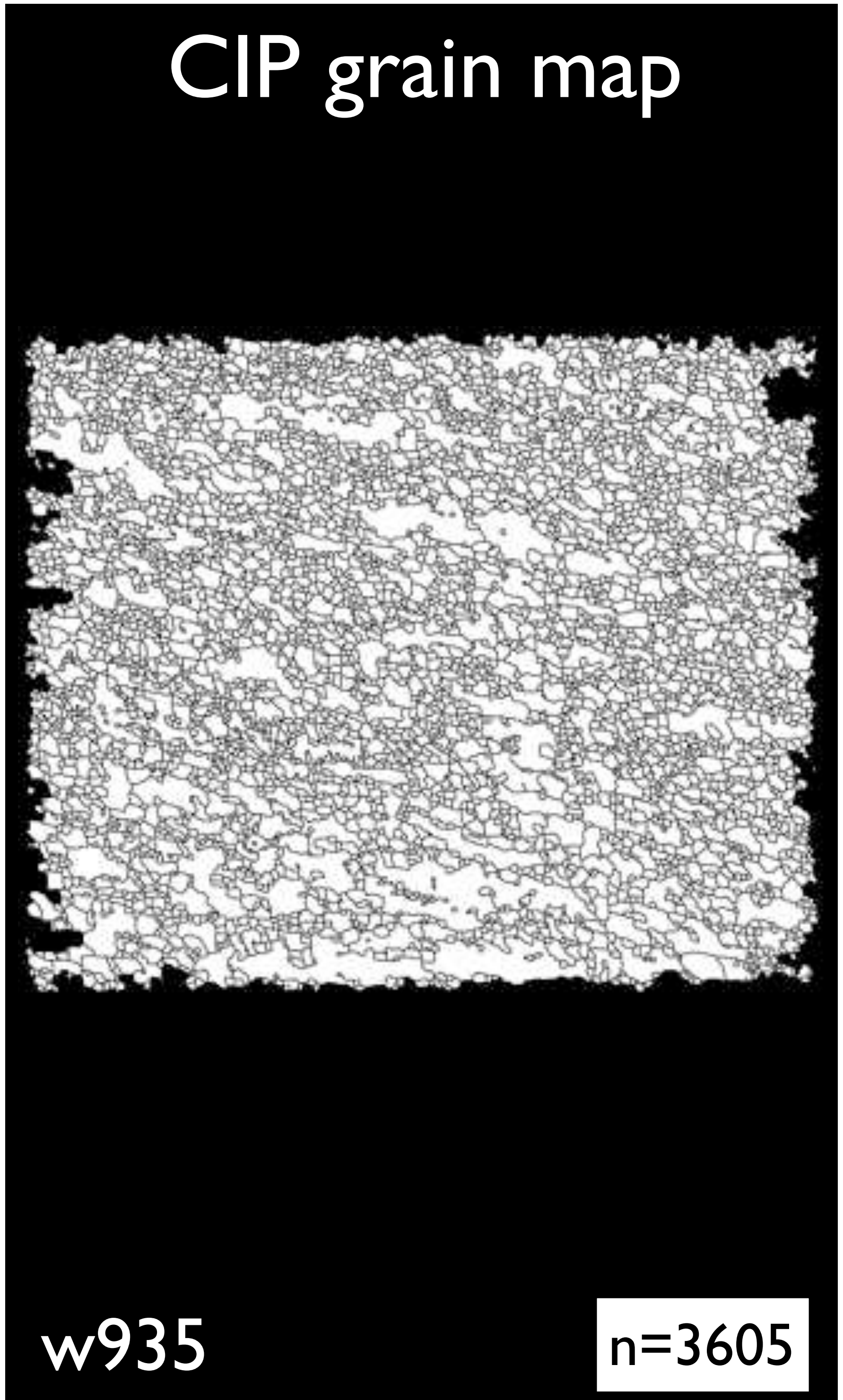
EBSD map of same sample

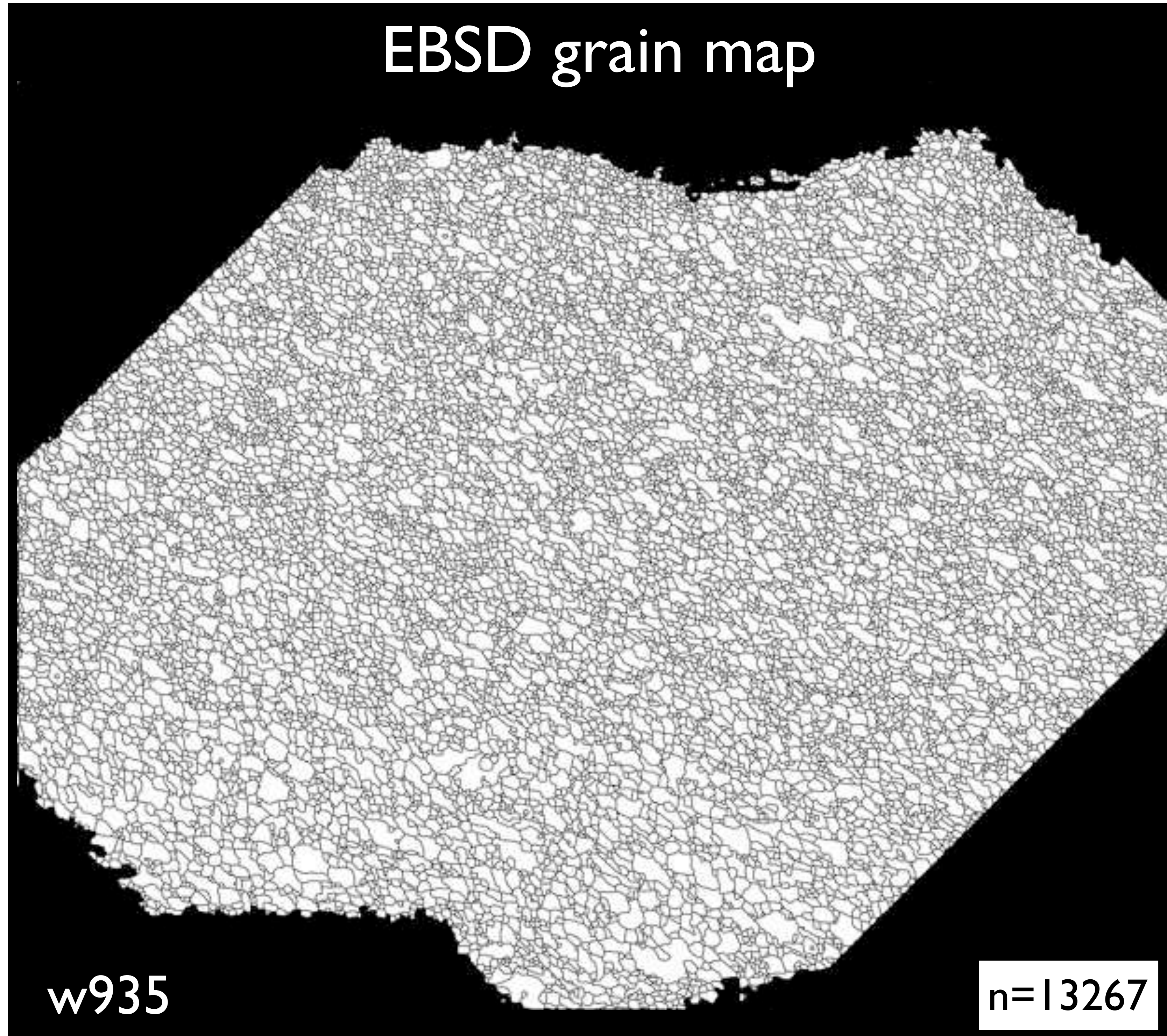


(Heilbronner & Barrett, Springer, 2014)

⇒ *use c-axis orientation for visualization*

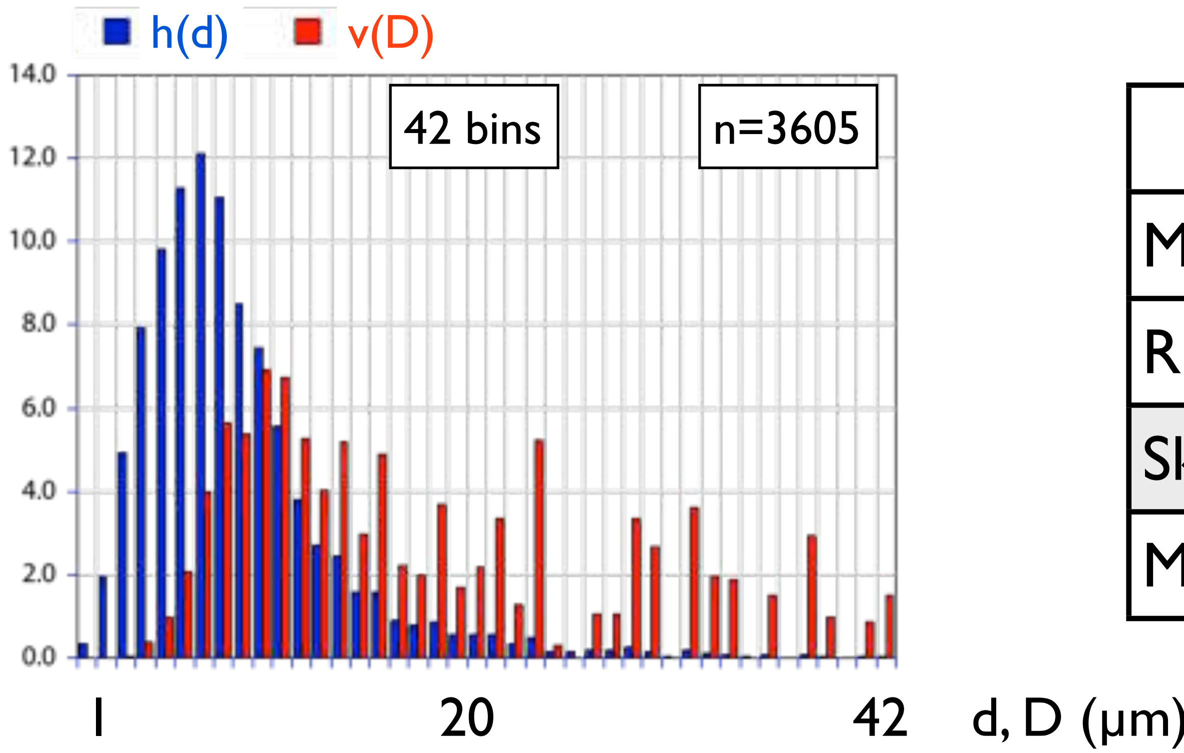
grain maps CIP and EBSD





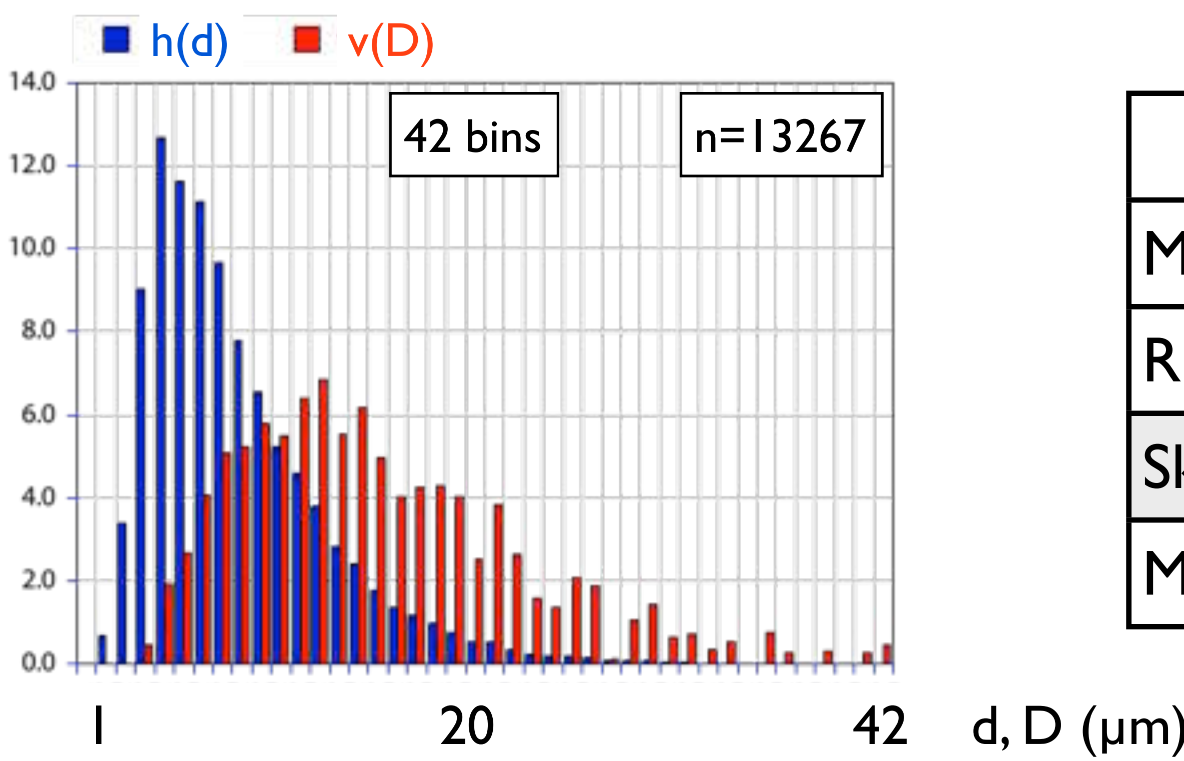
⇒ *segmentation is easy*

grain size from LM and SEM



CIP

	d(μm)	D(μm)	D(μm³)
Mean	9.721	8.075	17.907
RMS	11.353		
Skewness	2.013	2.385	0.727
Mode	bin(6-7)		bin(9-10)



EBSD

	d(μm)	D(μm)	D(μm³)
Mean	8.291	7.915	15.357
RMS	9.502		
Skewness	1.509	1.774	0.930
Mode	bin(4-5)		bin(12-13)

$\Rightarrow$ *CIP grain size = EBSD grain size*

finding the right mean...

arithmetic mean $\bar{X} = 1/n \cdot \sum x_i$

geometric mean $G = \sqrt[n]{\prod x_i}$

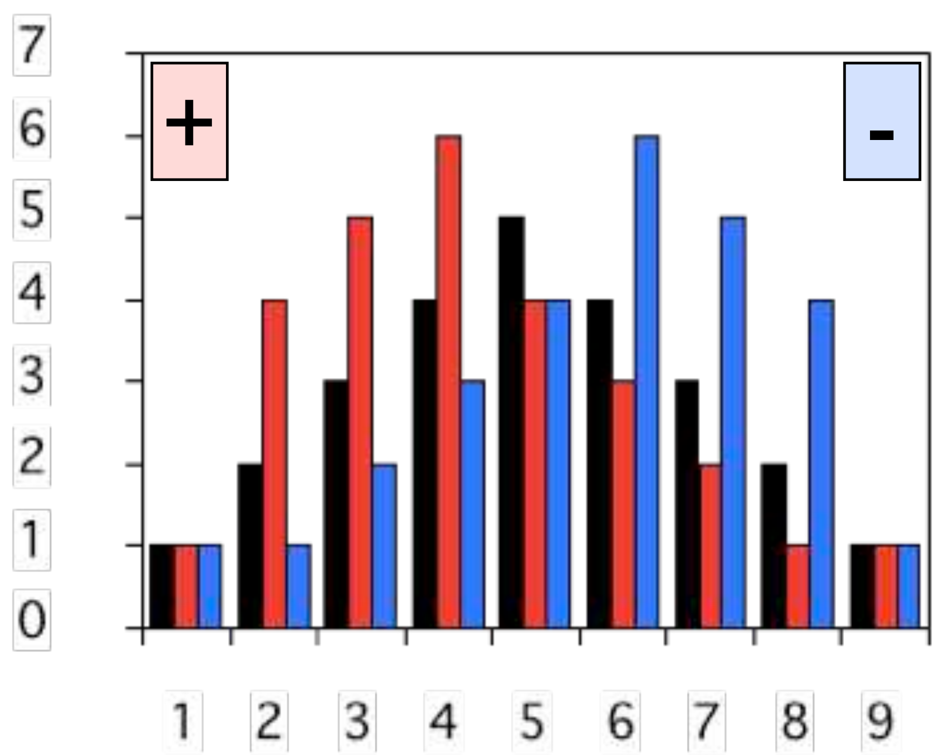
harmonic mean $H = 1 / (1/n \cdot \sum 1/x_i) = n / \sum 1/x_i$

root-mean-square $RMS = \sqrt{(1/n \cdot \sum x_i^2)} \approx$ area average

$$\text{Median} = \begin{cases} x_{(n+1)/2} & \text{if } n = \text{odd} \\ (x_{n/2} + x_{n/2+1}) / 2 & \text{if } n = \text{even} \end{cases}$$

Mode = most frequent value

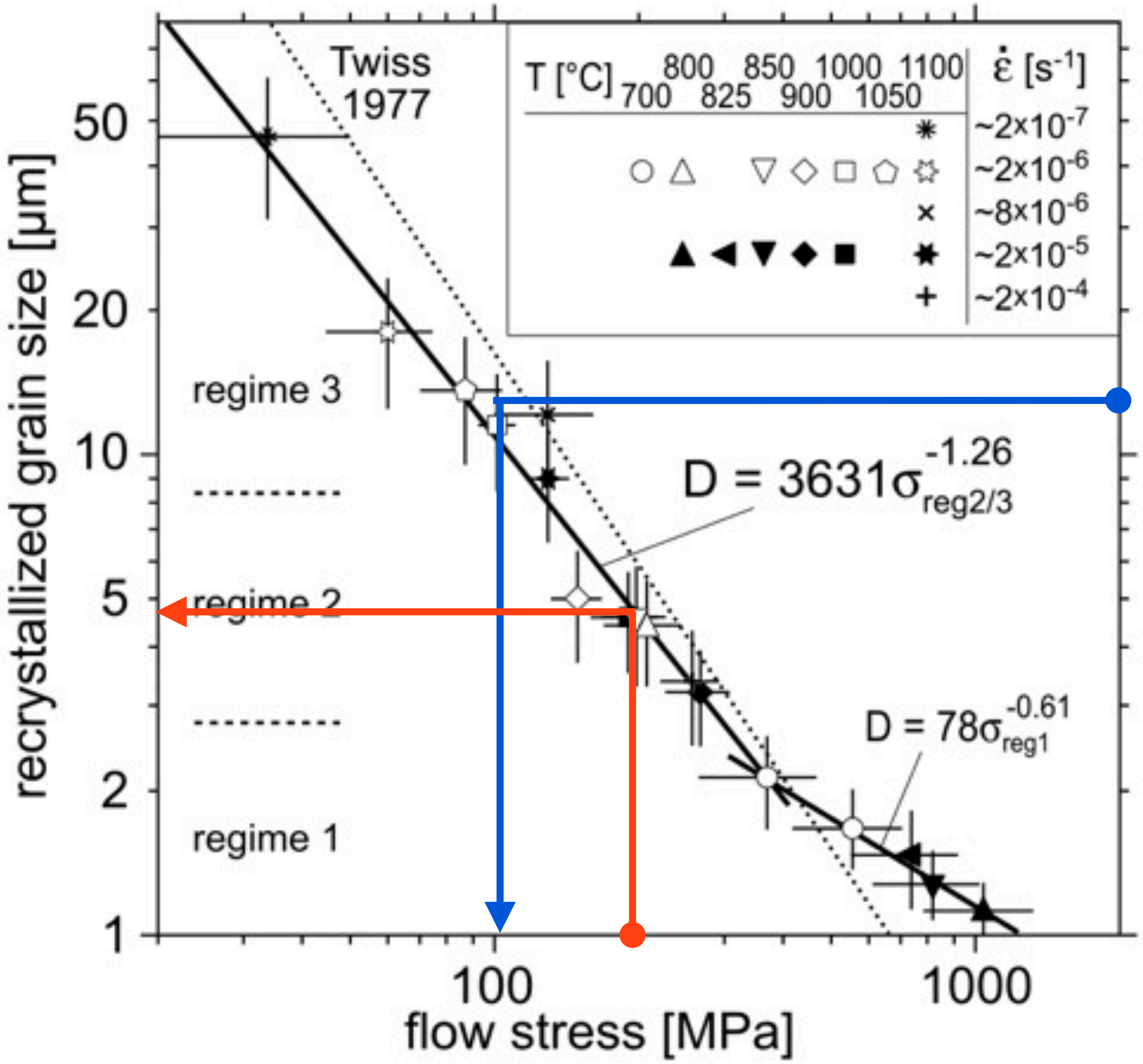
$$RMS > \bar{X} \geq G \geq H$$



	symm.	+ skew	- skew
$\bar{X}$	5.00	4.33	5.67
Mode	5.00	4.00	6.00
RMS	5.39	4.75	5.99
Skewness	0.00	0.53	-0.53
RMS/$\bar{X}$	**108%**	**110%**	**106%**

⇒ *RMS overestimates mean*

check the piezometer



$RMS(d) = 10^{(3.56\pm0.27)} \cdot \sigma^{-(1.26\pm0.13)}$

The diameter = diameter of a circle with he same area (d_{equ})

Measure for average 2-grain size = RMS of recrystallized grains

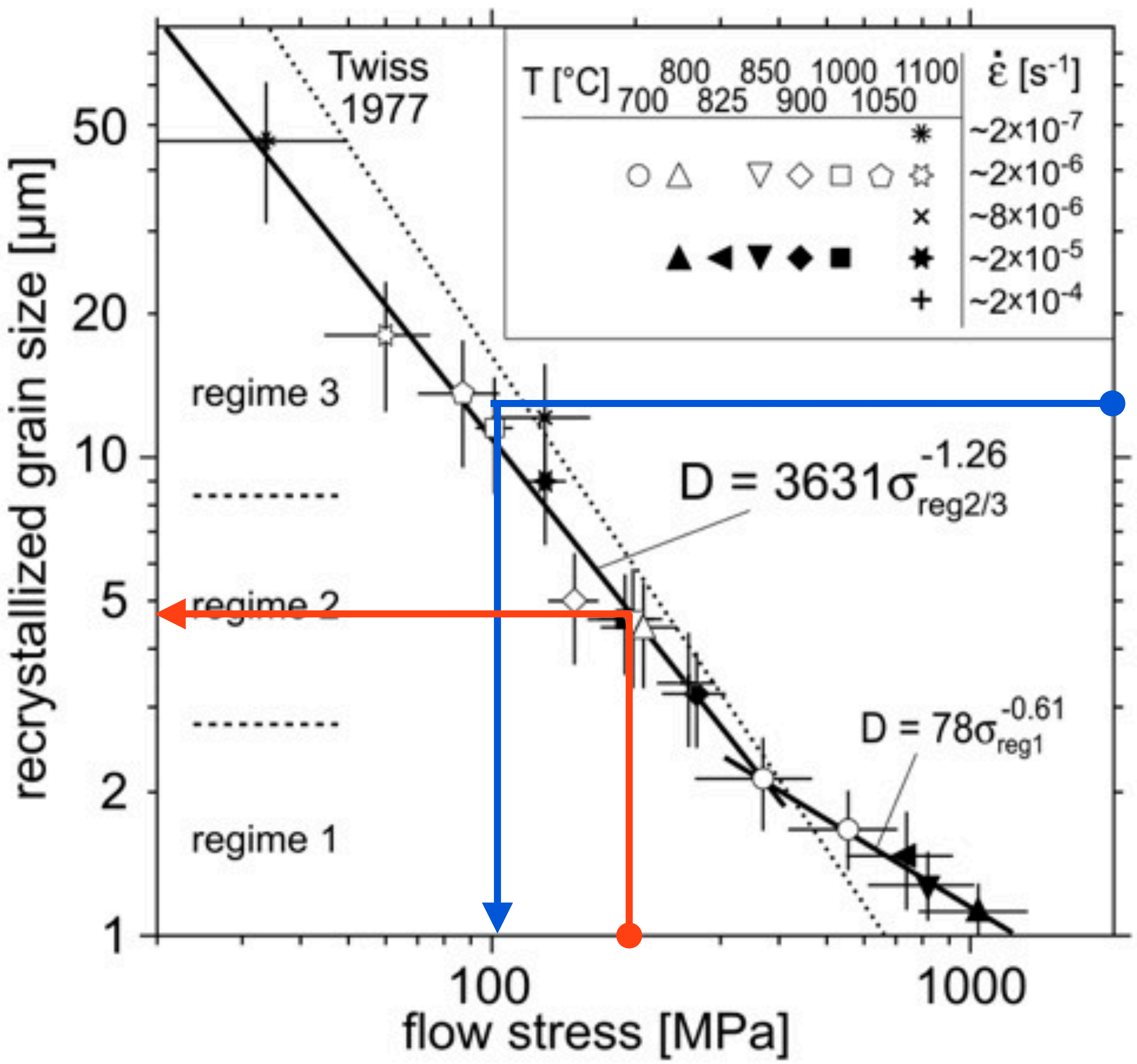
No stereological correction

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

(Stipp & Tullis, JGR, 2003)

⇒ *piezometer underestimates stress ... or underestimates grain size*

check the piezometer



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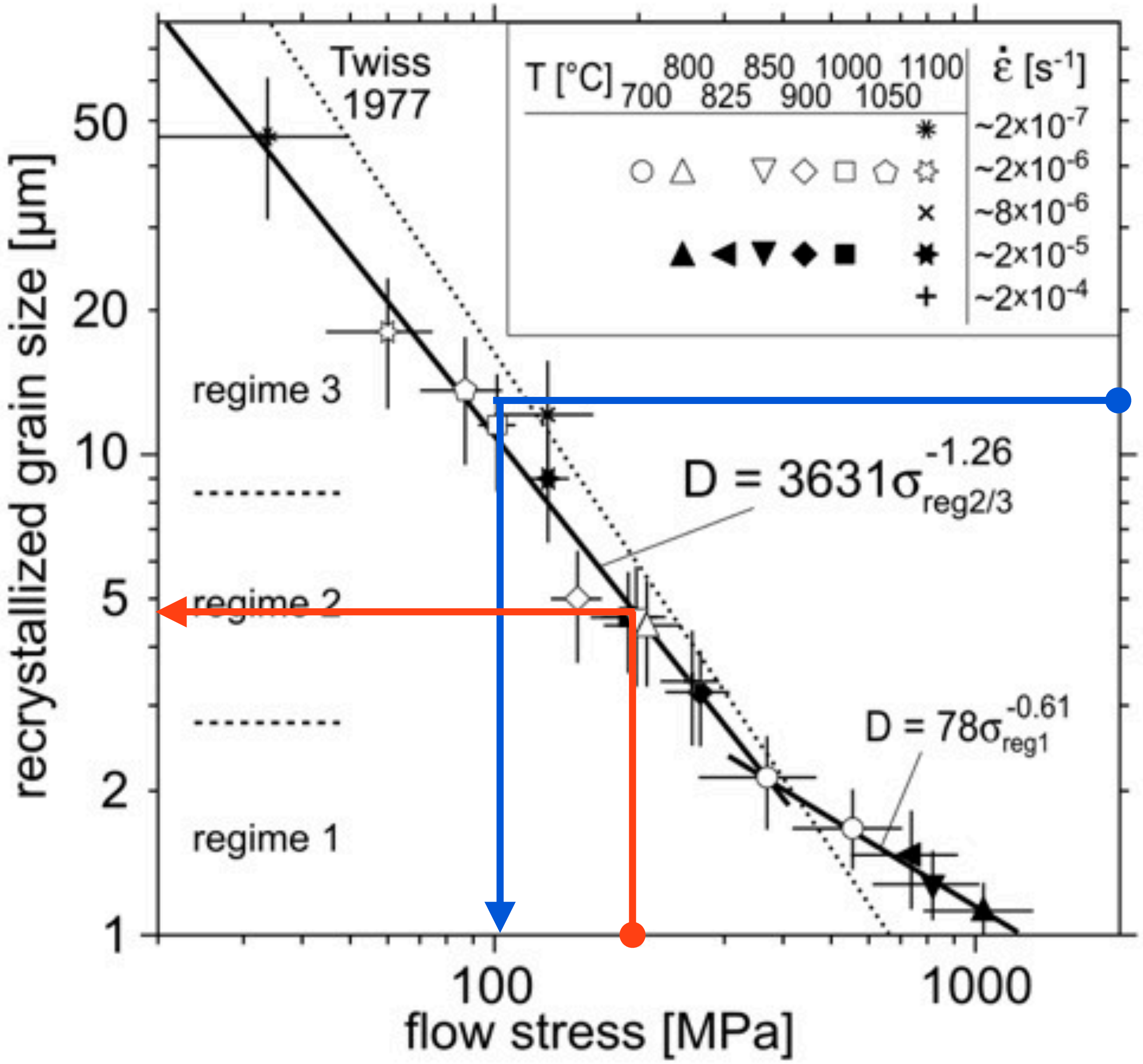
$\text{RMS}(d) = 78 \cdot \sigma^{-0.61}$

(Stipp & Tullis, JGR, 2003)

$\tau = 100$ MPa → $\Delta\sigma = 200$ MPa → $d = 4.6$ μm

⇒ *piezometer underestimates stress ... or underestimates grain size*

check the piezometer



$$RMS(d) = 10^{(3.56\pm0.27)} \cdot \sigma^{-(1.26\pm0.13)}$$

The diameter = diameter of a circle with he same area (d_{equ})

Measure for average 2-grain size = RMS of recrystallized grains

No stereological correction

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

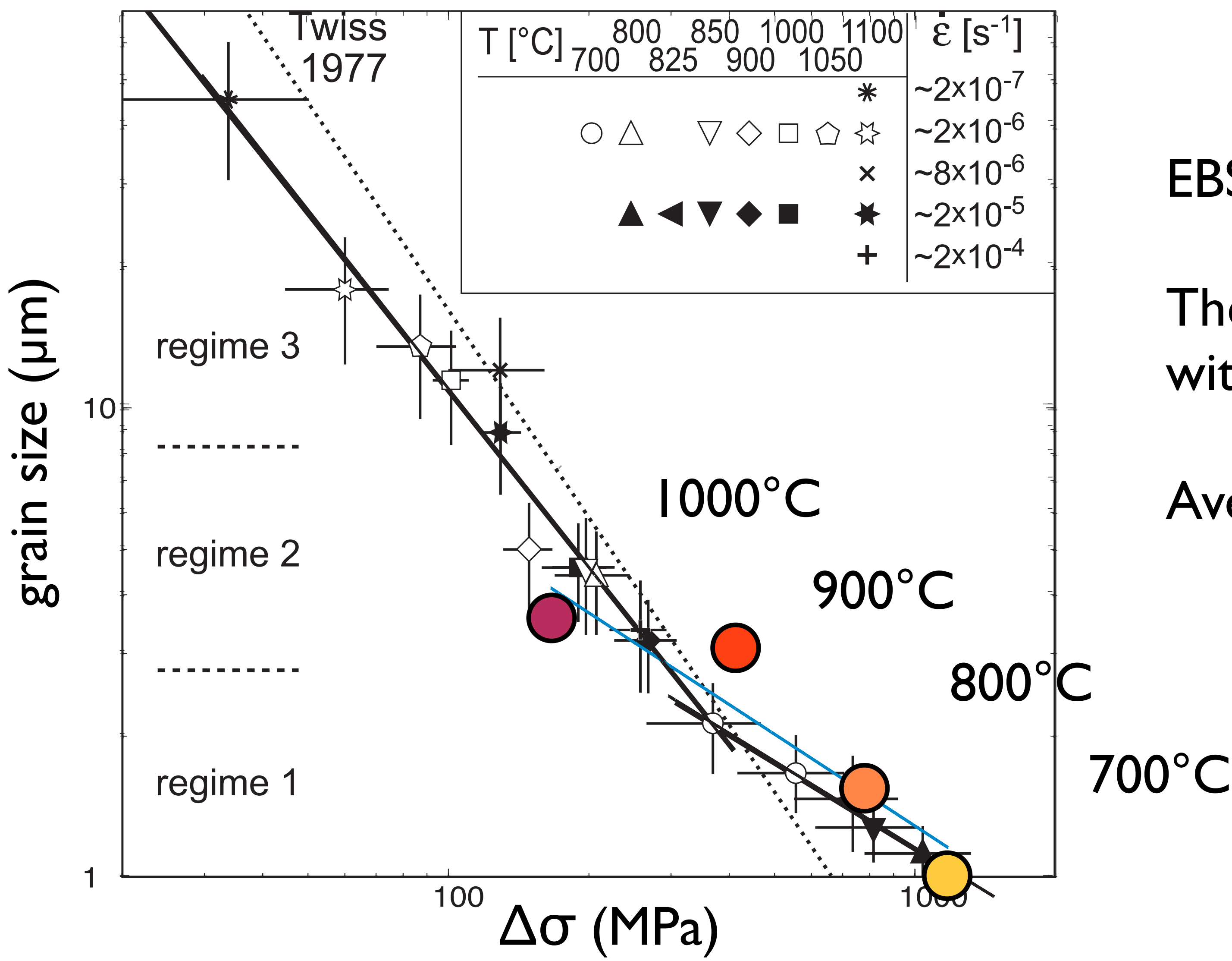
(Stipp & Tullis, JGR, 2003)

τ = 100 MPa → $\Delta\sigma$ = 200 MPa → d = 4.6 µm

d = 10 µm → $\Delta\sigma$ = 108 MPa → τ = 54 MPa

⇒ *piezometer underestimates stress ... or underestimates grain size*

check stresses (= work in progress)



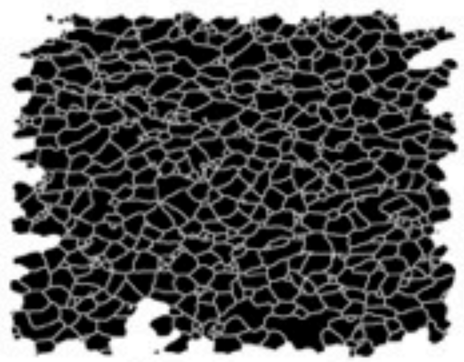
EBSD maps were used

The diameter = diameter of a circle with he same area.

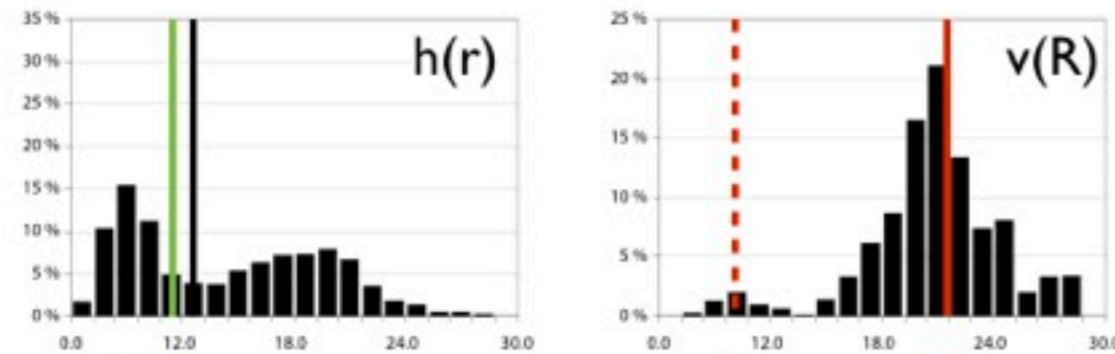
Average grain size = mode of $h(d_{equ})$.

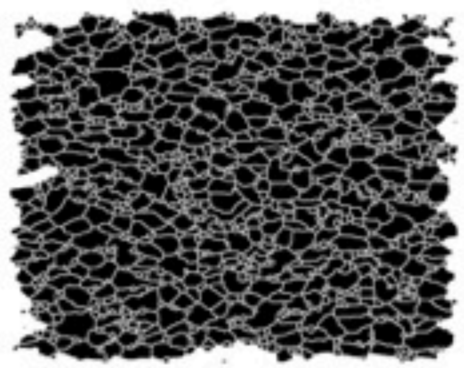
⇒ *re-calibrate the Griggs apparatus*

use 3D mode(s) (= my mission on earth...)

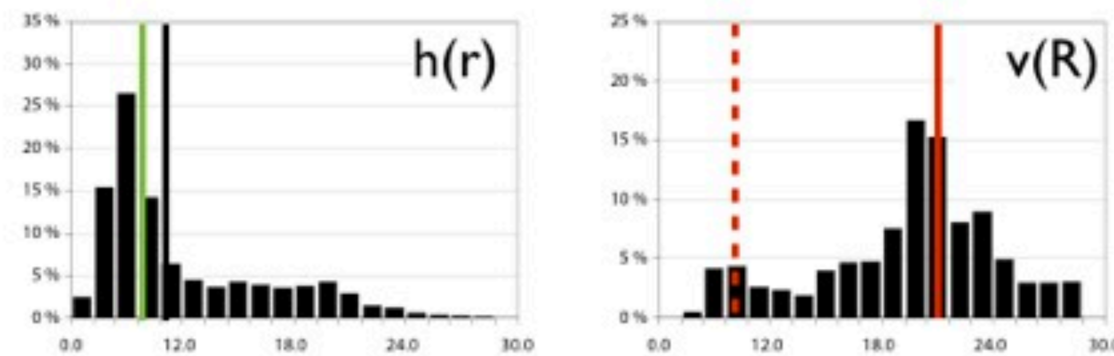


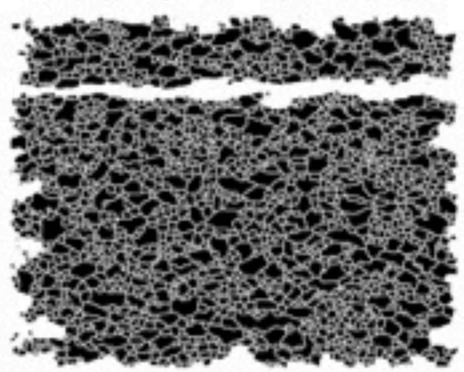
mean r_{equ} = 10.5px
RMS = 12.4px
RMS/mean = 118%



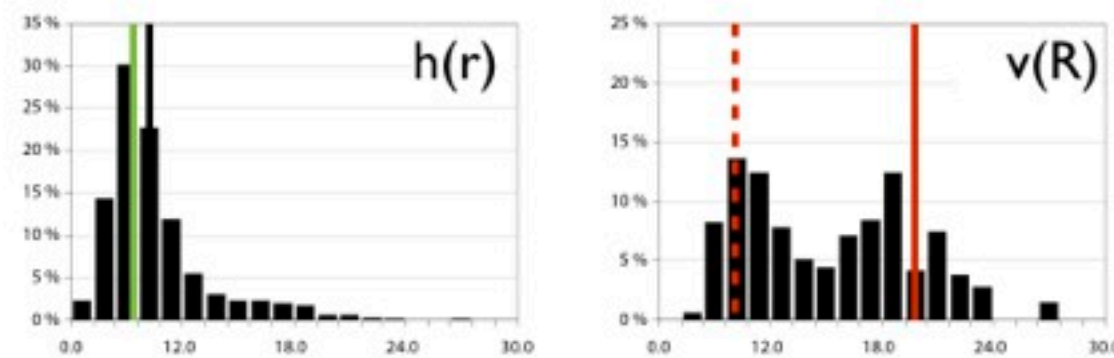


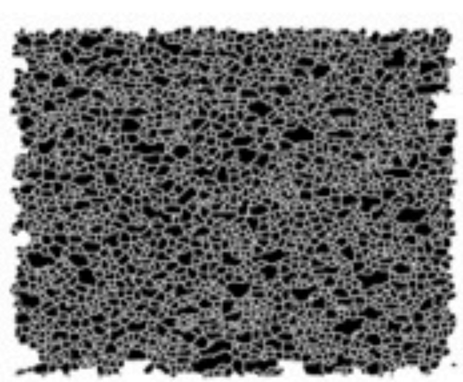
mean r_{equ} = 7.6px
RMS = 9.5px
RMS/mean = 125%



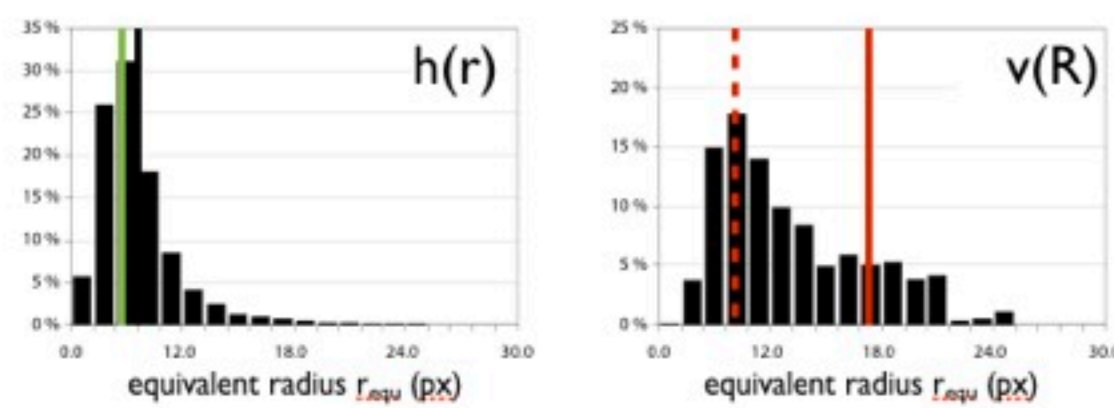


mean r_{equ} = 5.7px
RMS = 6.7px
RMS/mean = 118%





mean r_{equ} = 4.5px
RMS = 5.2px
RMS/mean = 117%



⇒ *3D mode more meaningful than 2D mean*

2. olivine - pyroxene (= work in progress)

motivation:
torsion experiments to find flow law for mantle material

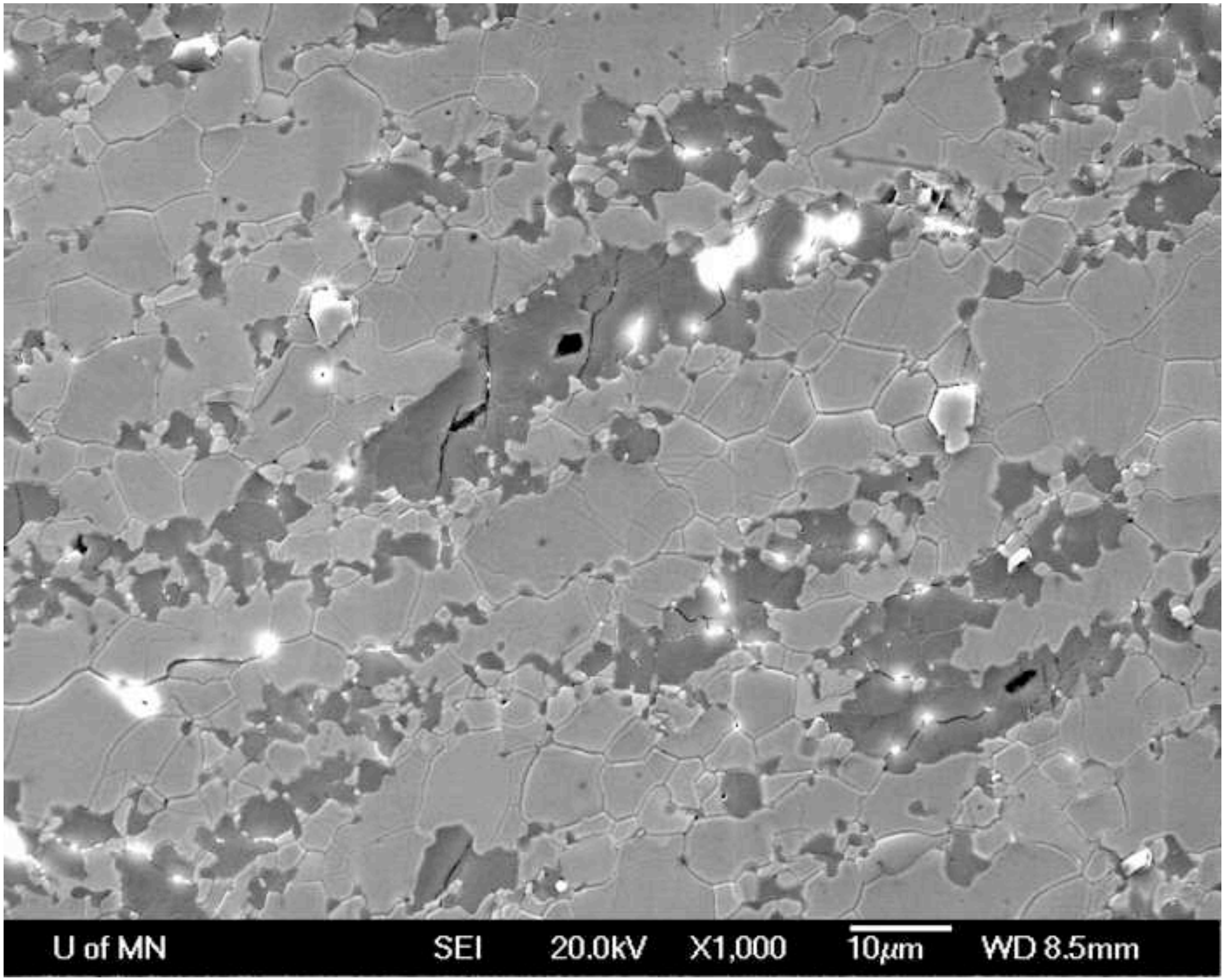
first finds:
dislocation creep and diffusion creep

aim of microstructure analysis:
step 1: find grain size(s) of olivine and pyroxene
step 2: find shape(s)
step 3: find spatial relations

... think about results

... see forthcoming paper by Miki Tasaka

torsion experiments on Ol - Opx



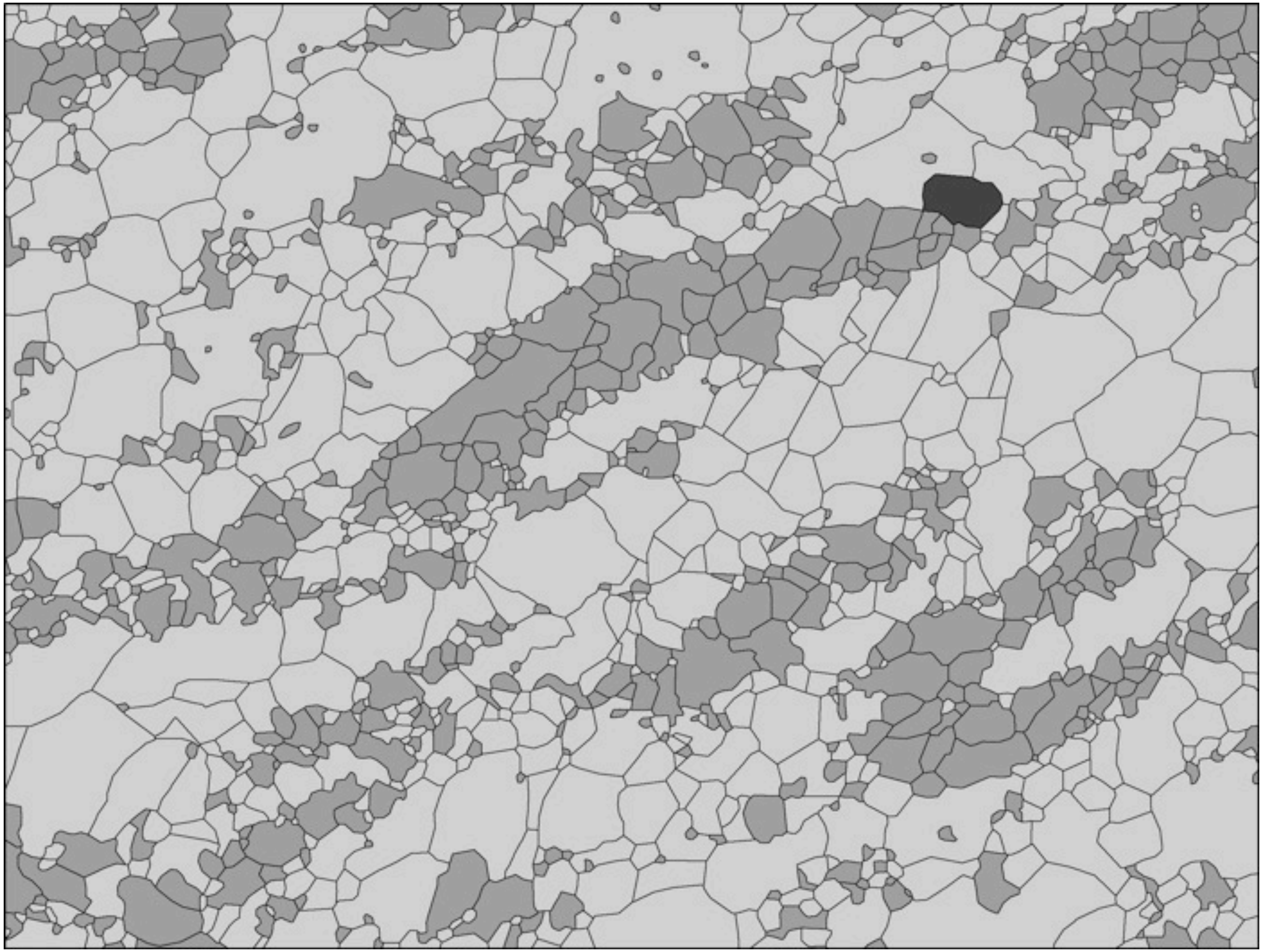
Miki Tasaka
David Kohlstedt
Mark Zimmermann

Univ. Minnesota, Minneapolis

70:30 mixture
olivine-orthopyroxene

Paterson apparatus
T = 1200°C
p_c = 300MPa
$\dot{\gamma}$ = $1.6 \cdot 10^{-4}\ s^{-1}$
γ = 1.9

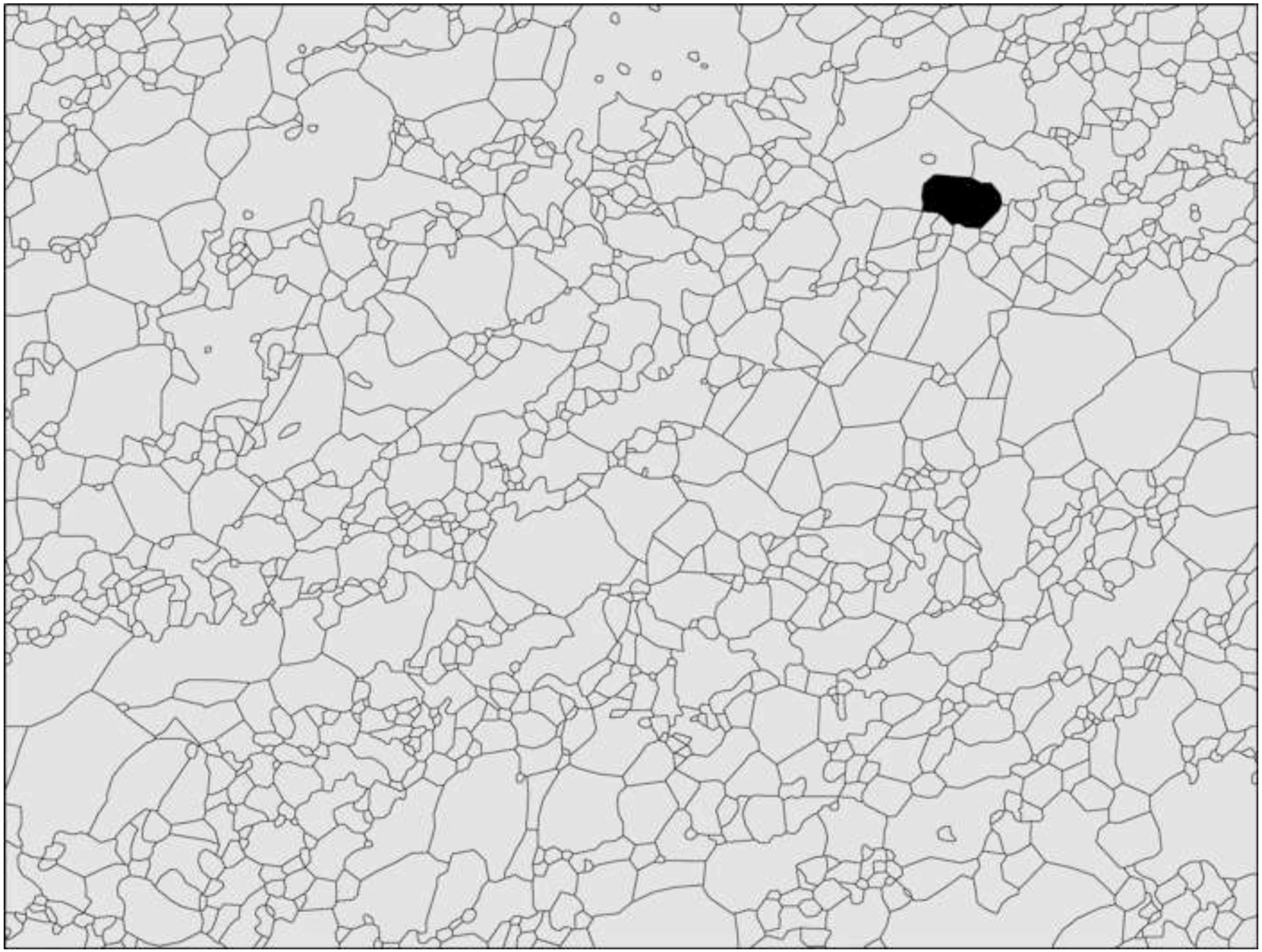
torsion experiments on Ol - Opx



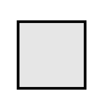
segmentation

⇒ *have to be careful with segmentation*

torsion experiments on Ol - Opx

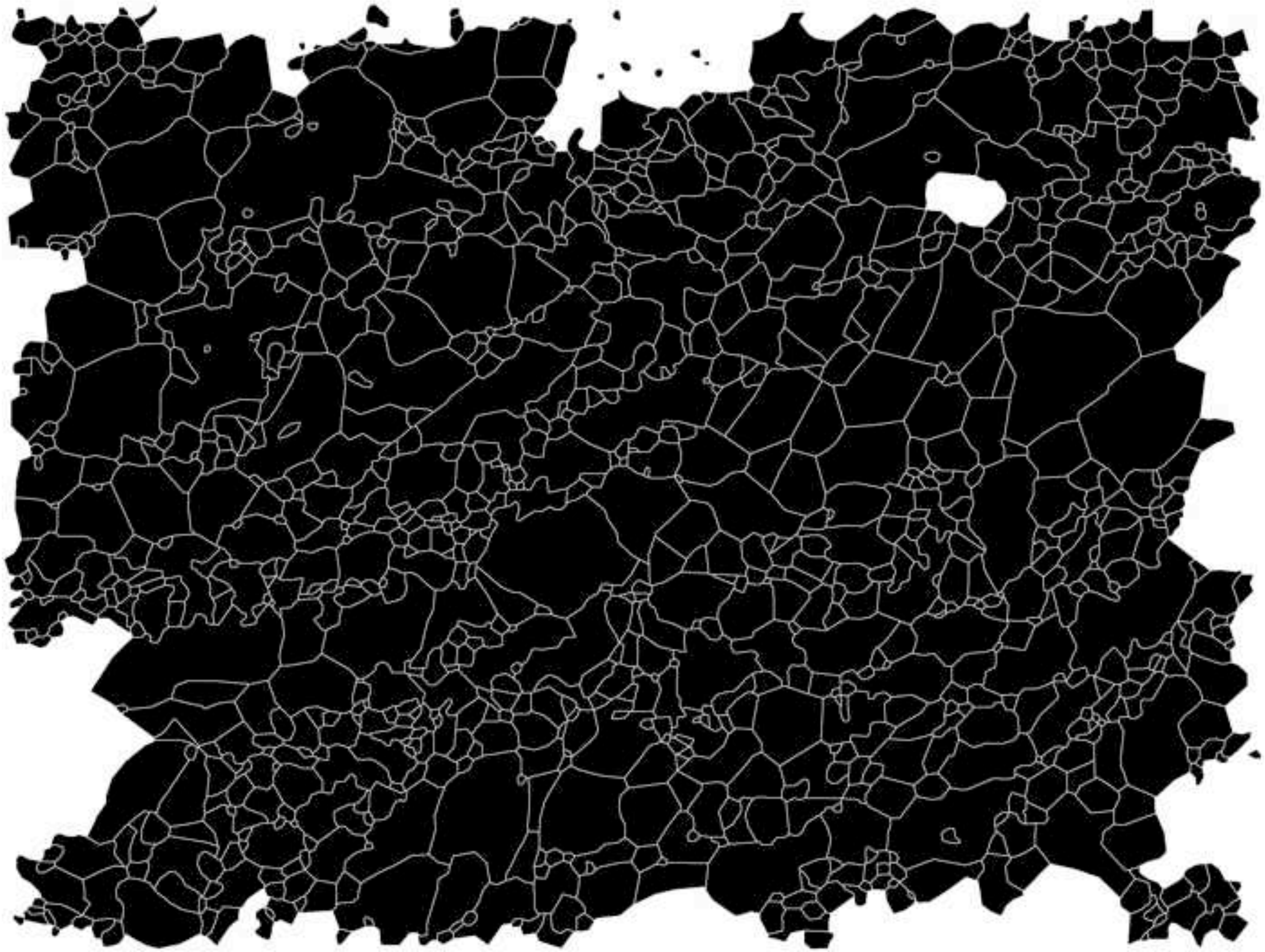


segmentation
grain boundary map



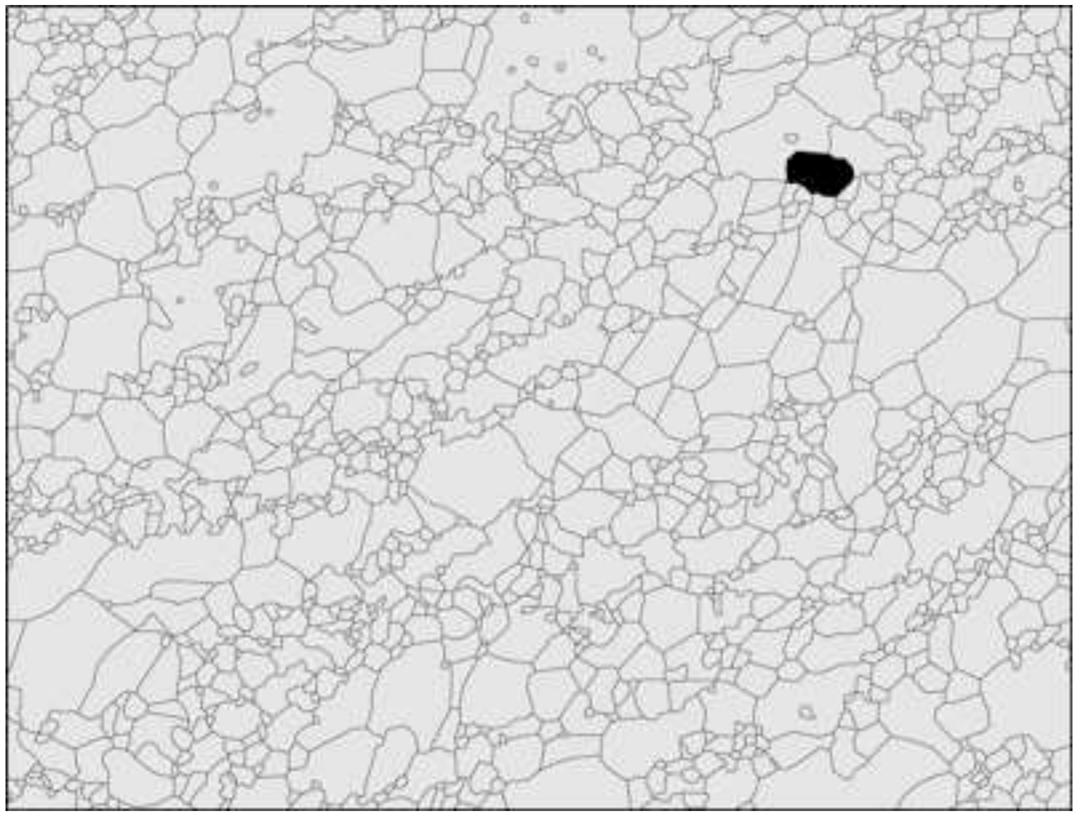
all grains

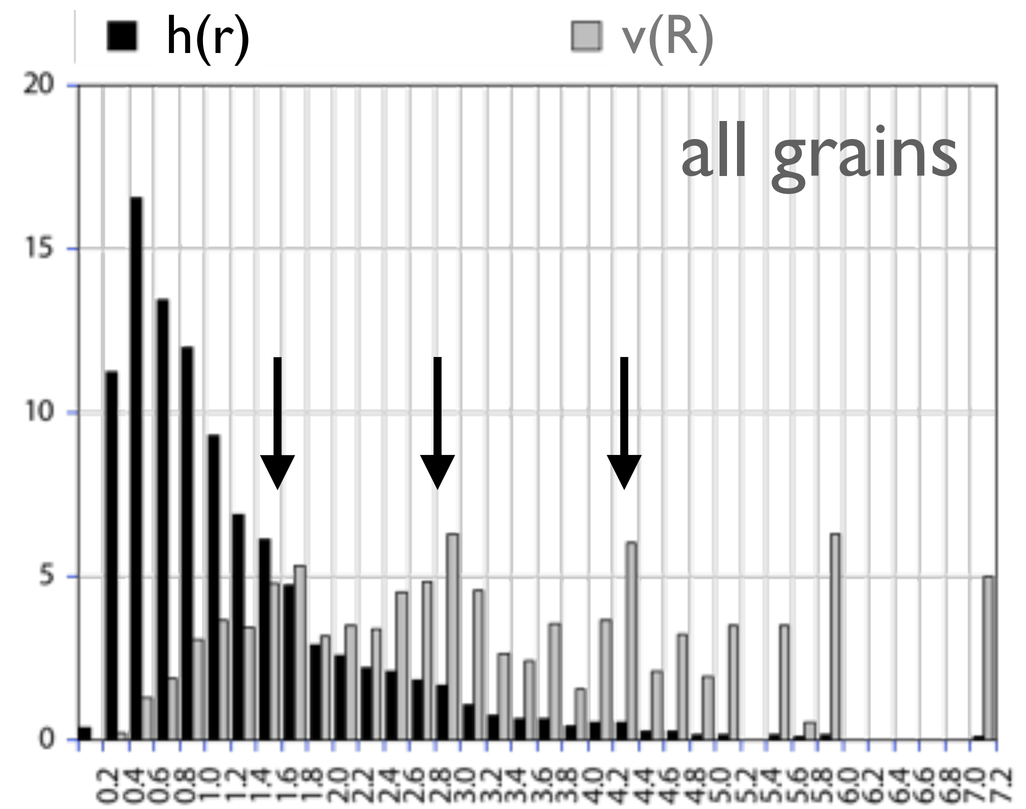
torsion experiments on Ol - Opx



segmentation
grain boundary map
grain map (segments)

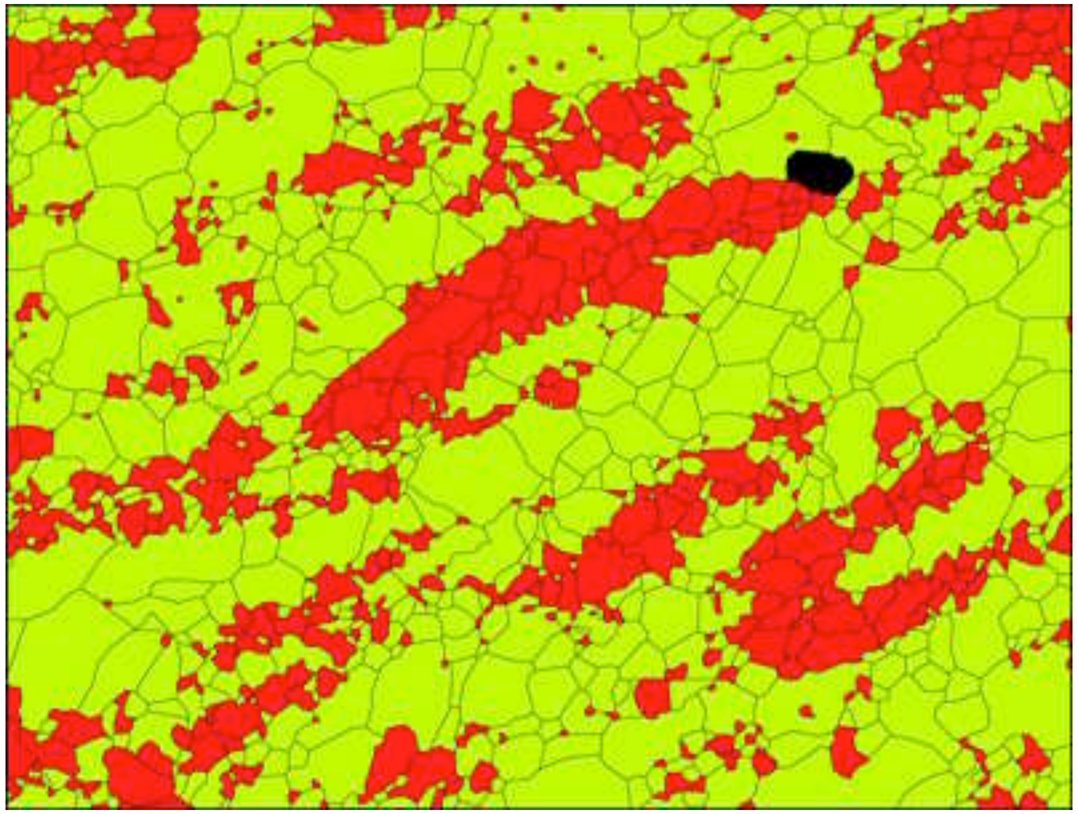
2D and 3D grain size distributions

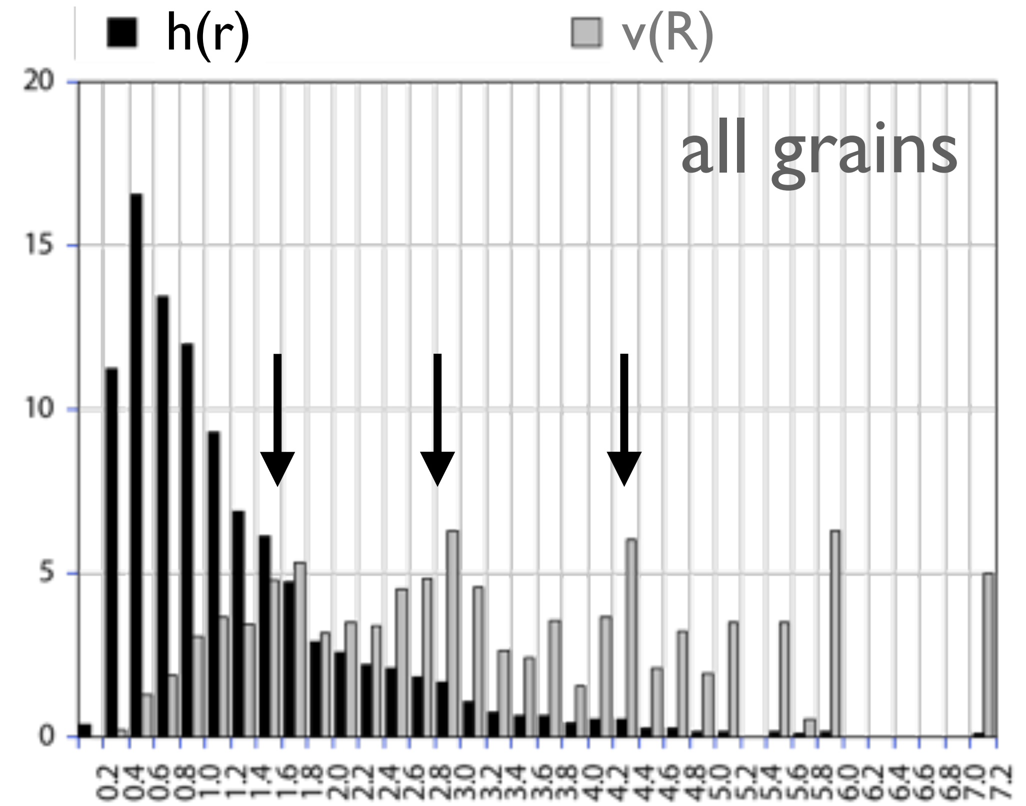


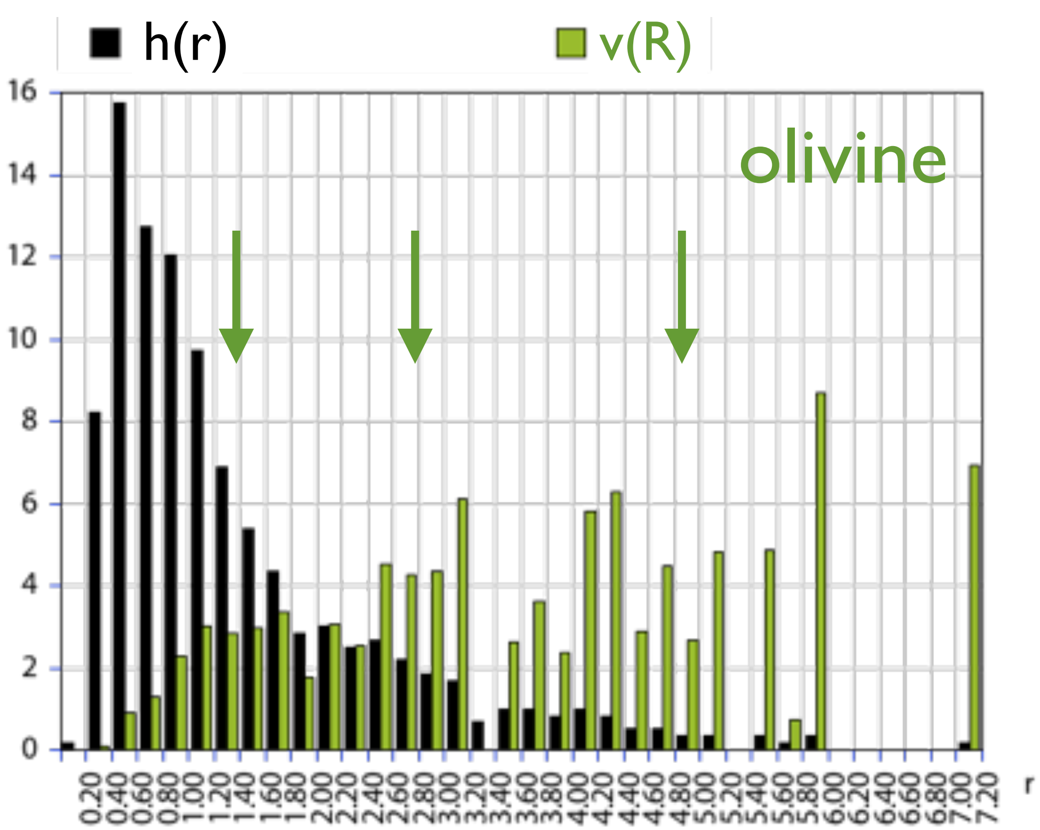


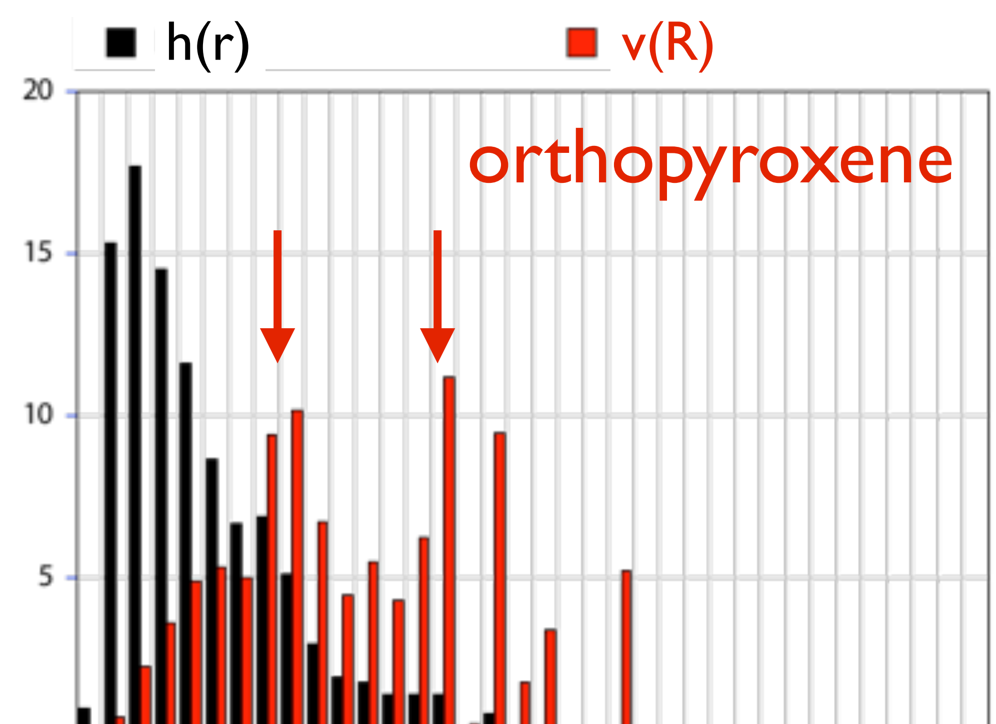
⇒ *detect multiple modes in 3D*

2D and 3D grain size distributions



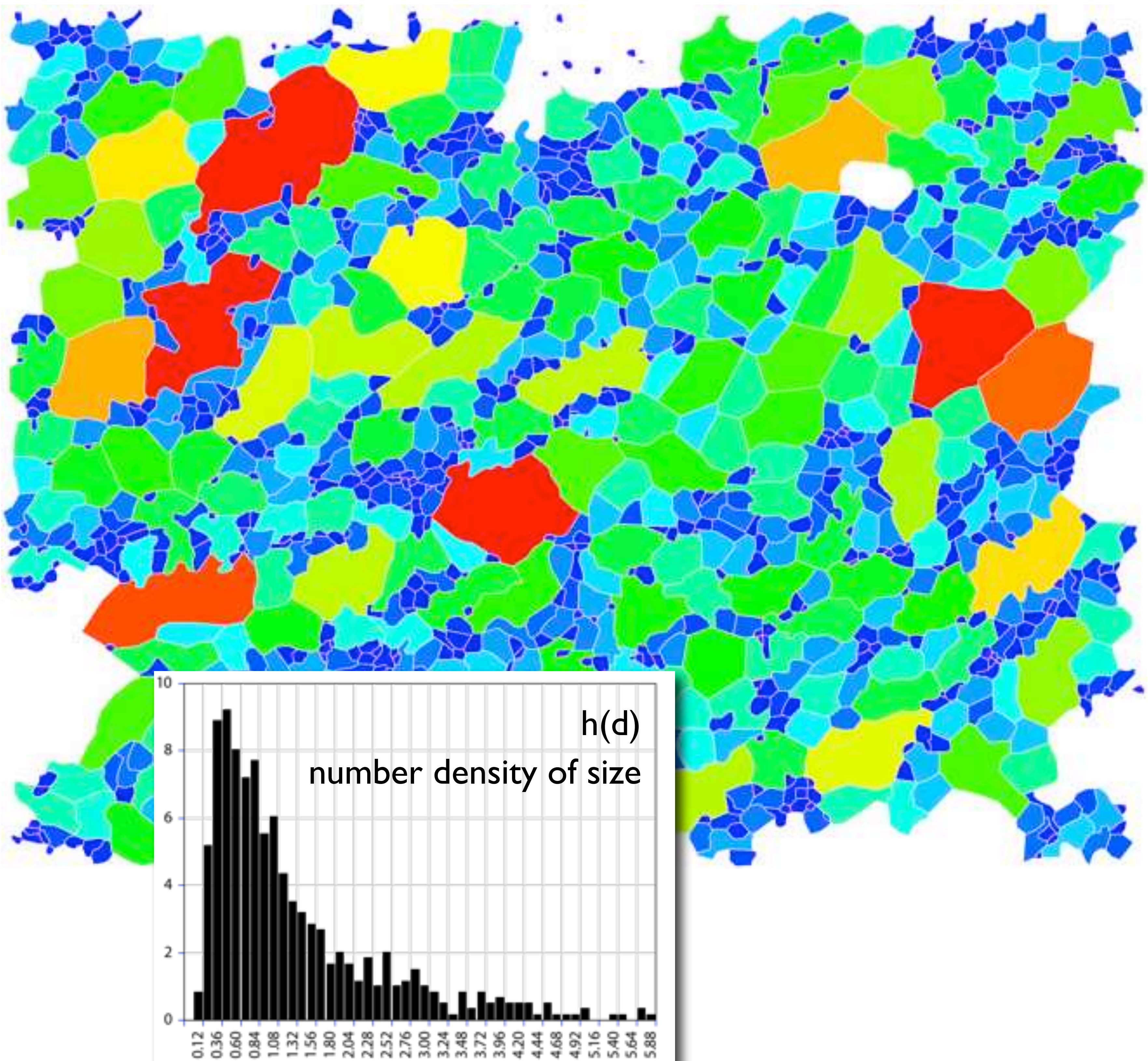


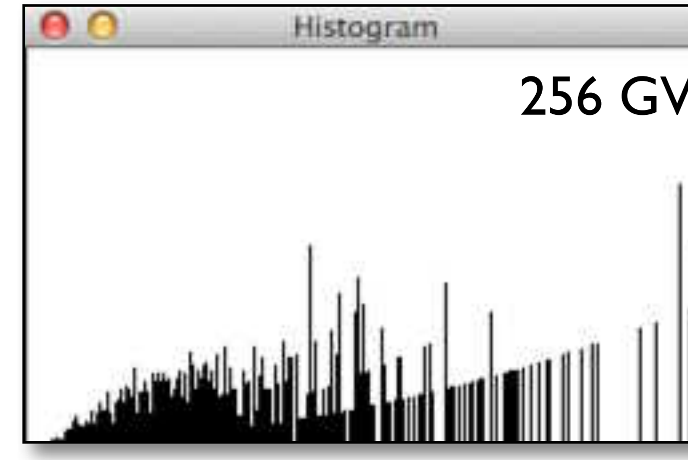


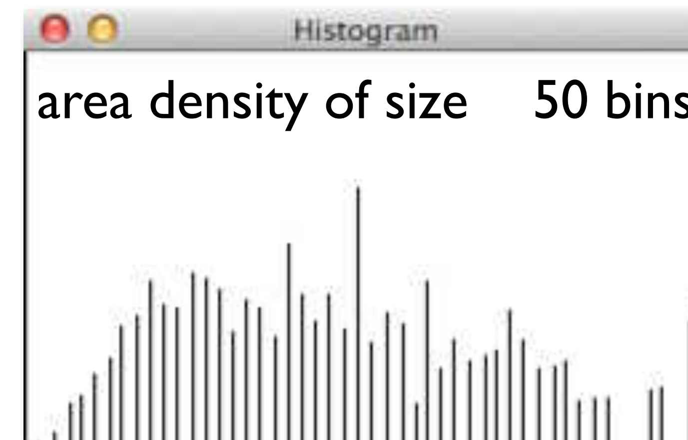


$\Rightarrow$ *detect multiple modes in 3D*

grain size mapping





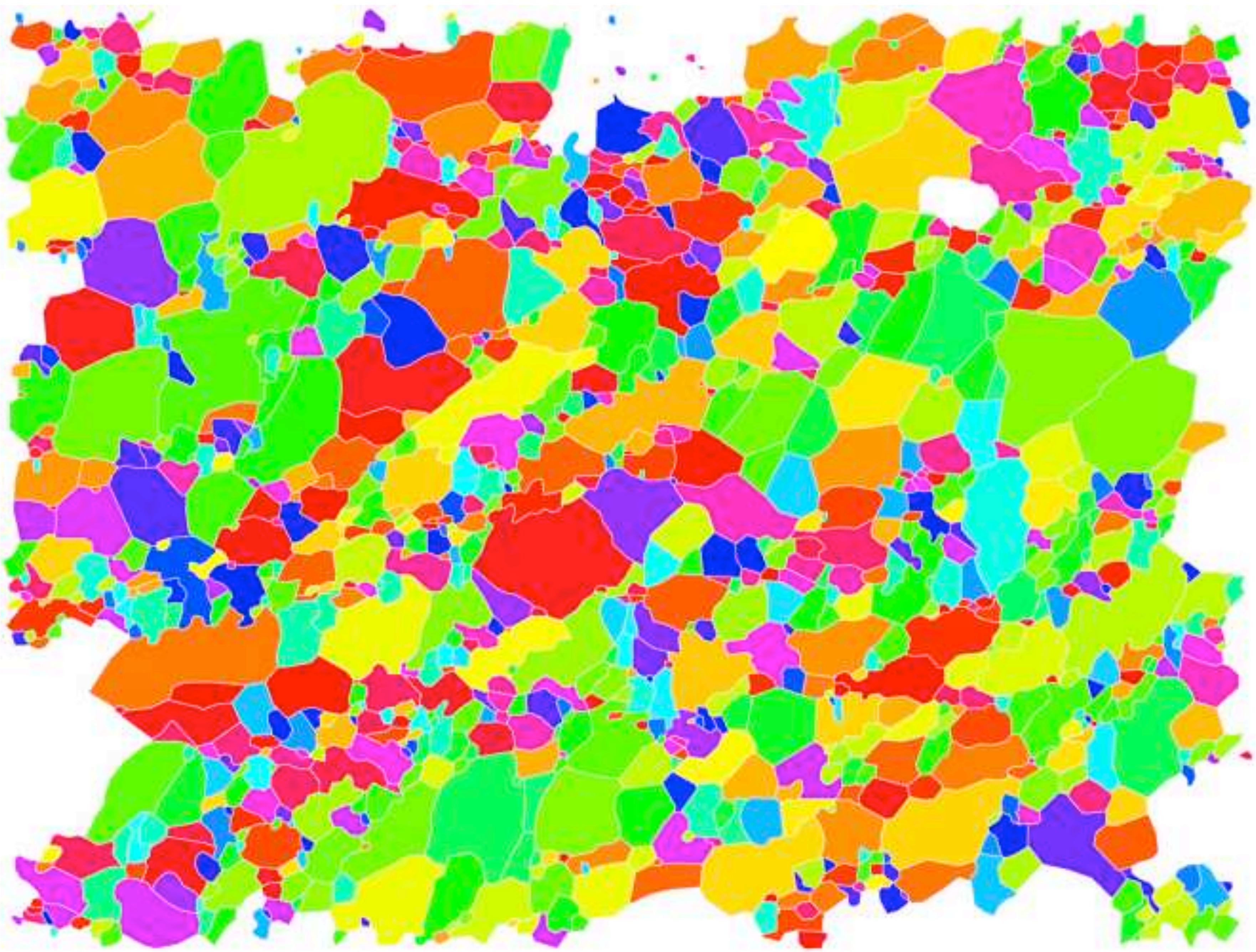


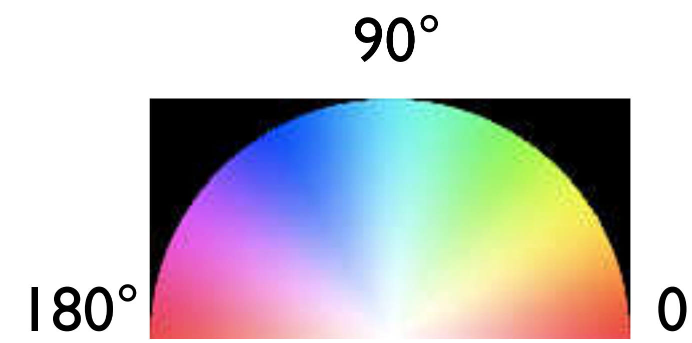
0.0 r_{equ} (µm) 6.0

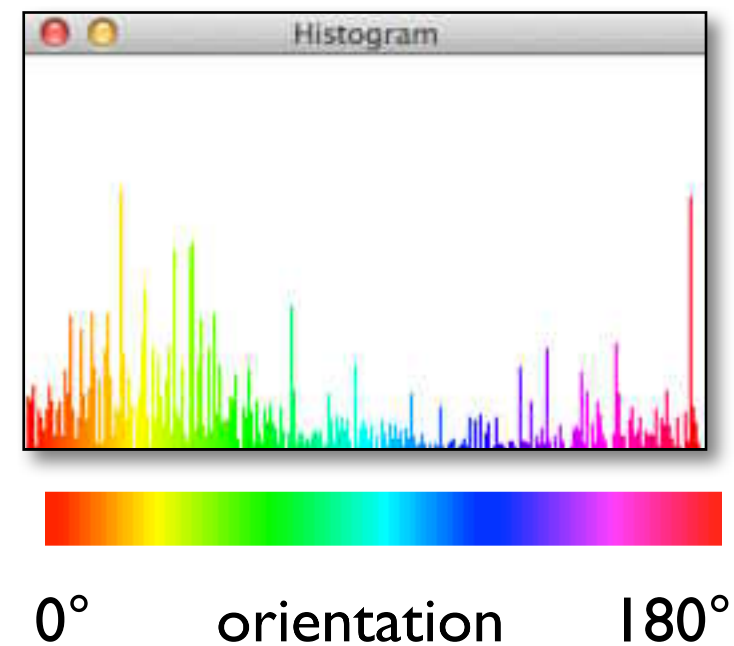
0.0 d_{equ} (µm) 12.0

⇒ *size domains*

orientation mapping

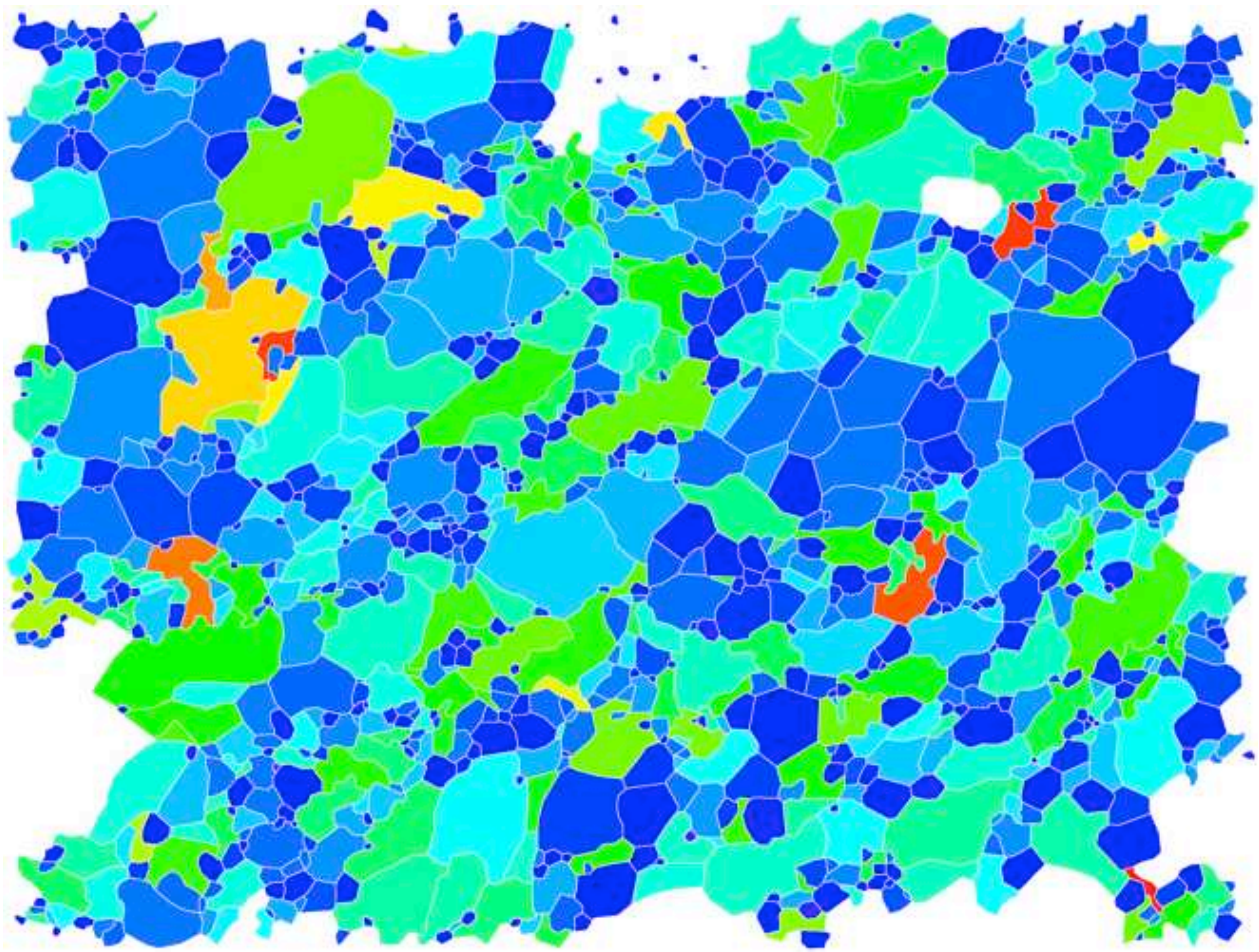


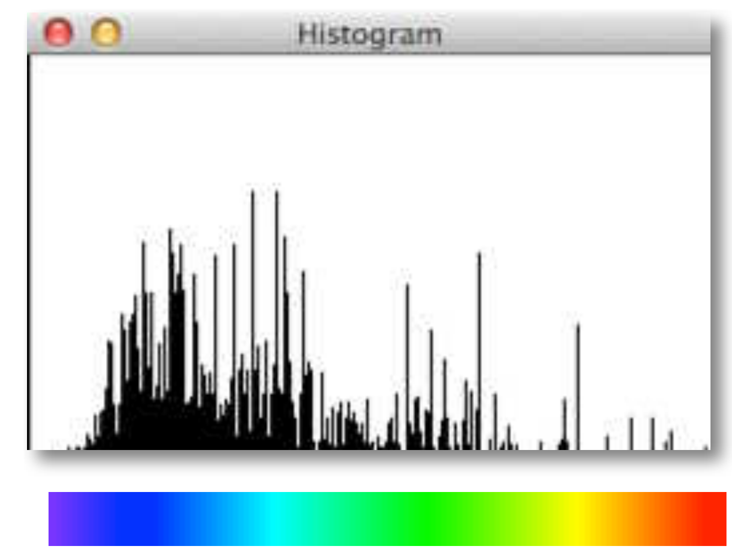




⇒ *random orientation*

shape factor mapping





0.0 P/P_{equ} 2.0

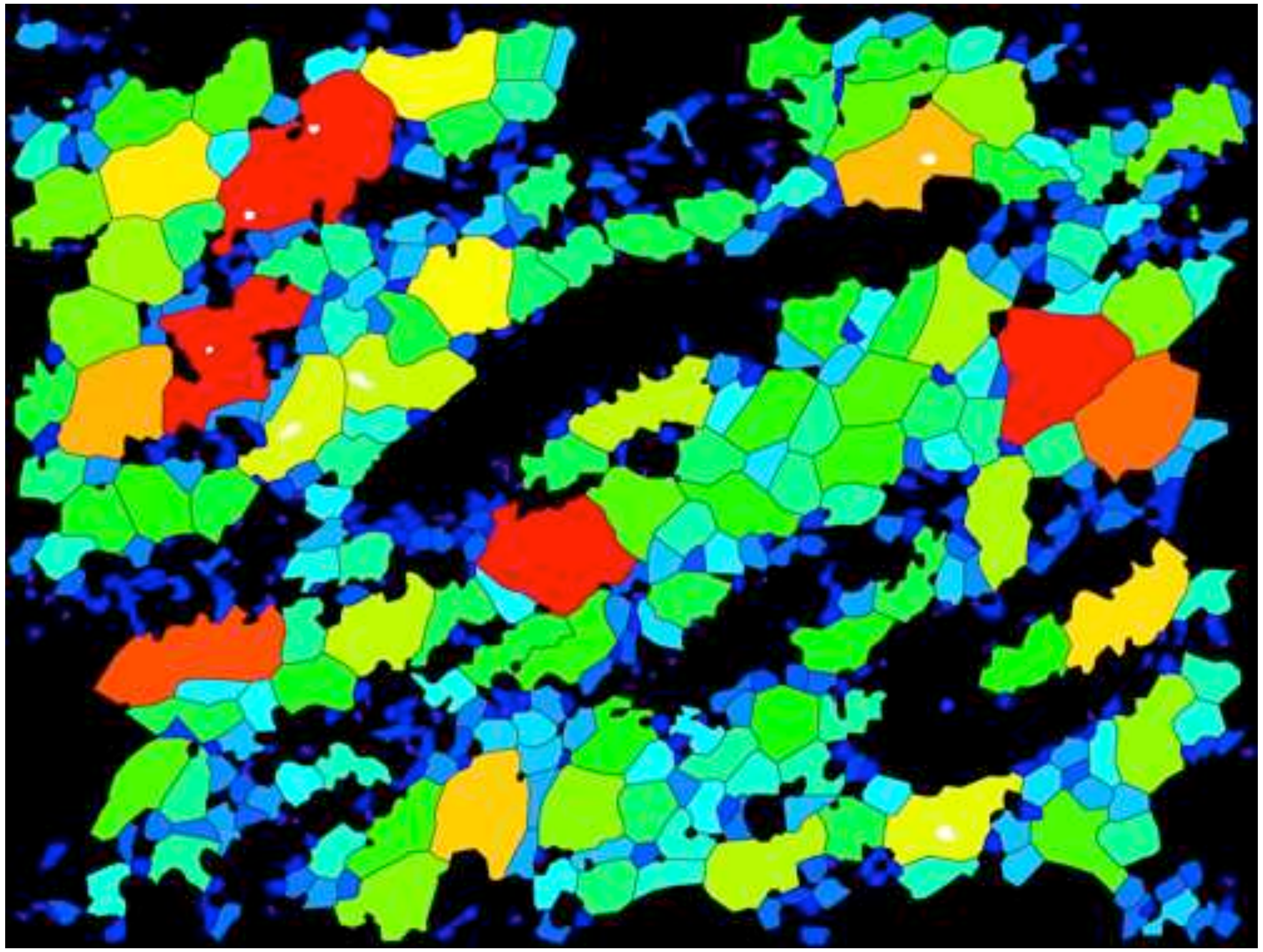
round convex ⟷ elongate convex-concave

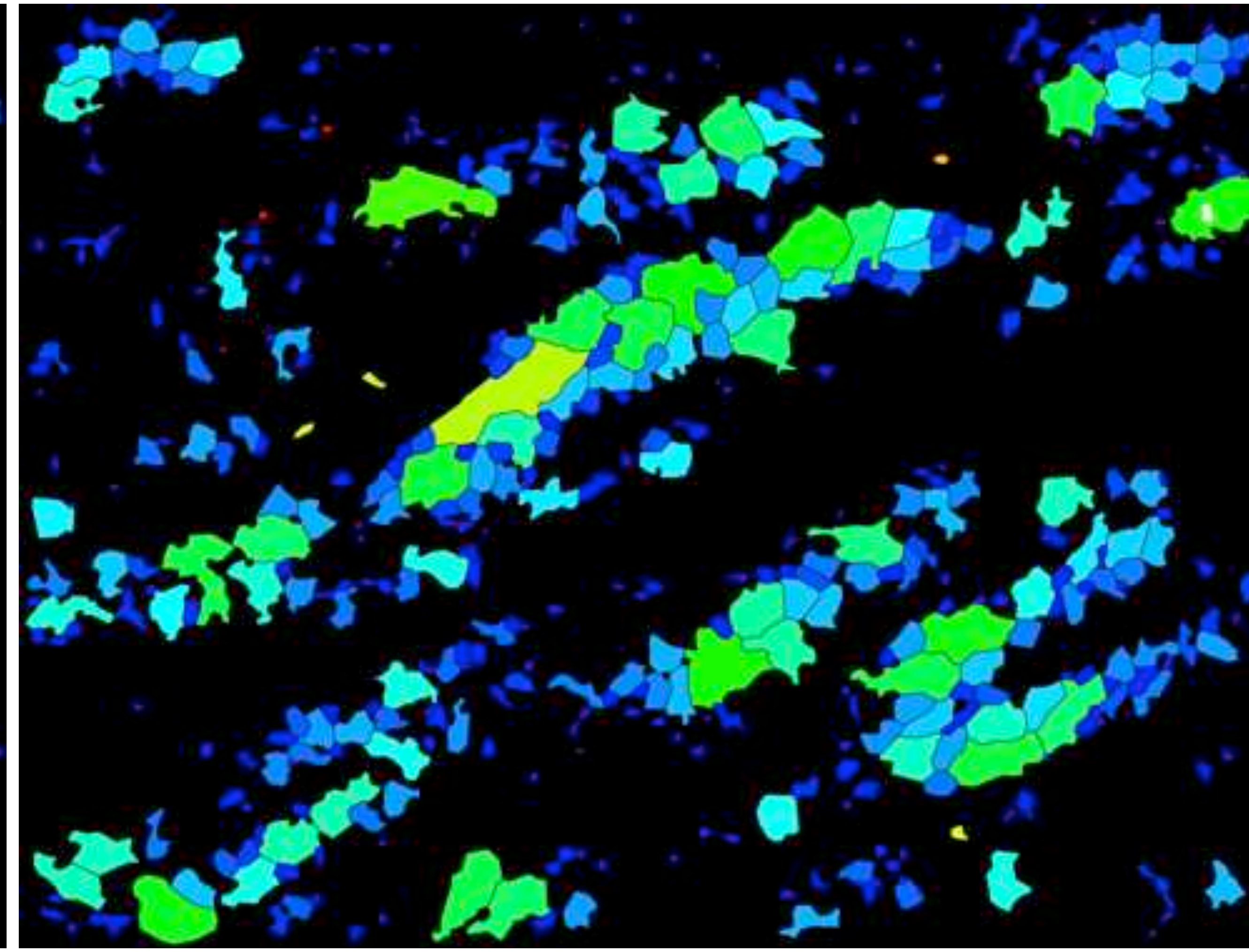
SF1 = $P_{measured} / P_{equivalent}$ = large if grain boundary lobate

$(0.00 < SF1 < \infty)$

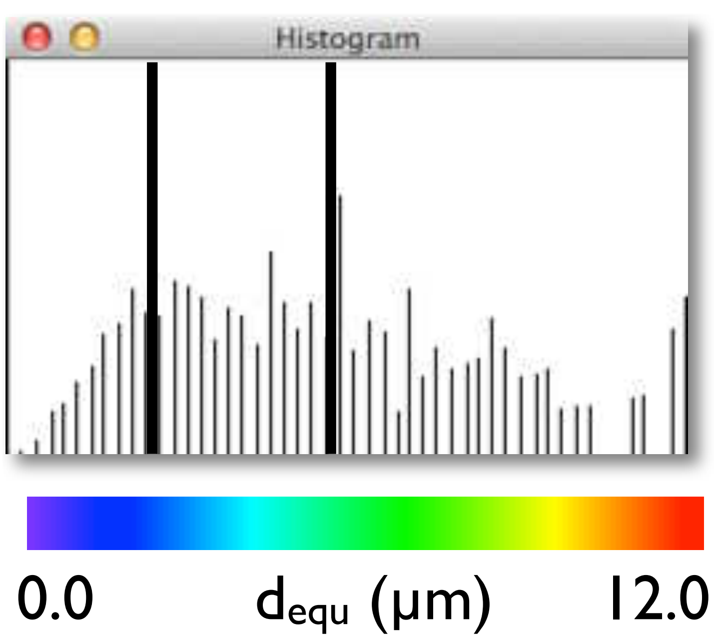
$(0.00 < SF1 < \infty)$

2 phases - 4 grain sizes !

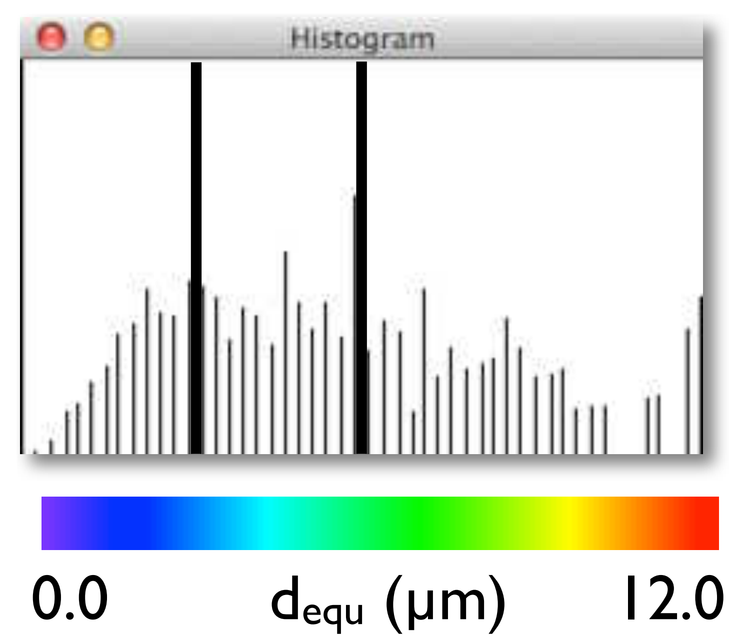




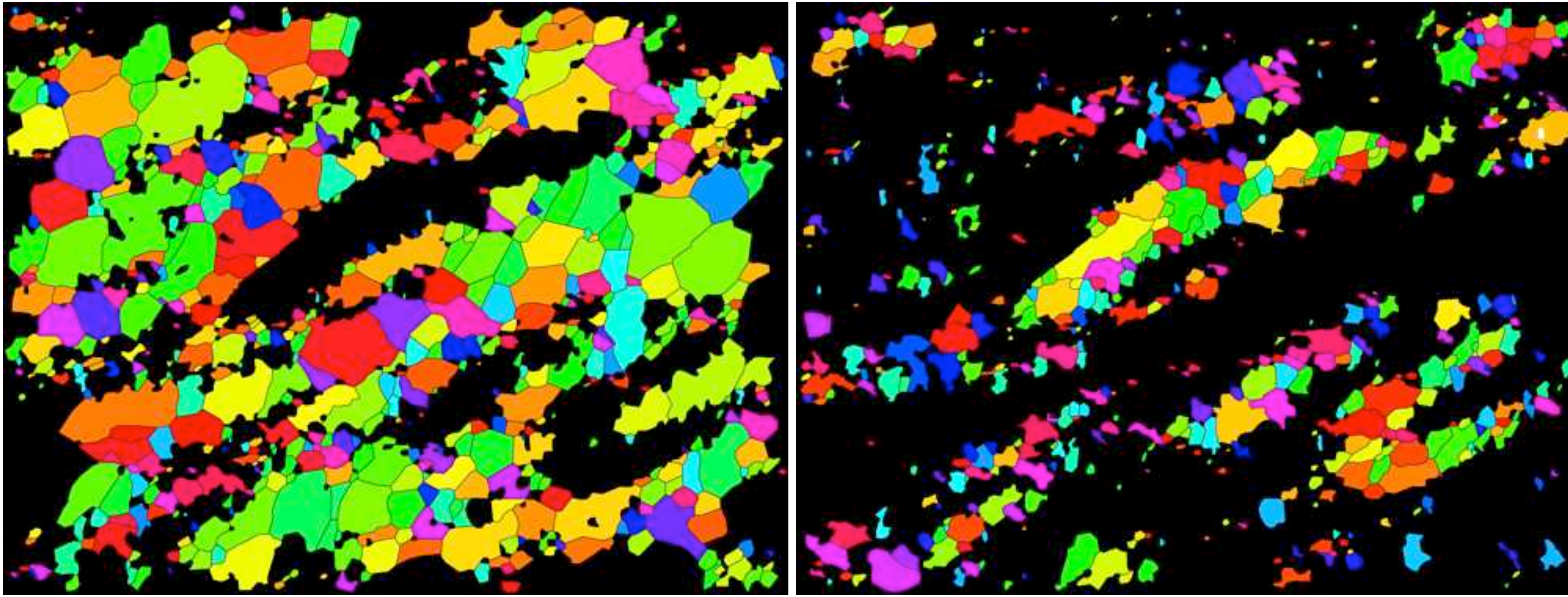
ol

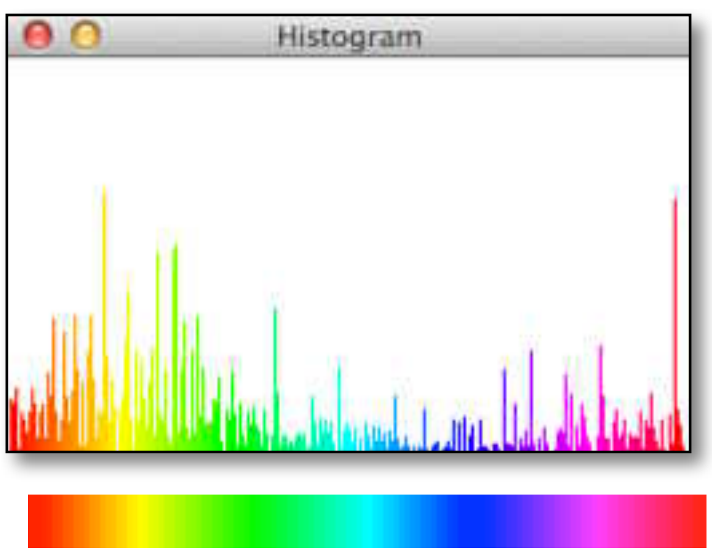


opx



preferred orientation ?





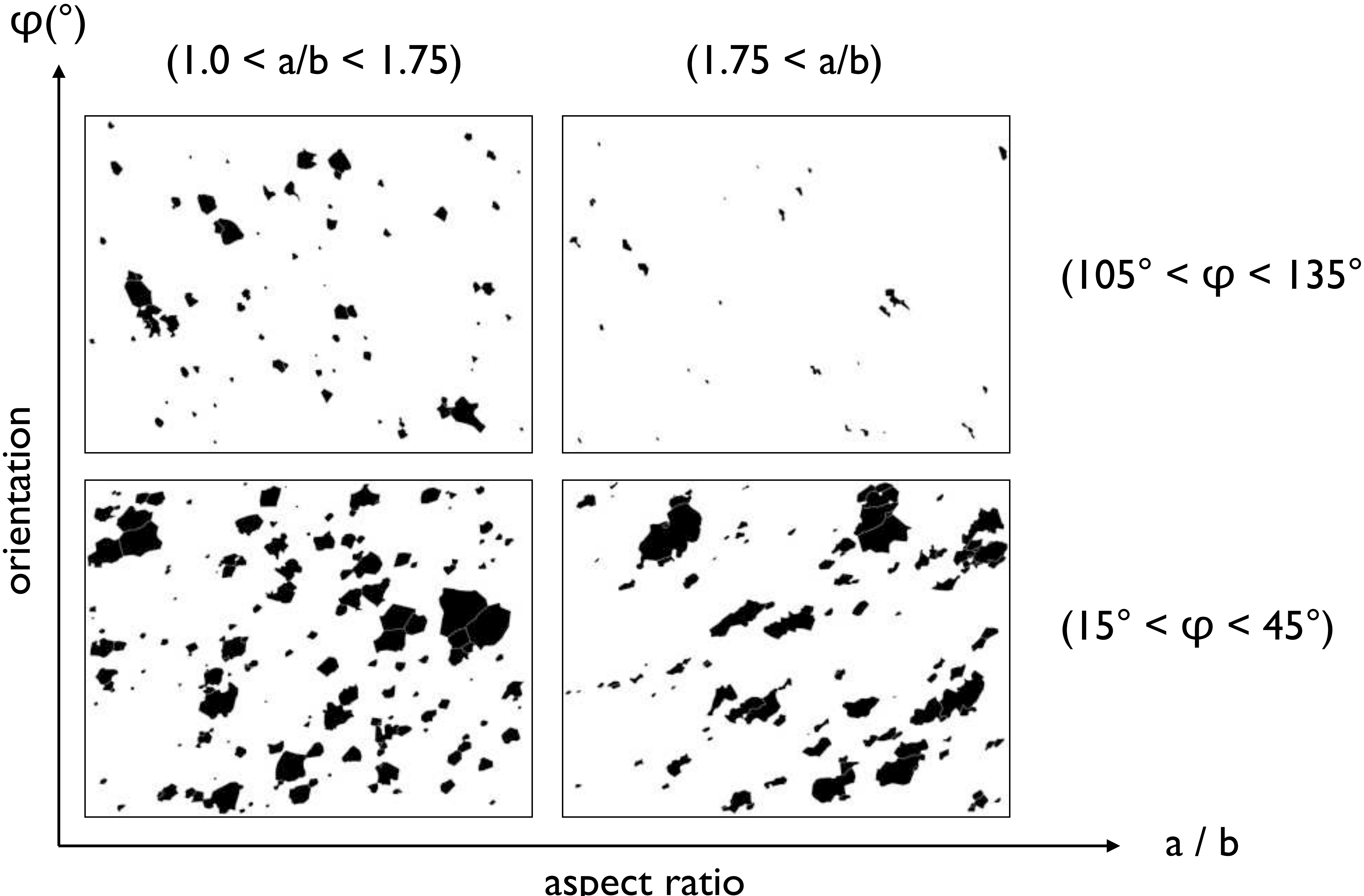
0° orientation 180°

90°

180°  0°

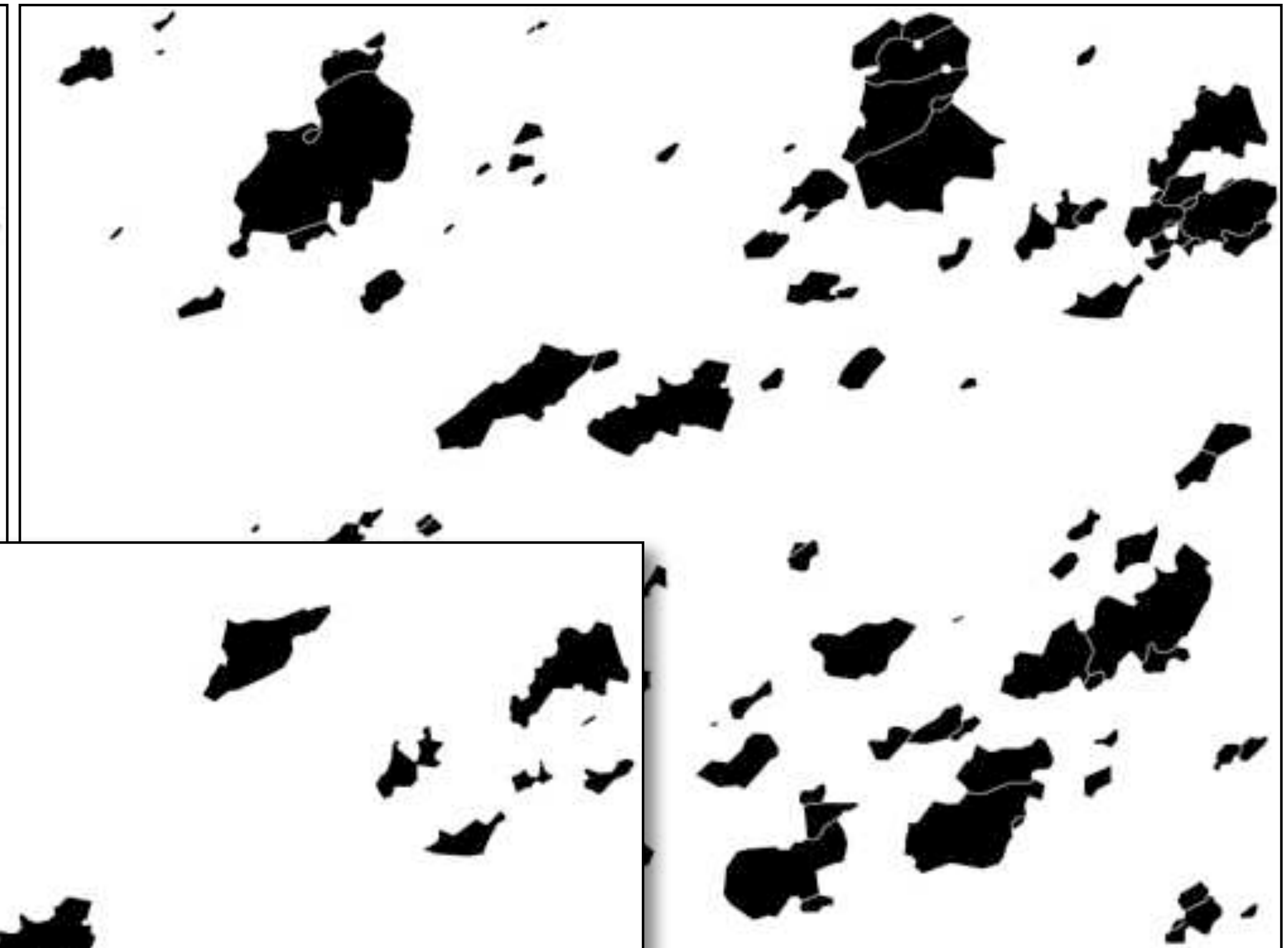
⇒ *Ol and Opx = random orientation*

intersecting 2 feature bitmaps



intersecting 3 feature bitmaps

(1.5 < SF1 < 2.0)

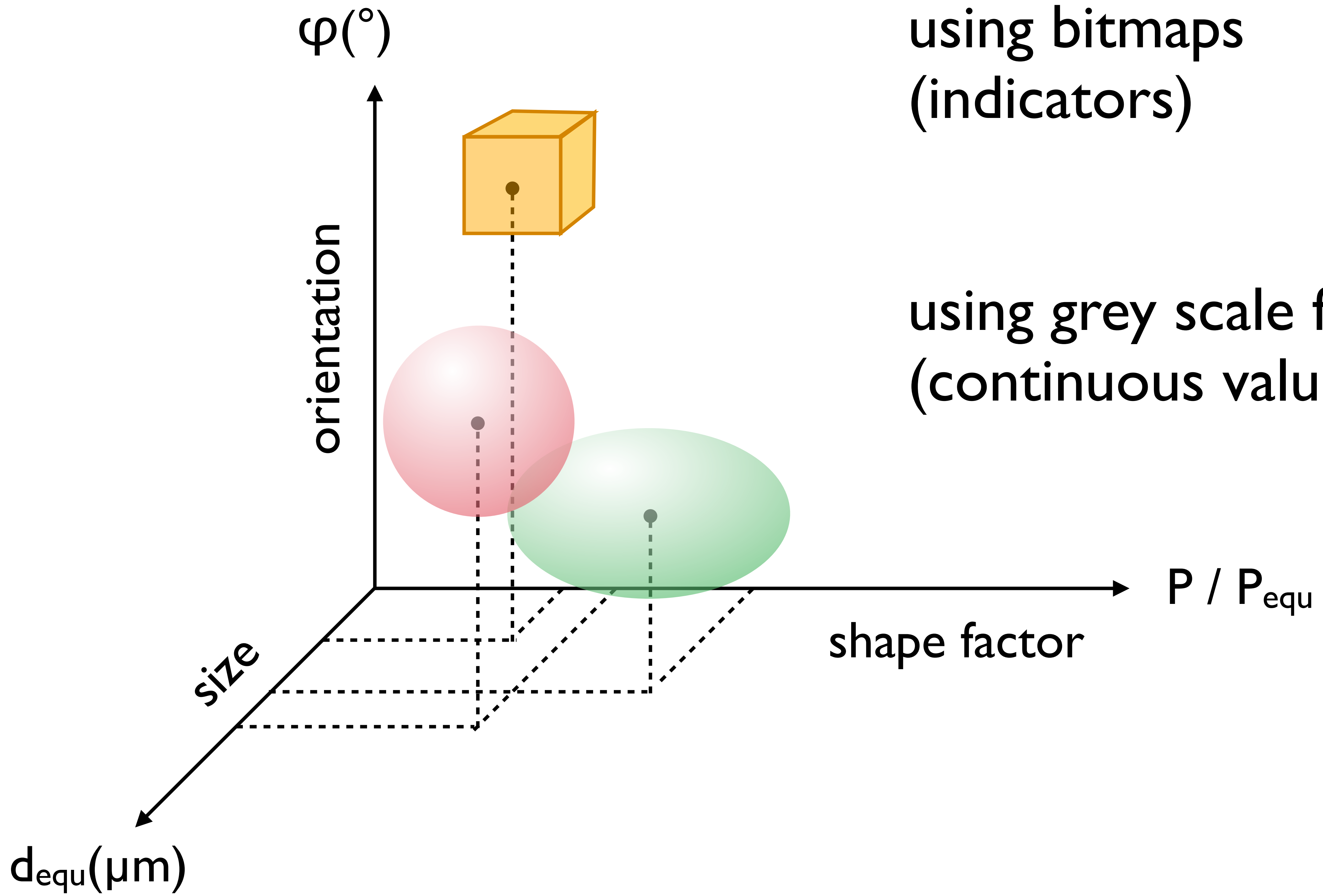


(15° < φ < 45°)

∩ (1.75 < a/b)

(1.5 < SF1 < 2.0) ∩ (1.75 < a/b) ∩ (15° < φ < 45°)

feature space



using bitmaps
(indicators)

using grey scale feature maps
(continuous values)

take-home message(s)

- use image analysis (processing) to measure - not to illustrate
- use state-of-the-art image analysis to match state-of-the-art experimentation

- think twice before declaring "the mean grain size"
- use modes of 3D grains - they are most meaningful

- put the numbers back into the picture → map → visualize
- think of images as maps → be quantitative → scale and calibrate
  (you can observe a lot by watching) → (you can understand a lot by measuring)

- think of microstructures as multidimensional → plot data in feature space (= intersect images)

... and be happy if you do not get a simple answer

announcement

European Geosciences Union
General Assembly 2016
Vienna | Austria | 17–22 April 2016

EGU.eu

TS1 – Brittle Deformation and Fault-related Processes

Programme Committee Login

Suggest a Session here

TS2 – Ductile Deformation, Metamorphism and Magmatism

Programme Committee Login

Suggest a Session here

Suggested Session

Advances in Microstructure and Texture Analysis

[Suggest a new Title]

Conveners: Renee Heilbronner, Rüdiger Kilian

[Suggest a Convener and Description Change]