Complete grain boundaries from incomplete EBSD maps: the influence of segmentation on grain size determinations

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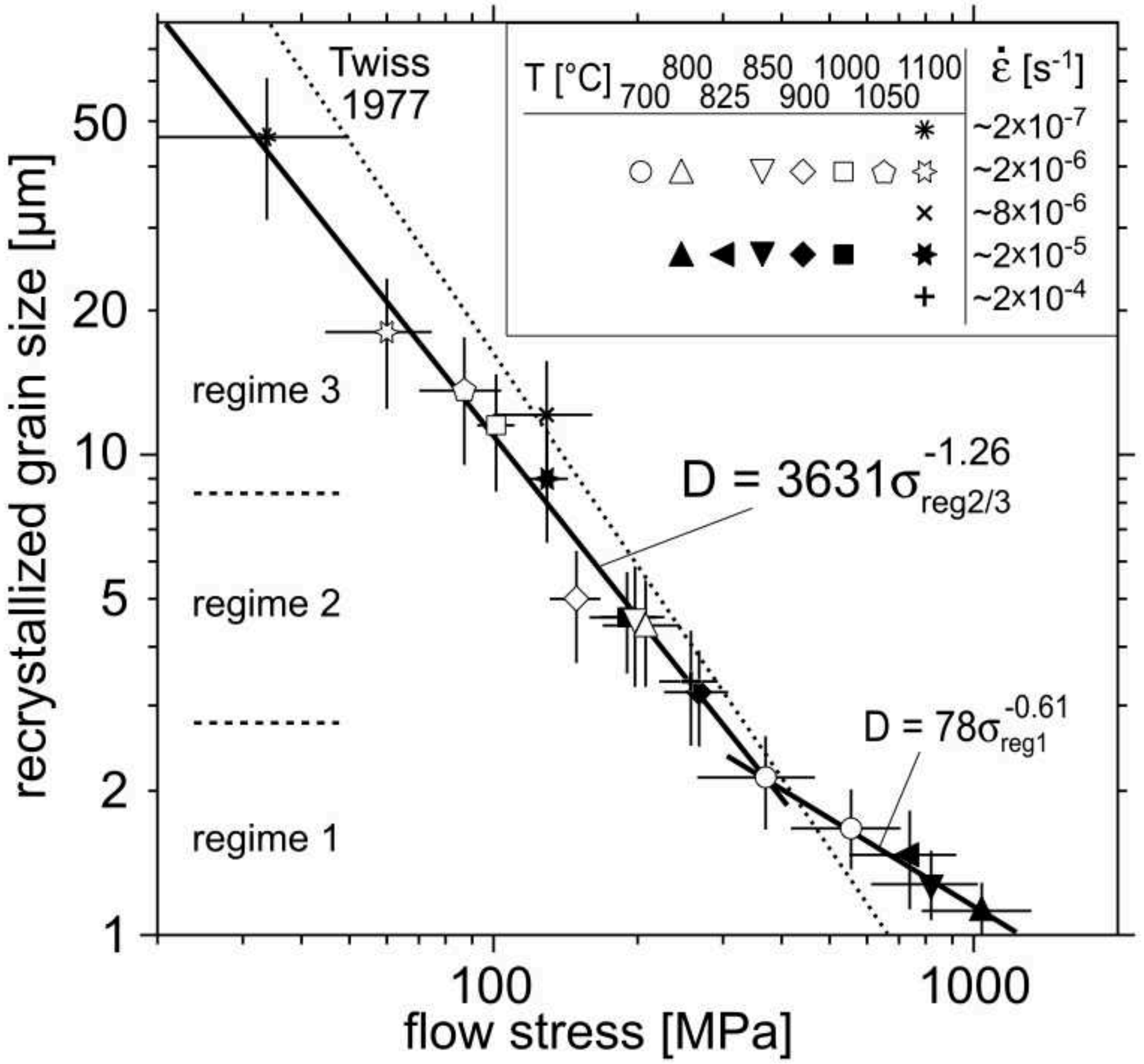
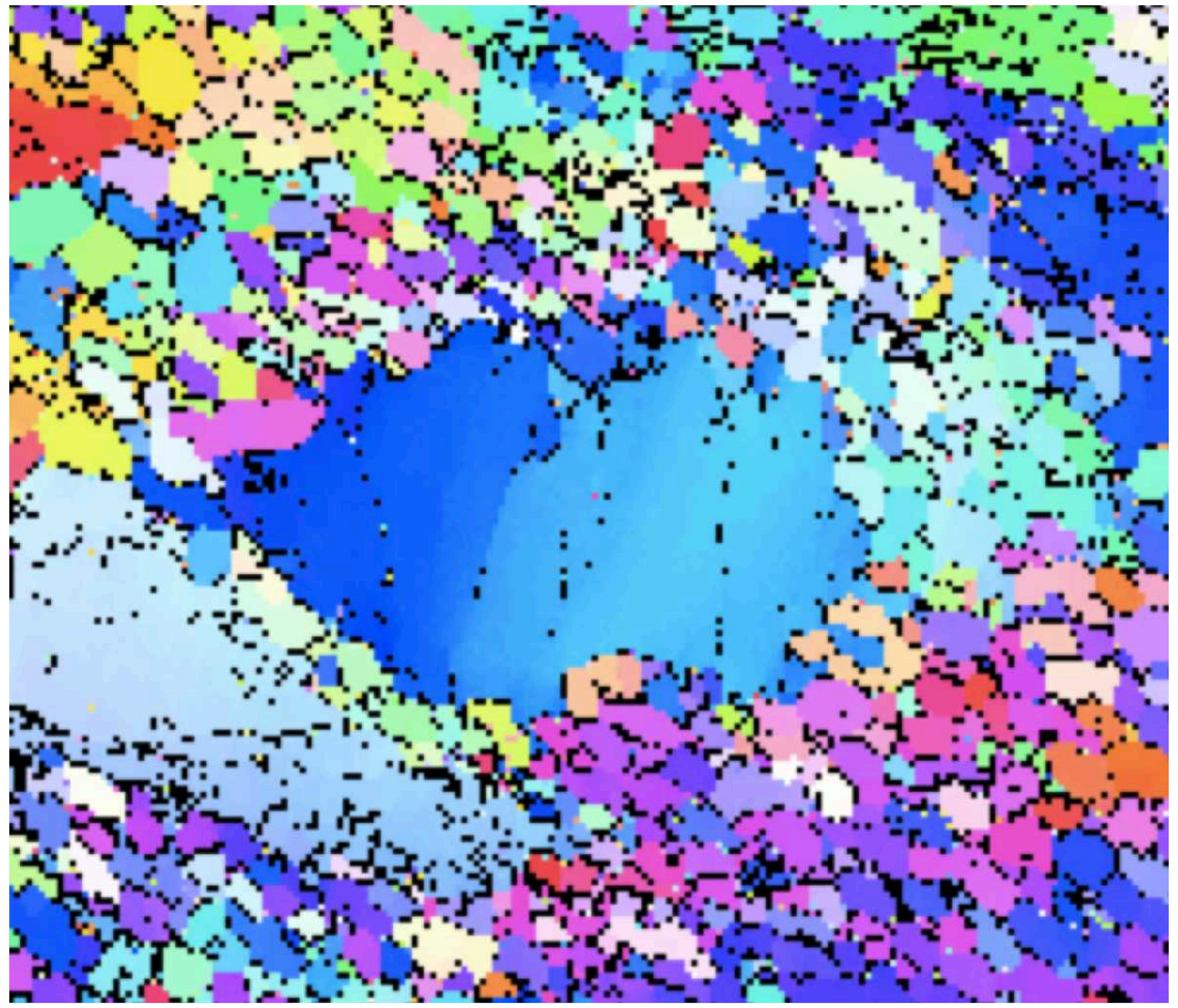
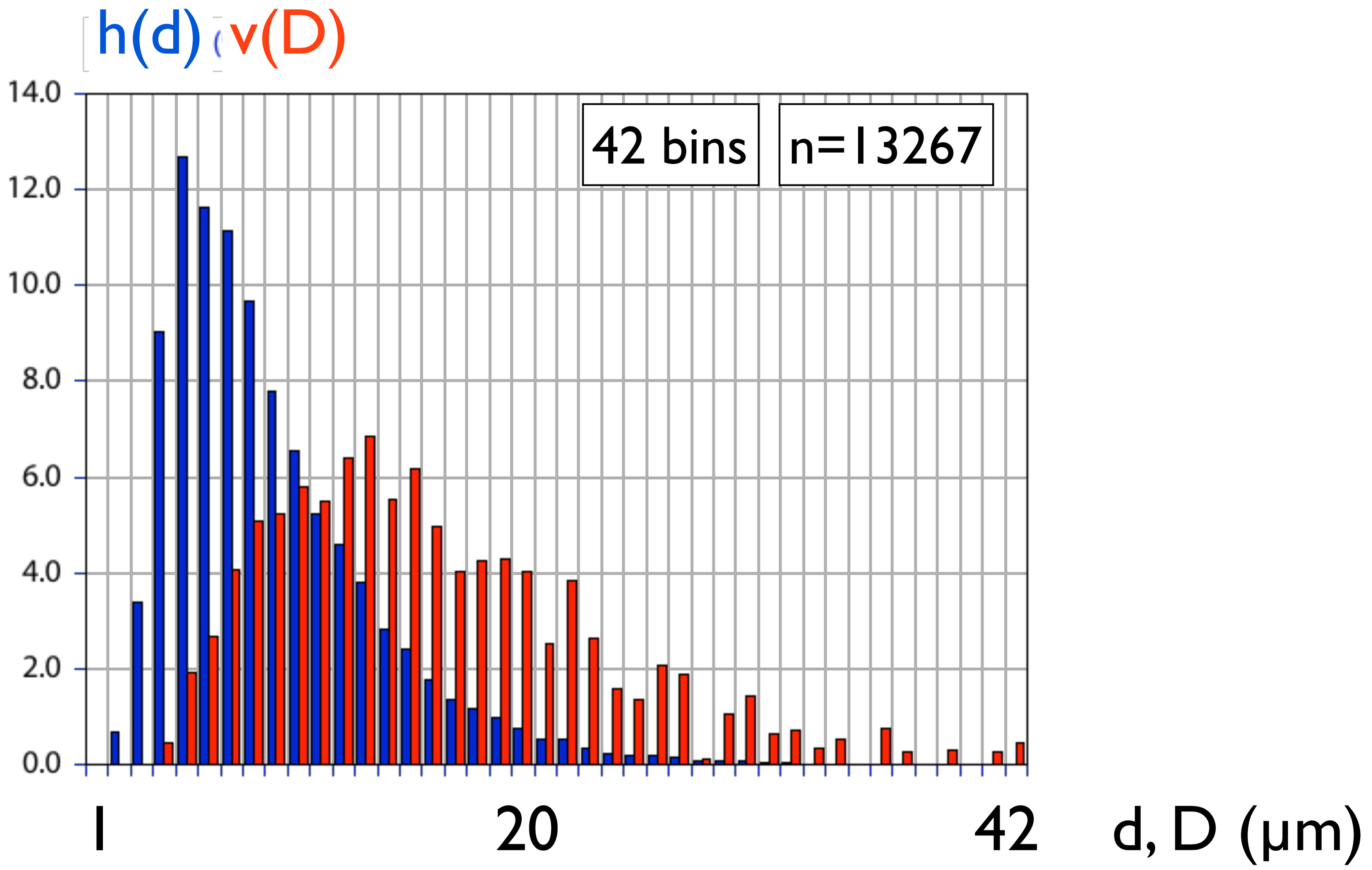


need a grain size ?



problem 1:
what is a grain ?



problem 2:
what is the grain size ?

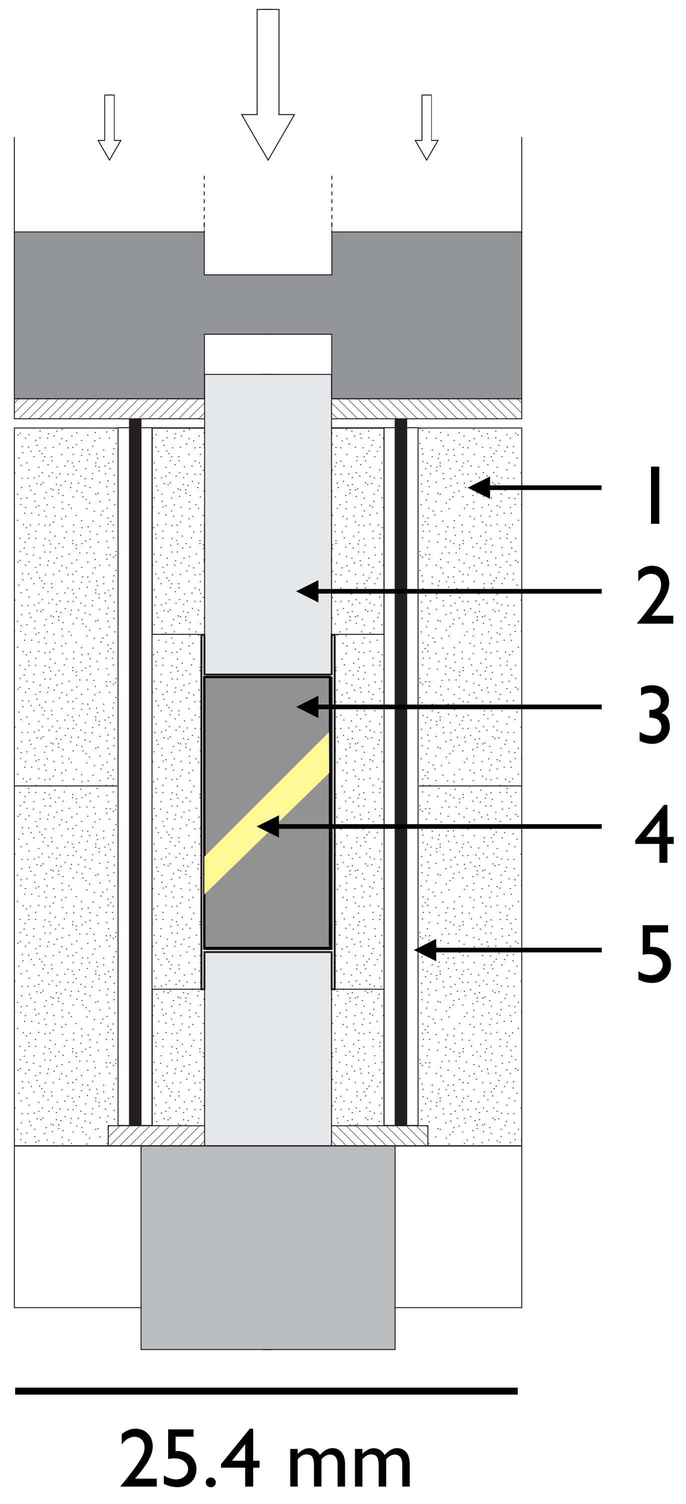
check: Heilbronner & Kilian paper in Discussion of EGU-Solid Earth

details >>

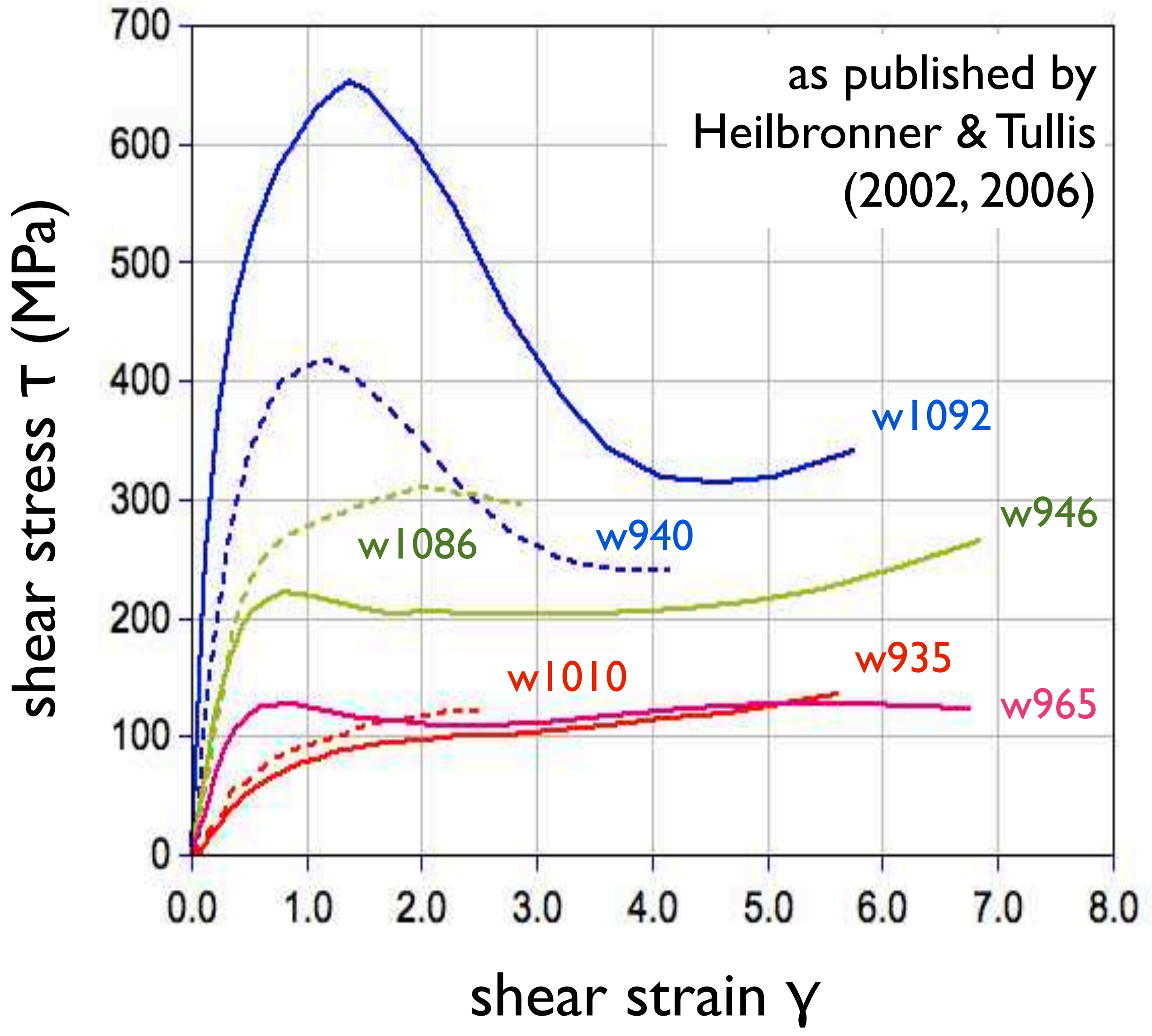
by way of an introduction (a paper submitted to EGU Solid Earth)

General shearing experiments on BHQ

(a)



(b)



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
#	Sample	Voltage (kV)	Probe current (nA)	Pressure (Pa)	Aperture (µm)	WD (mm)	Magn.	Speed (Hz)	Time (h:m)	Reflectors / Bands	Mean MAD	Hough resol.	Binning	Step size (µm)	Map size (µm · µm)	Hit rate (%)
	undeformed material:															
	BHQ	20	5.3	35	120	9.48	200x	40.5	9:19	48 / 9	0.58	120	4x4	1.0	1388 · 980	91.4
	scanned sites of experiments:															
1a	w940	20	n.a.	2	120	14.5	250x	22.6	17:50	75 / 9	0.89	70	2x2	0.5	500 · 725	44.1
1b	w1092	20	n.a.	28	120	14.47	250x	22.8	18:45	75 / 10	0.90	110	2x2	0.5	550 · 700	92.8
1b	w1092-s30	20	n.a.	n.a.	n.a.	14.7	n.a.	11.2	10:48	75 / 9	0.81	70	2x2	0.5	241.5 · 452	77.3
2a	w1086	20	3.0	20	120	14.6	150x	22.6	5:54	75 / 9	0.90	70	2x2	0.5	600 · 200	72.0
2b	w946	20	n.a.	28	120	13.49	300x	22.8	18:16	75 / 10	0.62	110	2x2	0.5	750 · 485	94.3
3a	w1010-s34	20	9.0	25	120	14.3	200x	40.3	3:02	75 / 9	0.78	70	4x4	1.0	430 · 980	82.1
3a	w1010-s36	20	9.0	25	120	14.3	200x	11.4	2:51	75 / 9	0.84	70	2x2	1.0	500 · 830	78.5
3b	w935	20	n.a.	28	120	13.35	200x	22.8	15:58	75 / 10	0.57	110	2x2	0.9988	1275.5 ·1025.8	93.1
3b	w965-s40	20	6.0	25	120	15.0	150x	40.3	14:28	75 / 9	0.82	70	4x4	1.0	840 · 700	76.9
3b	w965-s45	20	3.0	20	120	148	250x	22.6	14:00	75 / 10	0.75	70	2x2	0.25	180 · 400	89.0

General shear experiments on Black Hills quartzite.
(a) Simplified drawing of sample assembly for general shear experiments: 1 = confining medium (NaCl), 2 = axial load/ σ1 piston (Al2O3), 3 = forcing block (Al2O3), 4 = quartzite sample at 45° with respect to σ1 piston, 5 = furnace (carbon, pyrophyllite)
(b) Shear stress (τ) versus apparent shear strain (γ): blue = regime 1, green = regime 2, red = regime 3, stippled line = relatively low finite strain, solid line = relatively high finite strain (compare Table 1).

Research article 20 Mar 2017

The grain size(s) of Black Hills Quartzite deformed in the dislocation creep regime

Review status
This discussion paper is under review for the journal Solid Earth (SE).

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these are the samples from regime 1 to 3, low to high strain

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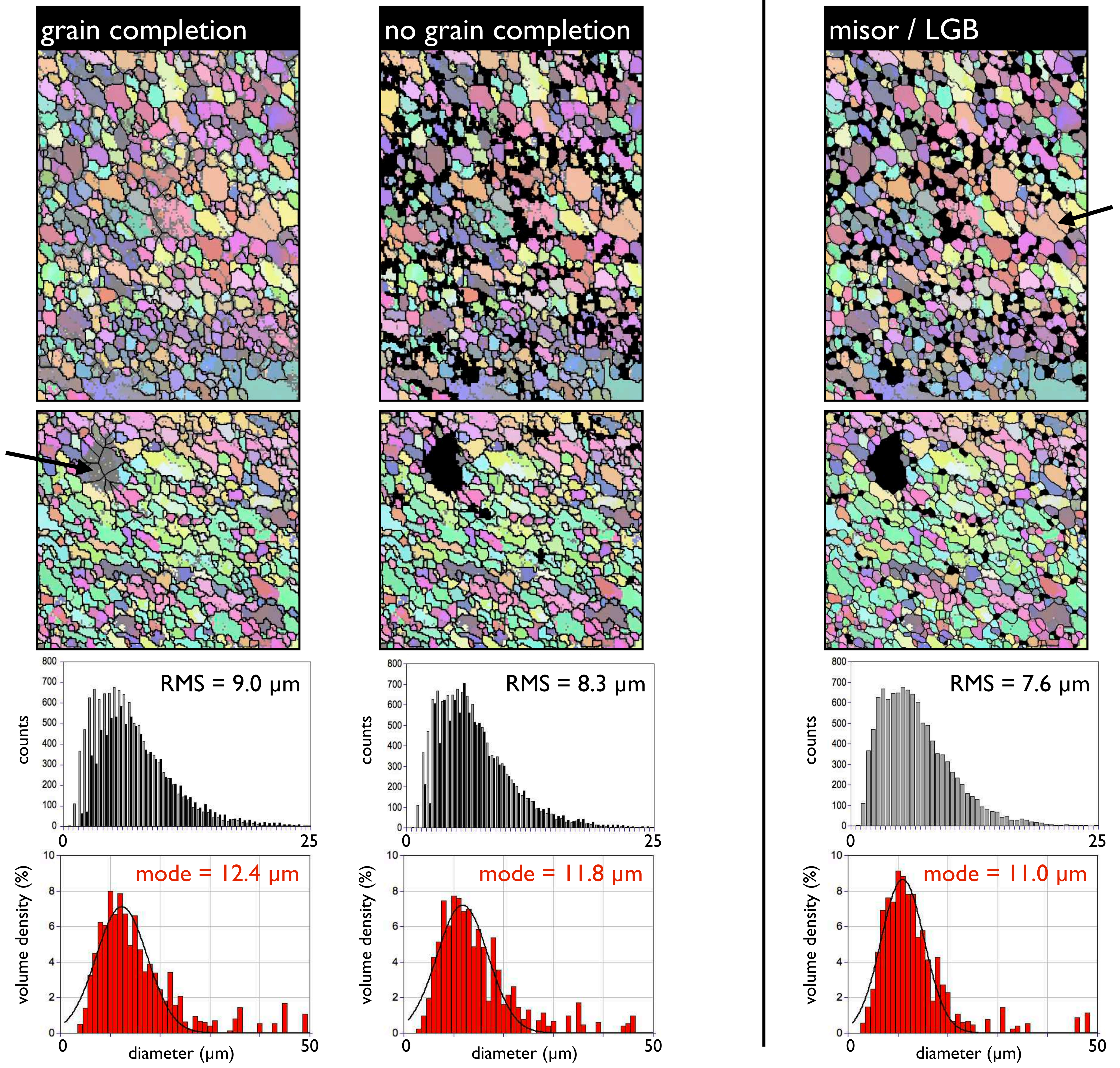
find the grains - find the grain boundaries !

full texture, hexagonal symmetry (EBSD)
region based

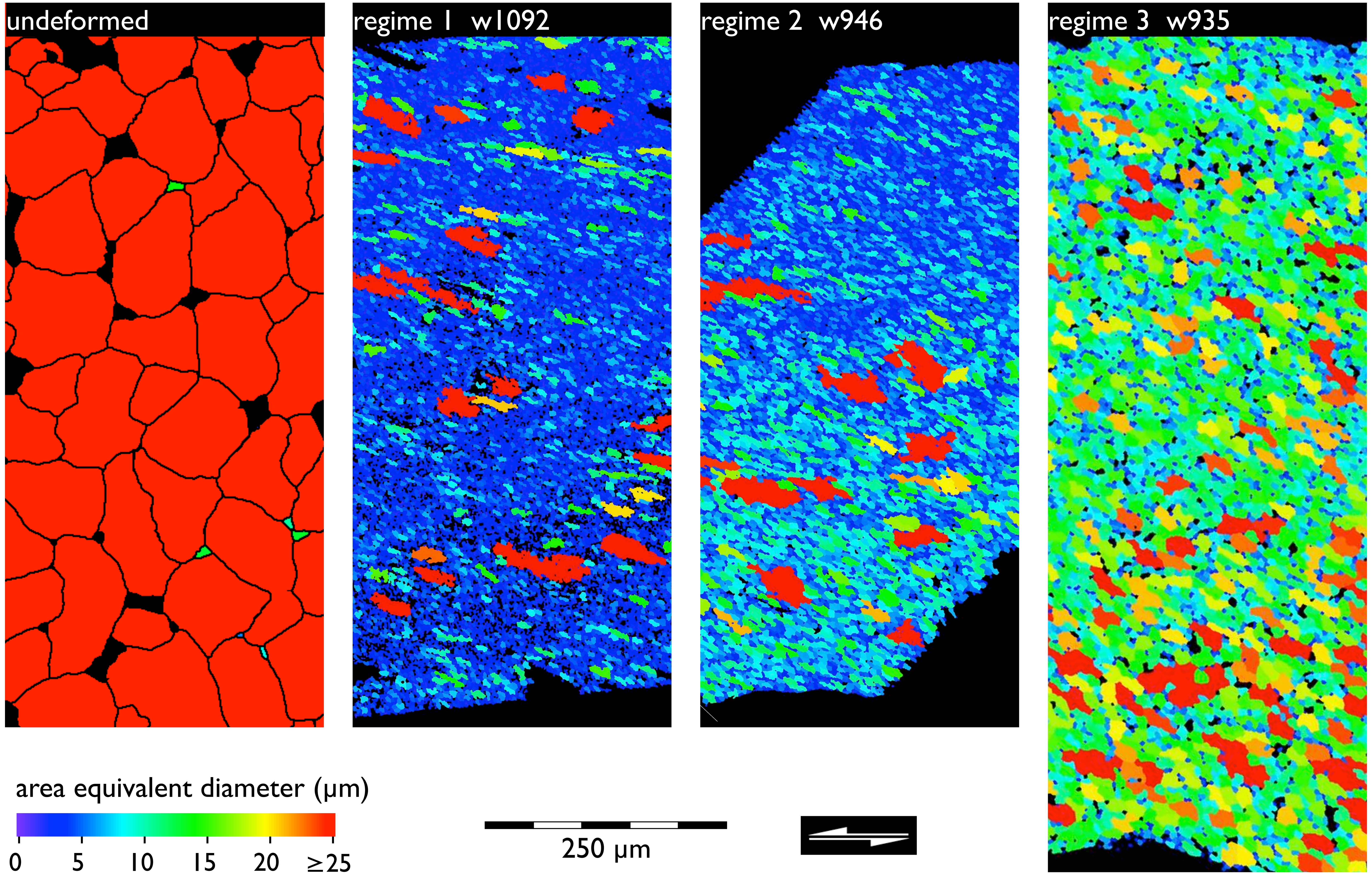
c-axis texture (CIP)
boundary based



Segmentation based on texture.
Comparison of segmentations based on full texture (EBSD) and c-axis texture and shape (CIP).
From top to bottom:
Grain boundaries superposed on Euler RGB image, area with relatively low (~78%) indexing ratio. Arrow points to low angle grain boundary that is detected through structural filtering.
Area with relatively high (~94%) indexing ratio. Arrow points to segmentation artefact.
Frequency distributions, h(d), d = diameter of area equivalent circle: black = EBSD segmentation, grey = CIP segmentation, root-mean-square values are indicated.
Volume density distributions, v(D), D = diameter of volume equivalent sphere, derived from input h(d) using stripstar (see text), modal values are indicated.

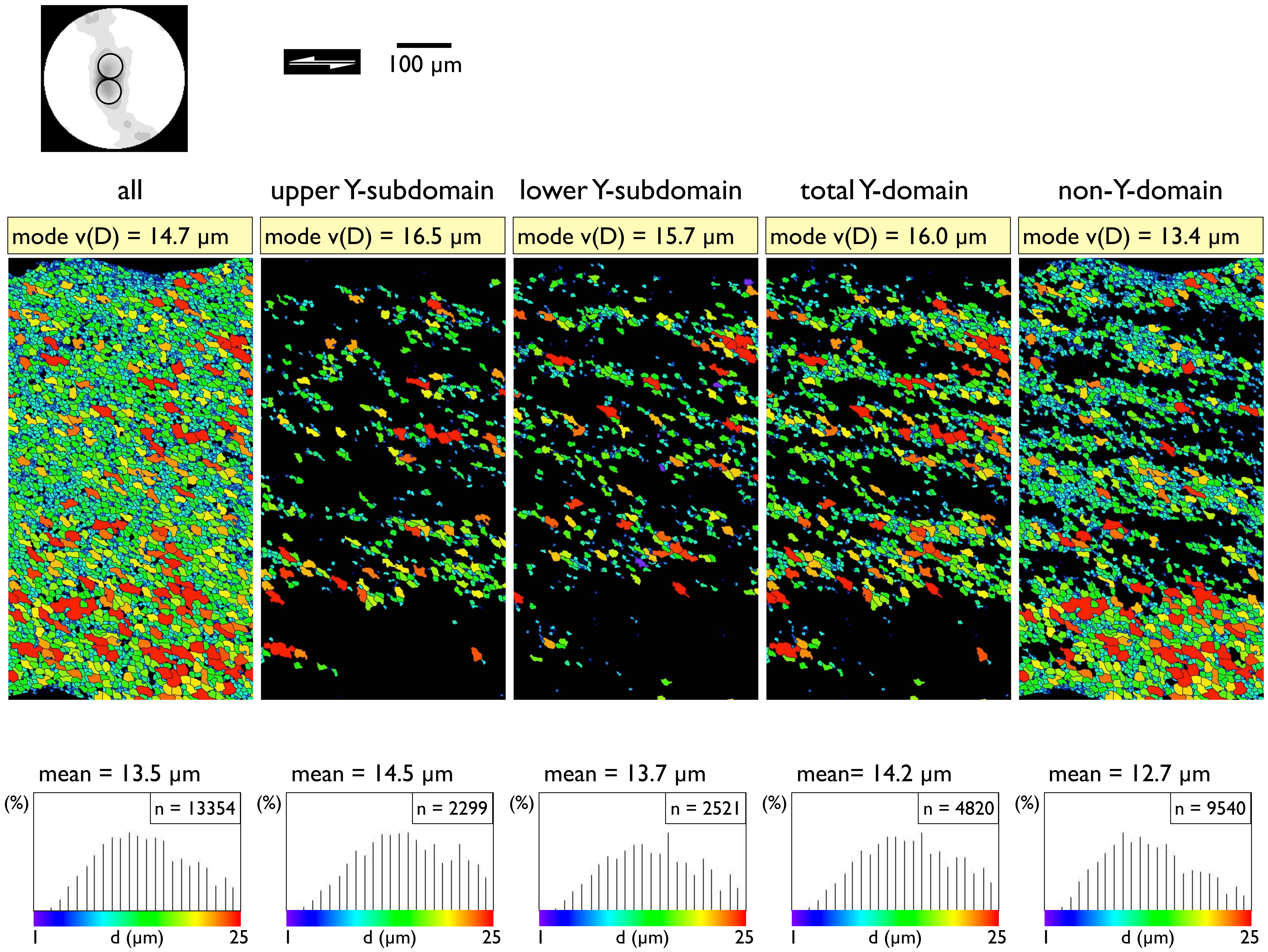
(a) Segmentation using full texture assuming hexagonal symmetry of quartz and grain completion (see text).
(b) Same as (a) without grain completion.
(c) Segmentation using c-axis orientations only (see text).

show the grain size on maps



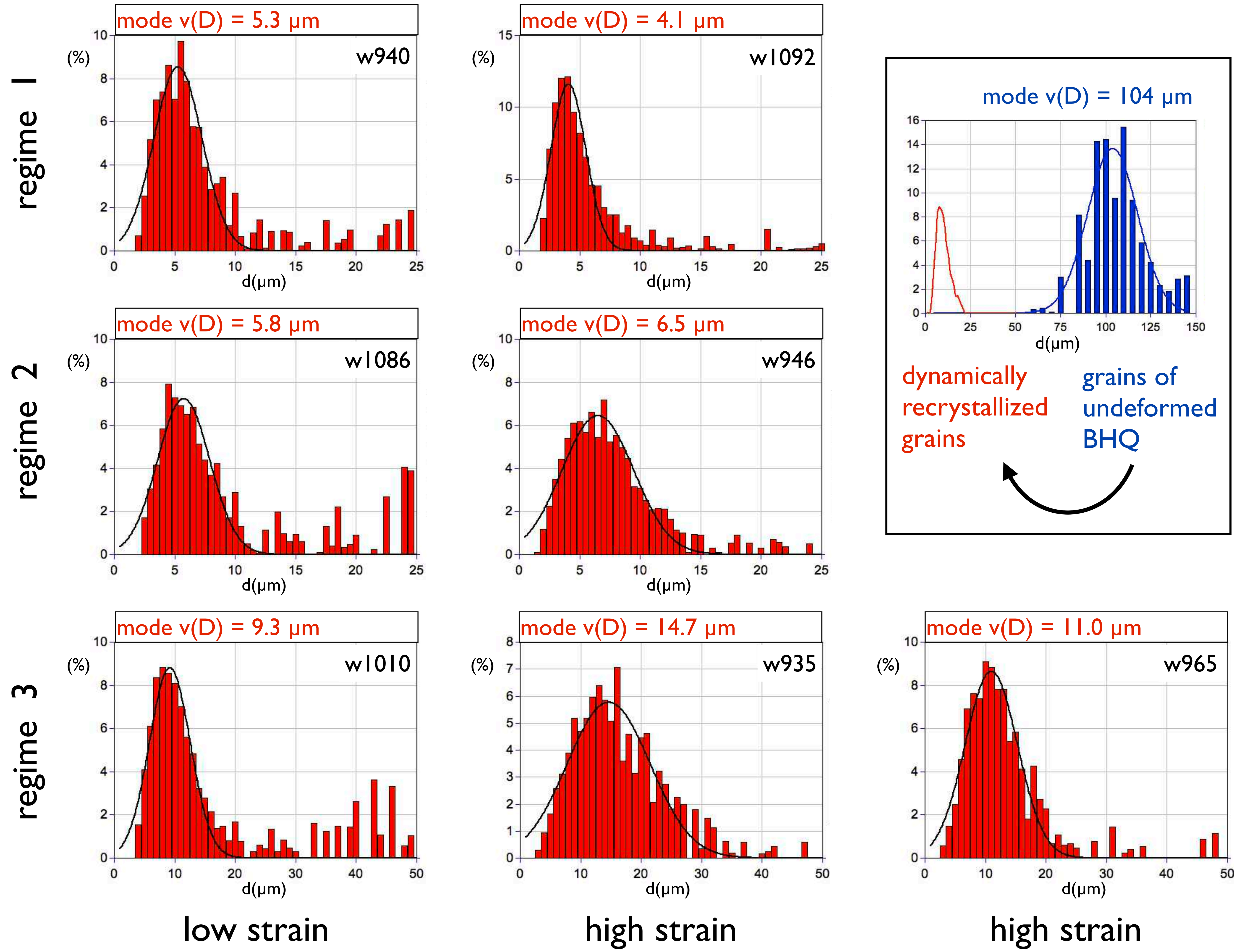
Grain size maps.
Color coded grain size maps visualizing the diameter of area equivalent circles, d
From left to right: for undeformed Black Hills quartzite and samples deformed in regime 1, 2 and 3. Scale, shear sense, and look-up table for grain size apply to all. Red indicates the diameter of an area equivalent circle d ≥ 25 µm. Note, the diameter of undeformed Black Hills quartzite is ~ 100 µm.

map the grain size in texture domains



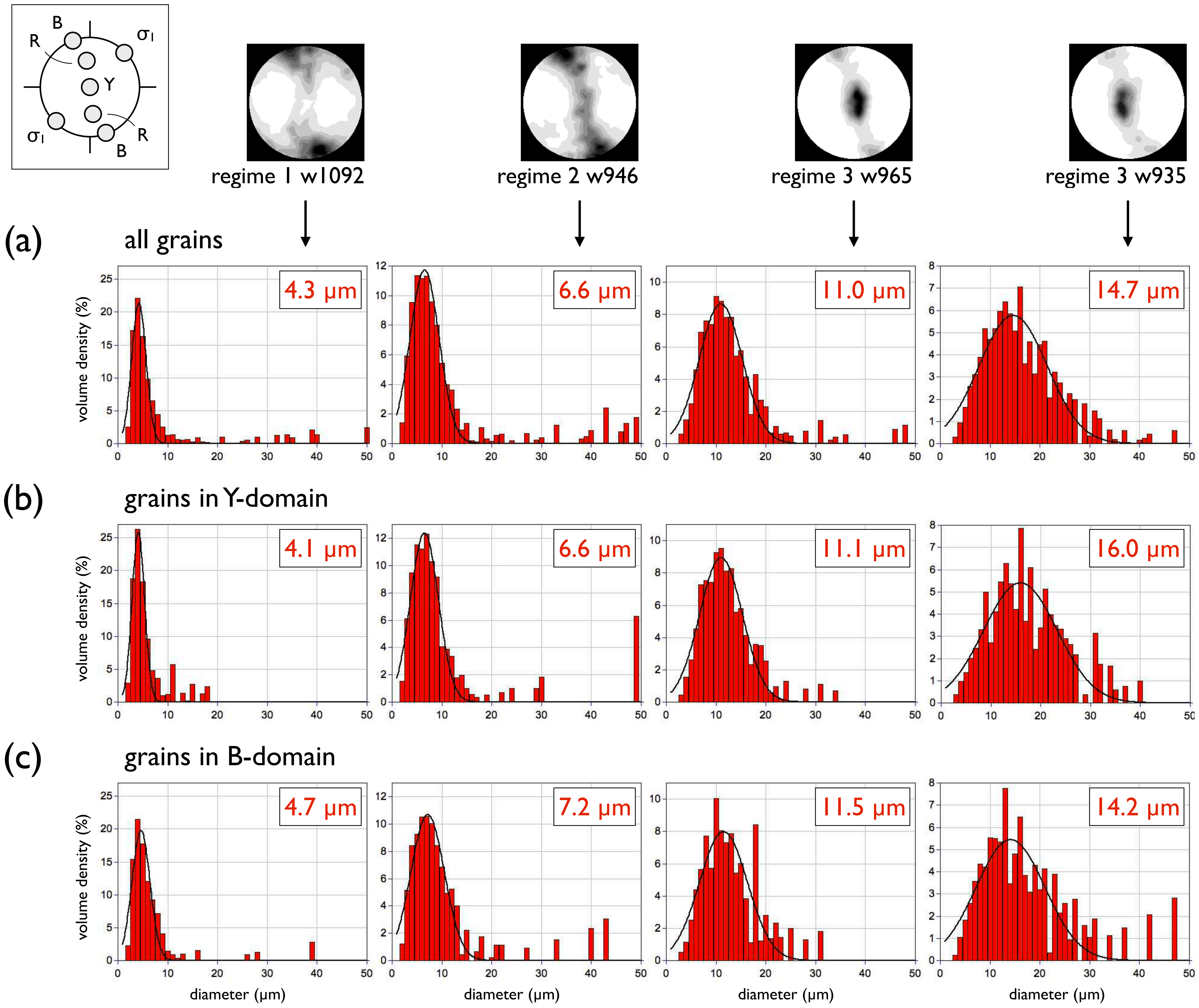
Mapping grain size in texture domain.
Grain size maps of detail of sample w935 (regime 3) are shown. From left to right: showing all grains, grains in the upper and lower Y-subdomains, in the whole Y-domain and for c-axis orientations outside the Y-domain (see c-axis pole figure), same subdomains as in Figure 7. Domain maps are derived for c-axes orientations within a 30° cone (15° opening angle) with respect to the central orientation. Scale bar and shear sense apply to all.
Above maps:
Modes of v(D) are indicated above maps, where v = volume density distribution, D = diameter of volume equivalent sphere.
Below maps:
Histograms showing area weighted distributions of grain size (= grey value histogram of gain size map, see Heilbronner & Barrett, 2014 chap. 12), n = number of grains, mean = arithmetic mean of histogram. Note that the grain size in the Y-domains is larger than in the non-Y-domain, but the difference between upper and lower Y-subdomain is not considered significant.

find 'the' grain size for regime 1, 2, and 3



Recrystallized grain size for dislocation creep regimes 1, 2, and 3.
Volume weighted histograms v(D) are shown for 7 samples for relatively low (2.7 < γ < 4.3) and high shear strains (5.8 < γ < 7.1).
D = diameter of volume equivalent sphere. The mode of v(D) is obtained by a Gauss fit to the distribution.
Note histograms with different size ranges: (0 < D < 25 μm) for regime 1 and 2, (0 < D < 50 μm) for regime 3.
Inset shows the grain size distribution of undeformed Black Hills quartzite for comparison.

find the grain size as function of texture



Recrystallized grain size as function of texture.
Grain size distributions of recrystallized grains for four samples of regime 1, 2, and 3 of dislocation creep, arranged in 4 columns with c-axis pole figure above.

(a) Grain size distributions of all recrystallized grains.
(b) Grain size distributions of recrystallized grains with c-axis orientations within 30° cone (15° opening angle) about Y direction.
(c) Same as (b) for B direction.

Inset (upper left) shows location of c-axis orientations of B- and Y-domain on the pole figure.

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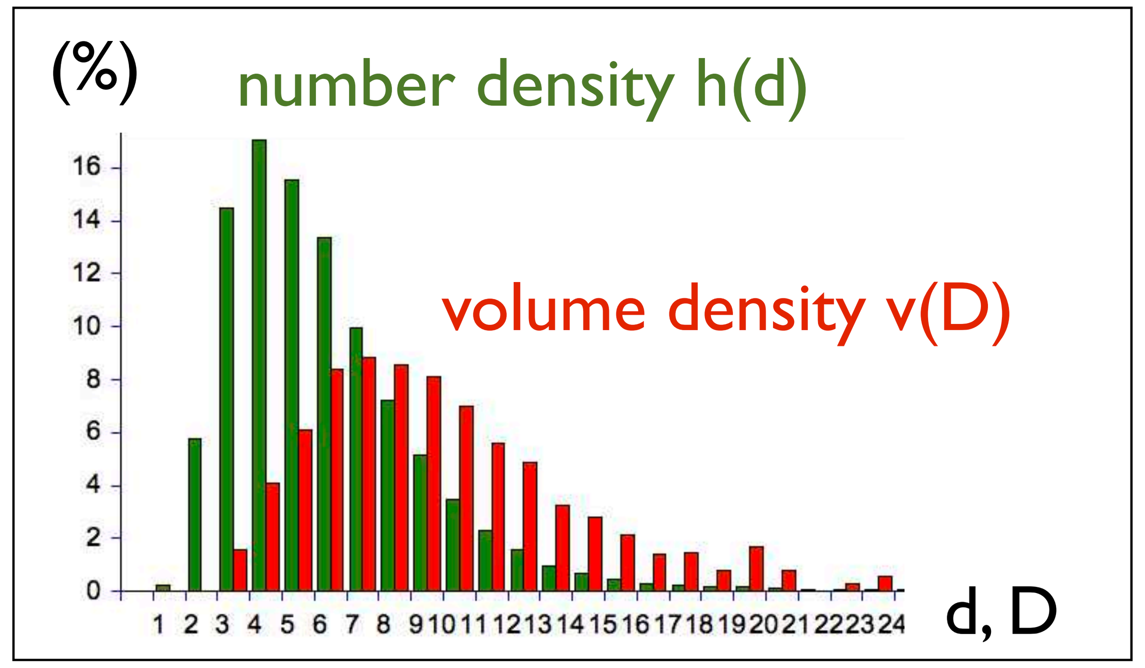
plot the grain sizes as function of flow stress

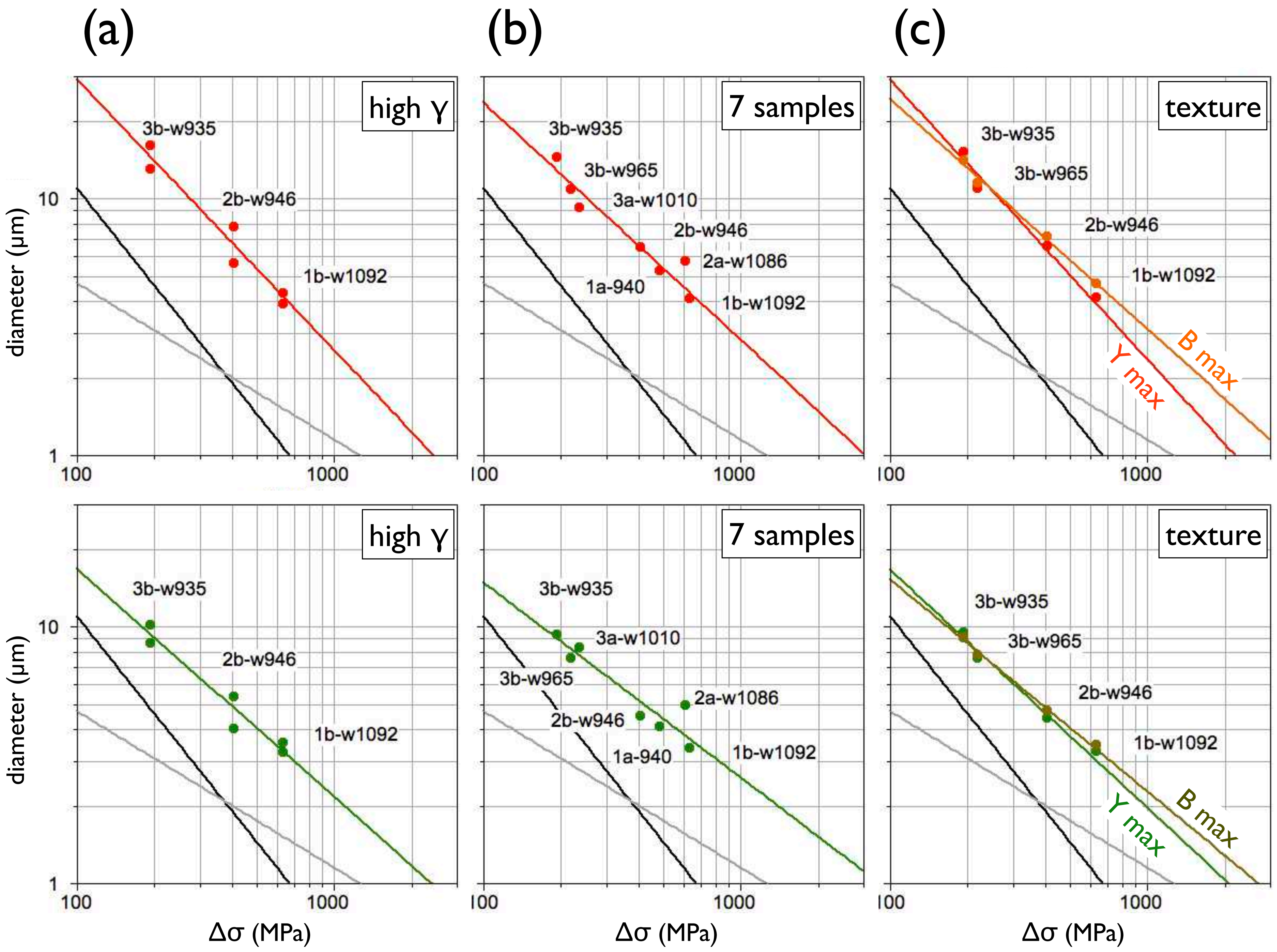


— RMS of h(d)
— mode of v(D)

d = diameter of 2D circles
D = diameter of 3D spheres

Piezometer of Stipp & Tullis (2003):

— $d(\mu m) = 3631 \cdot \Delta\sigma^{(-1.26)}$ regime 2 & 3
— $d(\mu m) = 78 \cdot \Delta\sigma^{(-0.61)}$ regime 1



Recrystallized grain size as function of flow stress.
Two measures of average grain size are plotted against differential stress, Δσ (with $\Delta\sigma = 2\cdot\tau$, see Table 1).
Top row: Mode of v(D), where D = diameter of volume equivalent sphere, and v = volume weighted frequency distribution (=3-D mode).
Bottom row: Root-mean-square of h(d), where d = diameter of area equivalent circle, and h = frequency distribution, as used for the piezometer relation by Stipp & Tullis (2003) (= 2-D RMS).

(a) High strain experiments ($5.8 < \gamma < 7.1$): in each case, higher value from low gKAM region, lower value for high gKAM region (see Figure 6).
(b) One measurement for each experiment (see Figure 1, Table 1).
(c) Grain sizes of Y- and B-domains (see Figure 7, 8)

and now for the details !

... on the process of segmentation:

EBSD / mtex segmentation - CIP segmentation

noise filtering - segmentation

comparison   mtex - Lazy grain boundary

segmenting CIP-type misorientation images

grain from misorientation images

segmenting CIP-type orientation gradient images

grains from orientation gradient images

comparing grain size maps

big difference - small difference ?

... on finding the correct grain size:

choosing a mean grain size

the influence of bin size

the influence of sample size

no access to stripstar ?!   ... fake it !

filled - not filled

compare segmentations

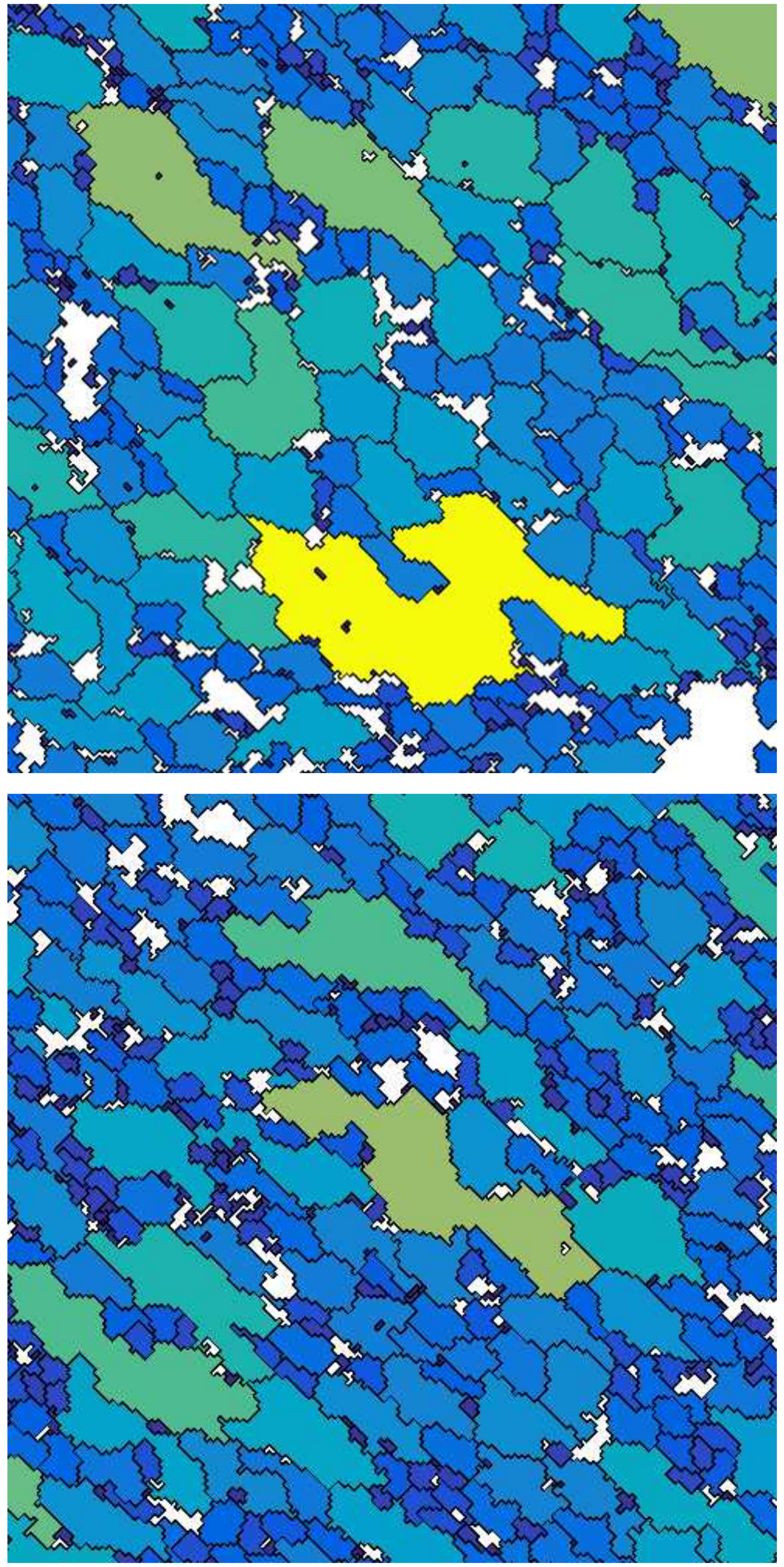
Abstract

EBSD data acquisition, image processing and segmentation

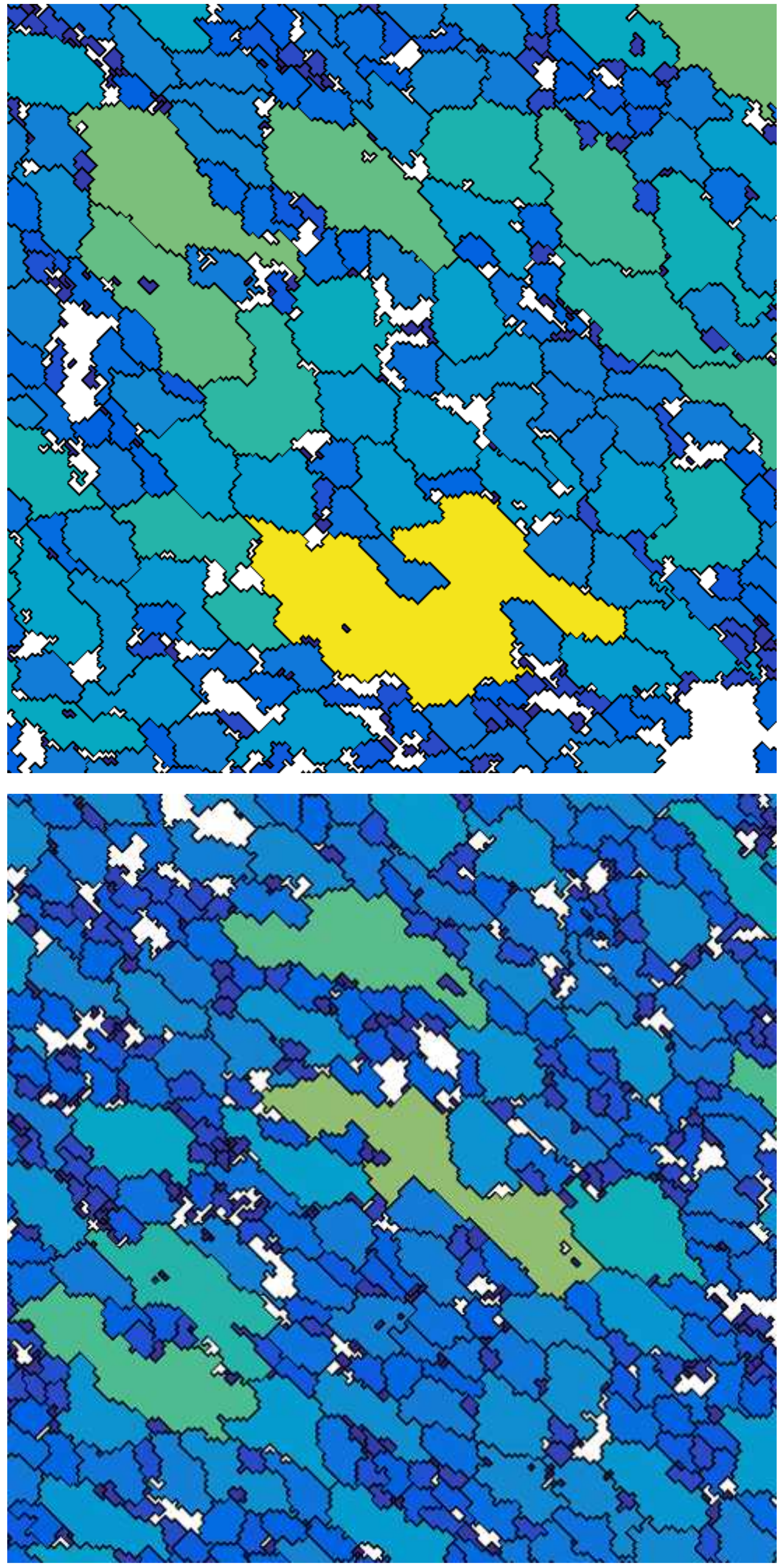
Grain size measurements

EBSD / mtex segmentation - CIP segmentation

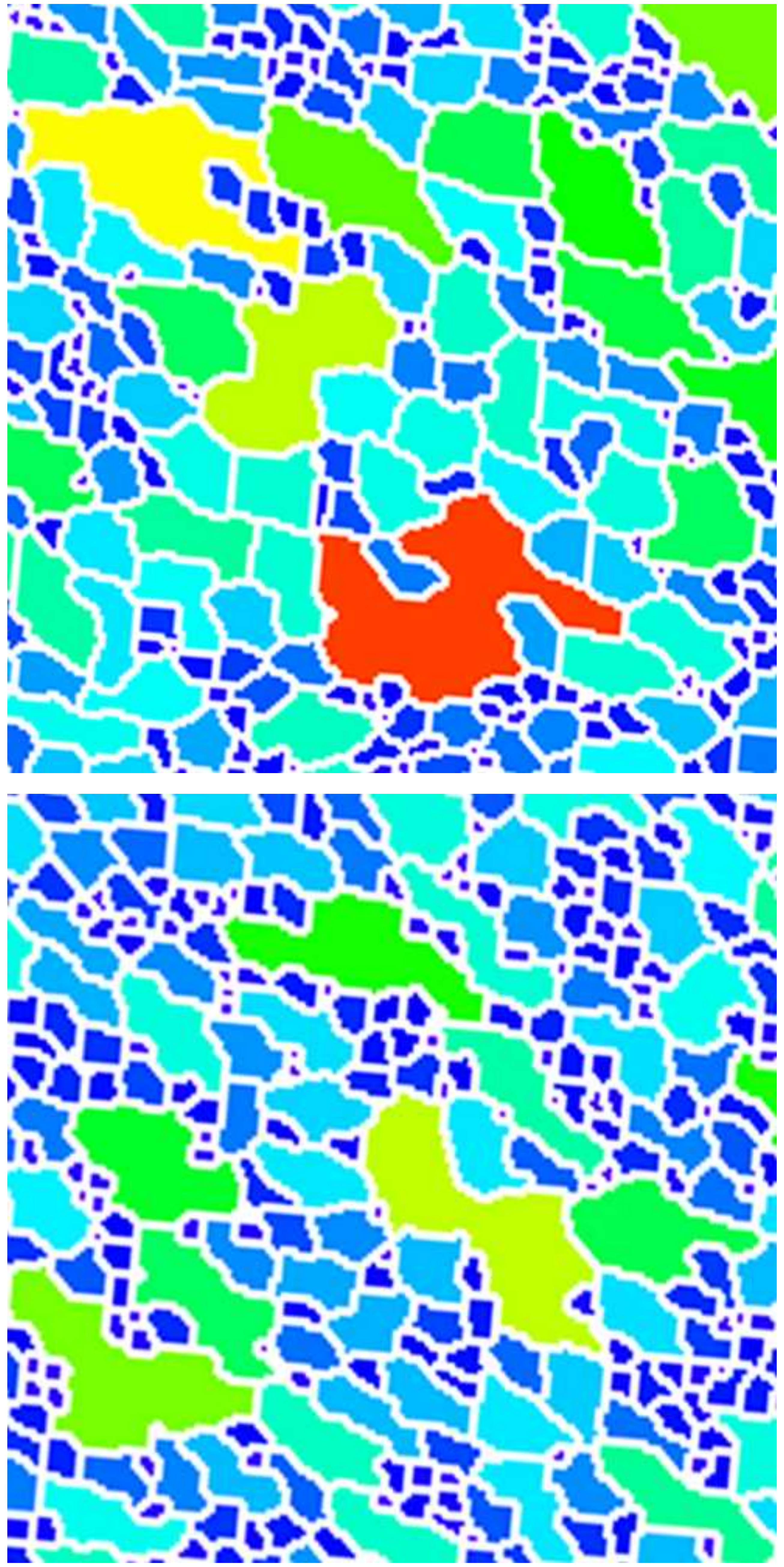
seg >6° misorientation



seg >3° misorientation

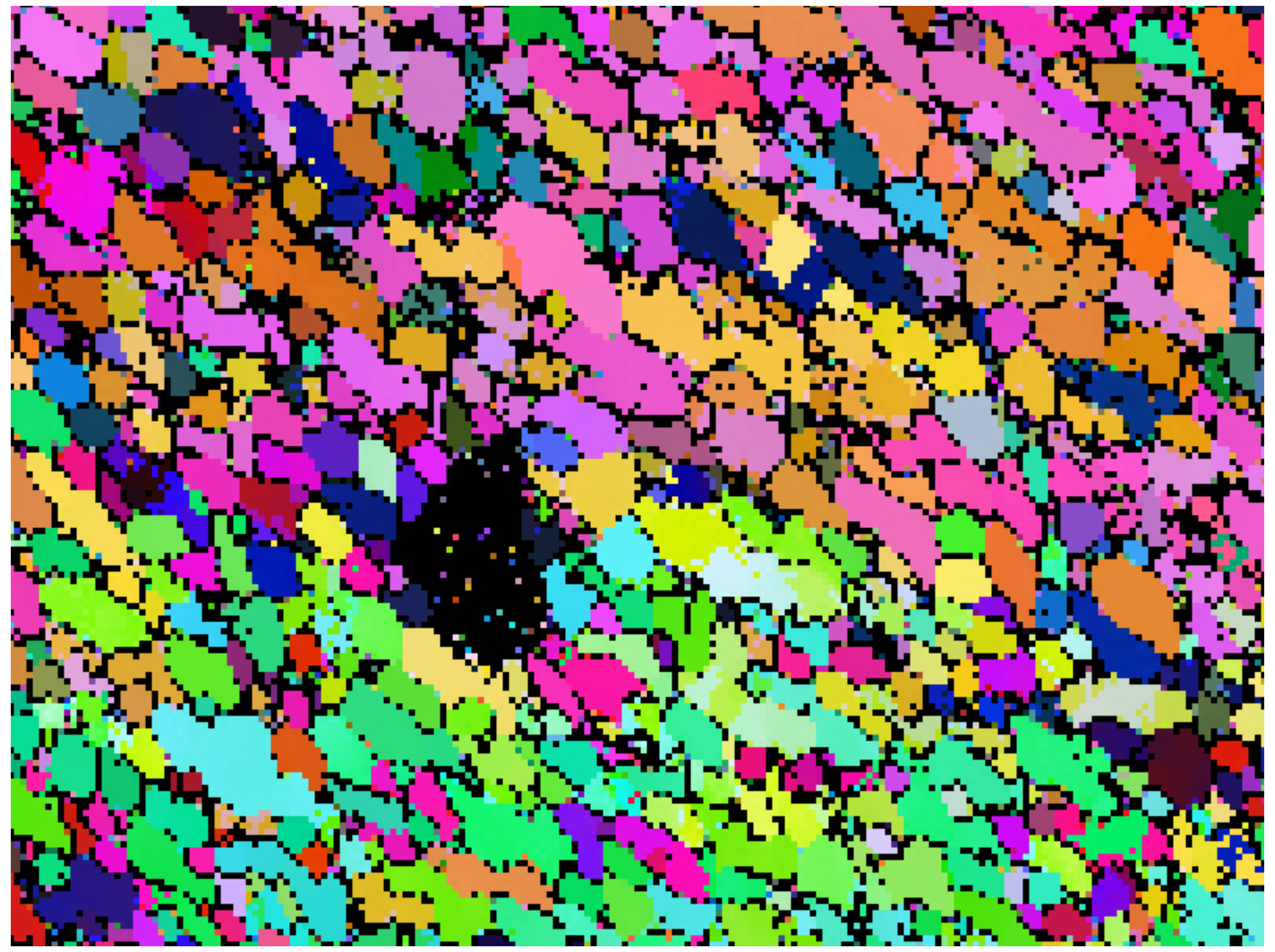


CIPseg > 1° EDG8a & tji

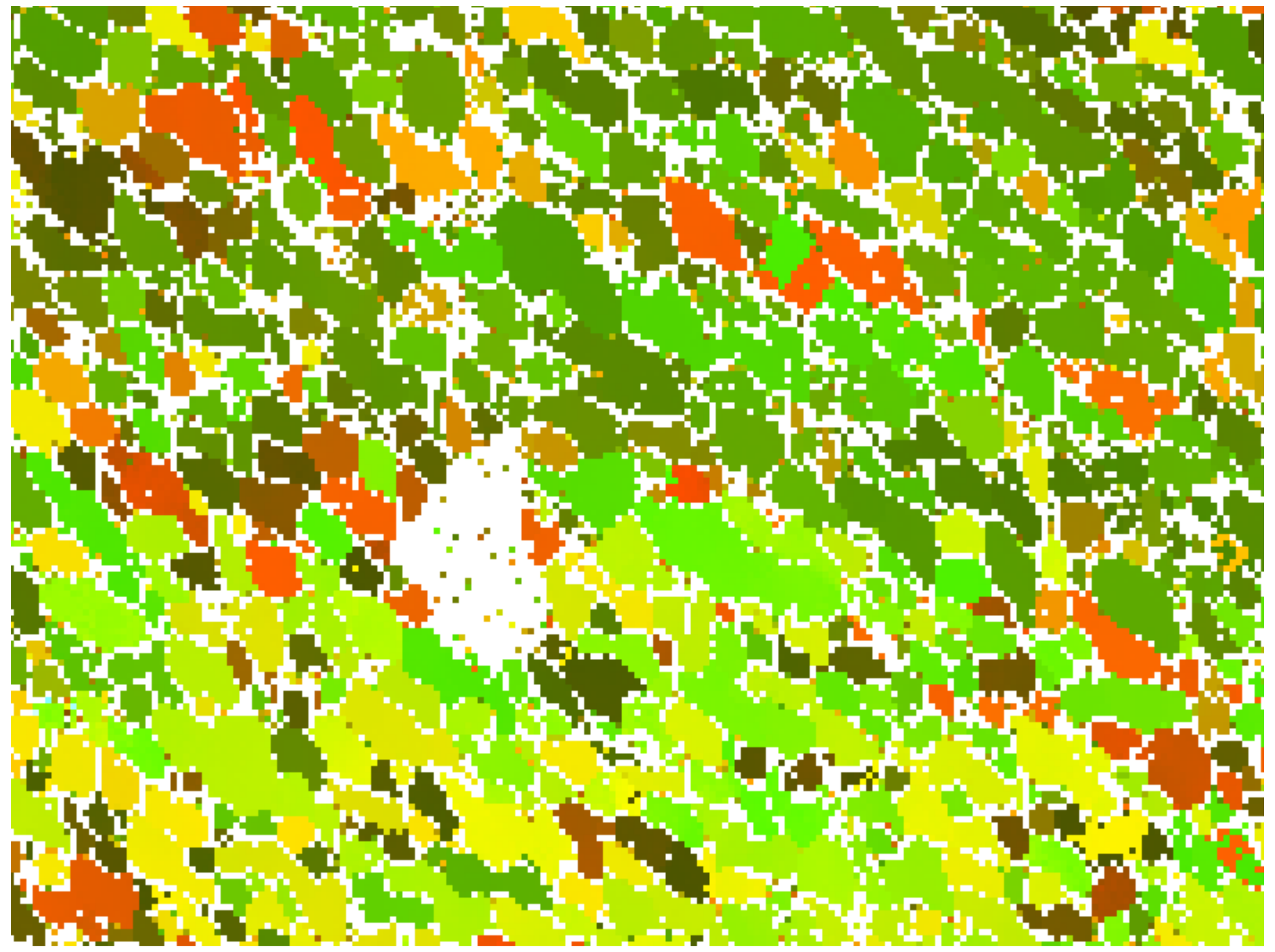


<< details >>

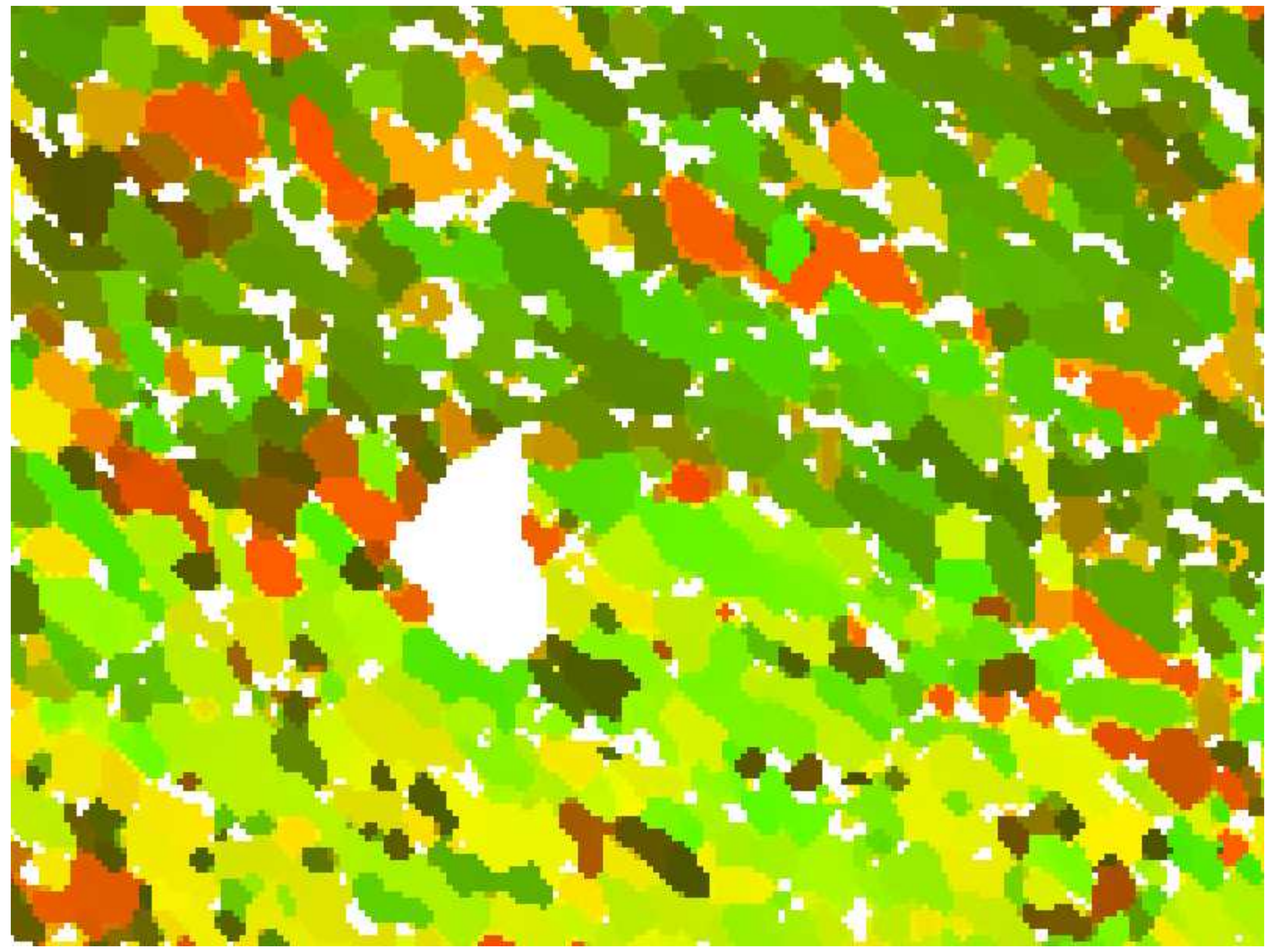
noise filtering - segmentation



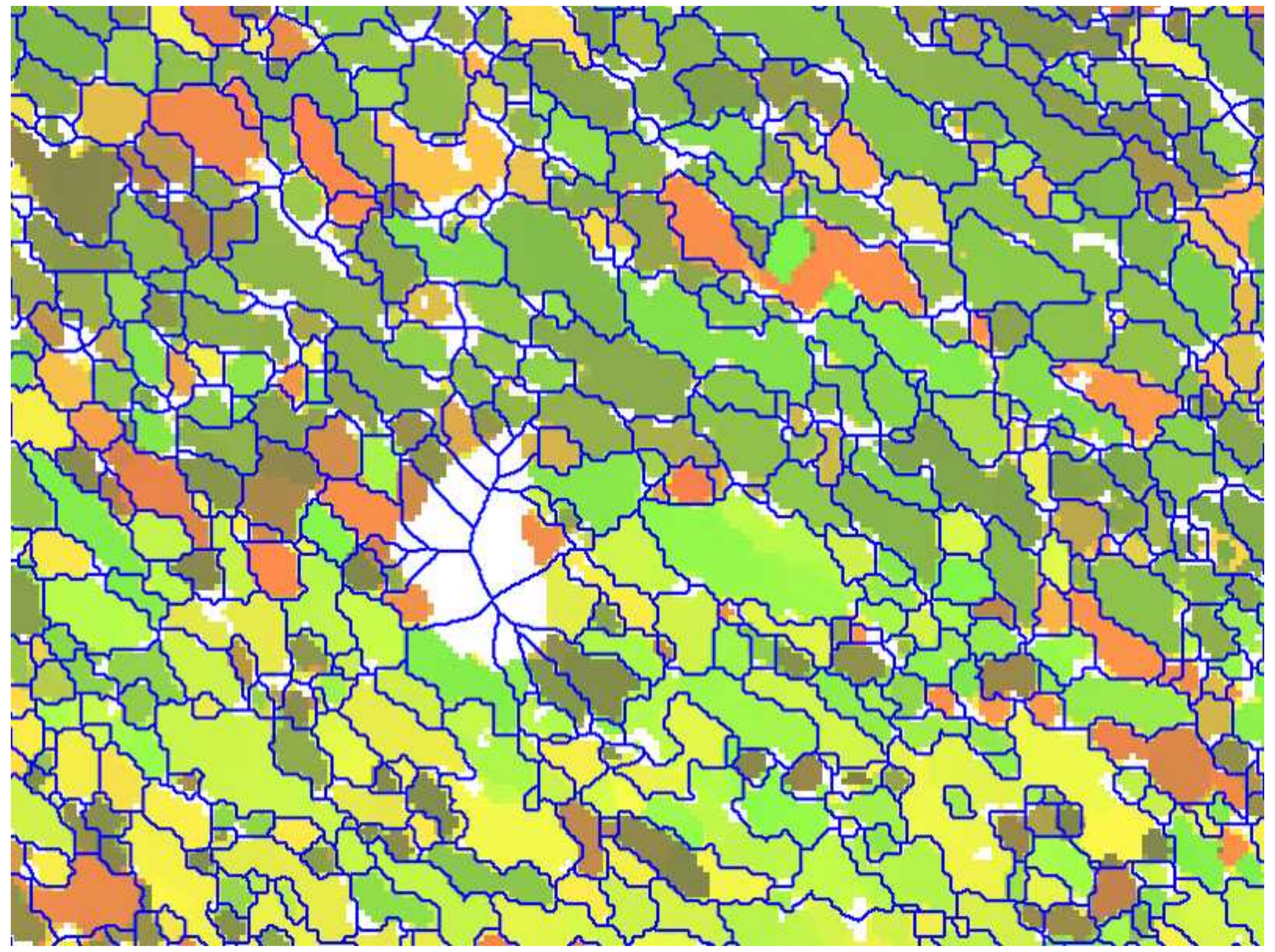
(1) Euler



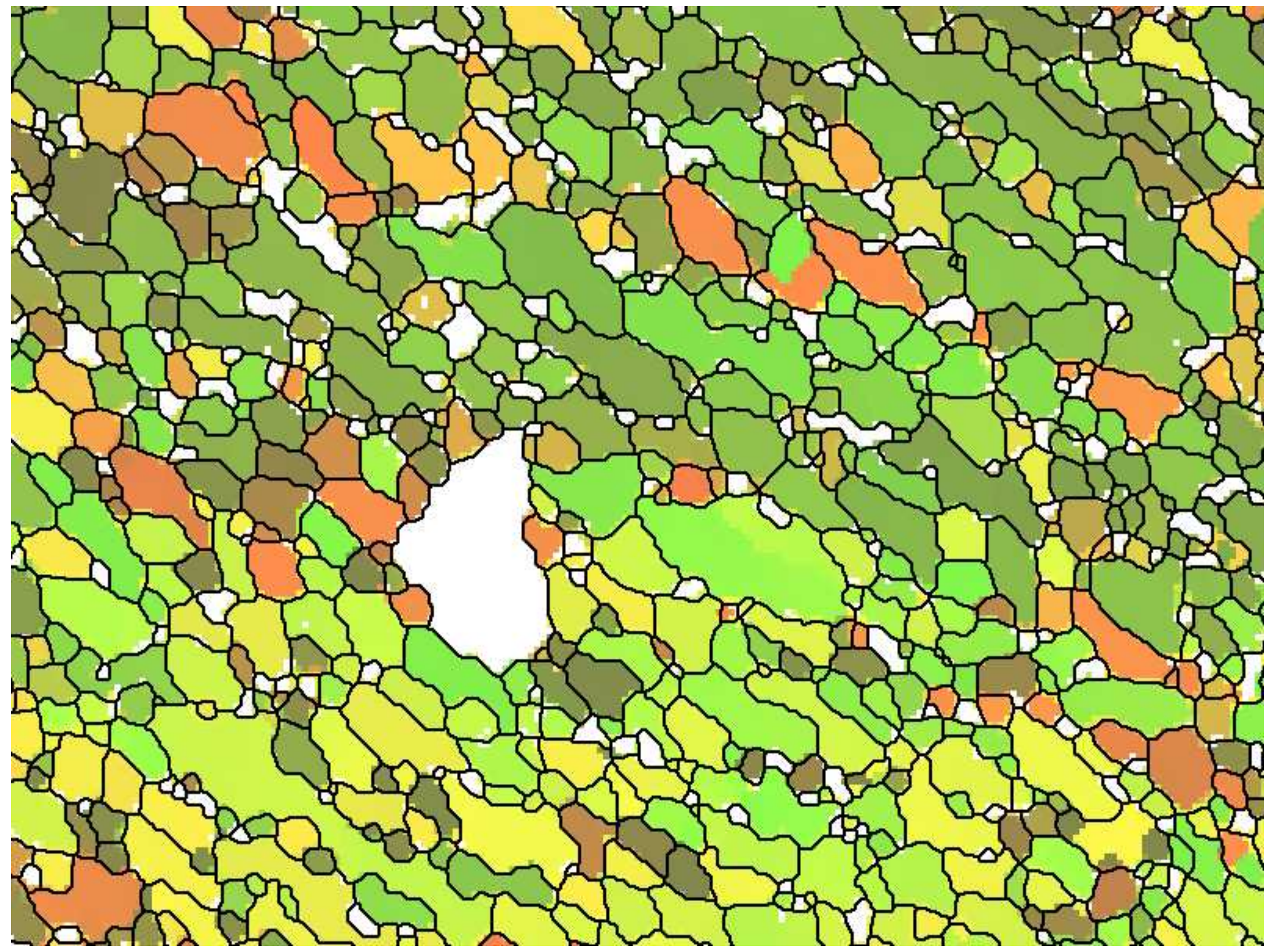
(2) azi inc mask



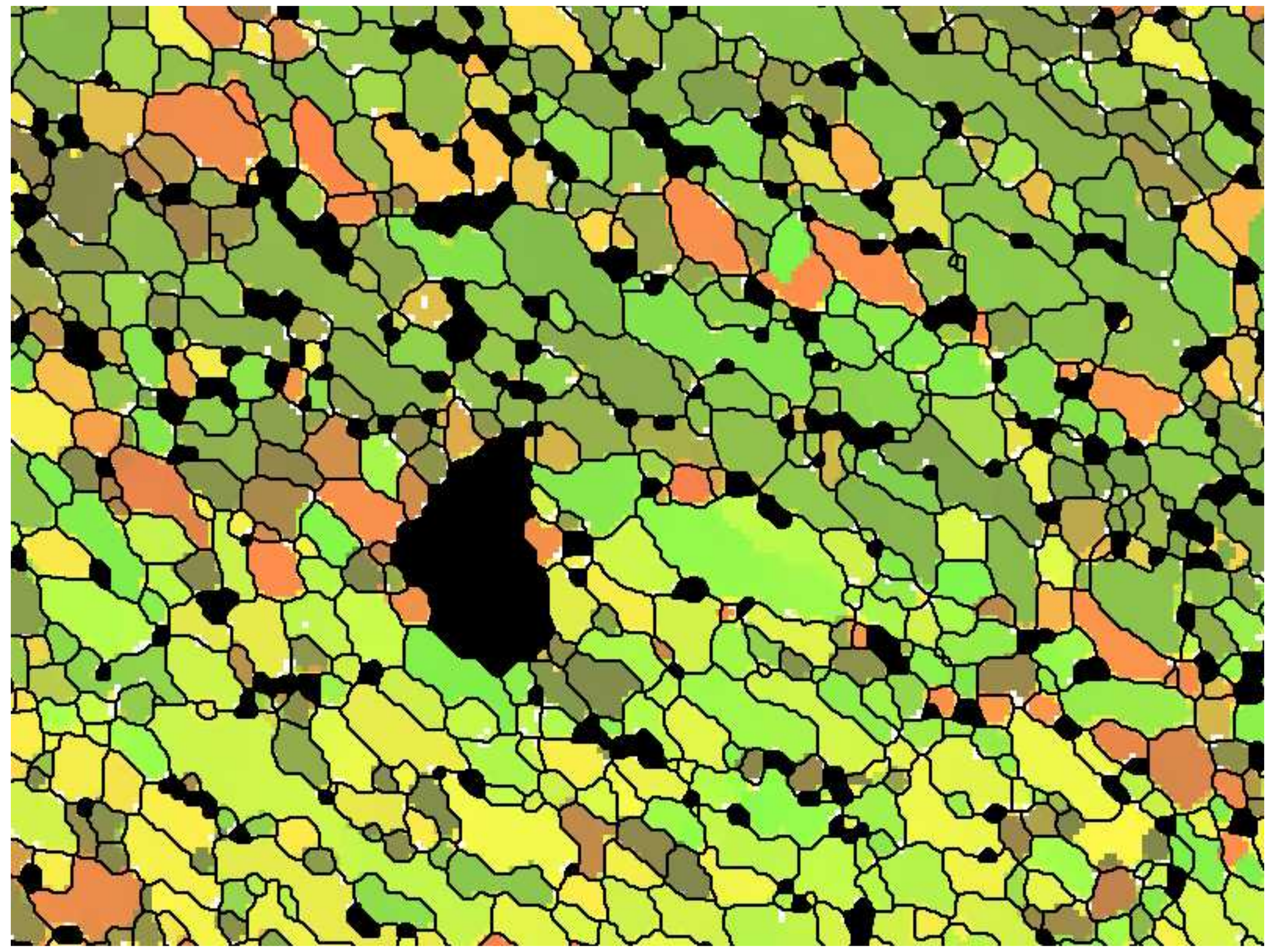
(3) azi inc mask filtered



(4) mtex grain boundaries



(5) misor grain boundaries



(6) misor grains >75%index

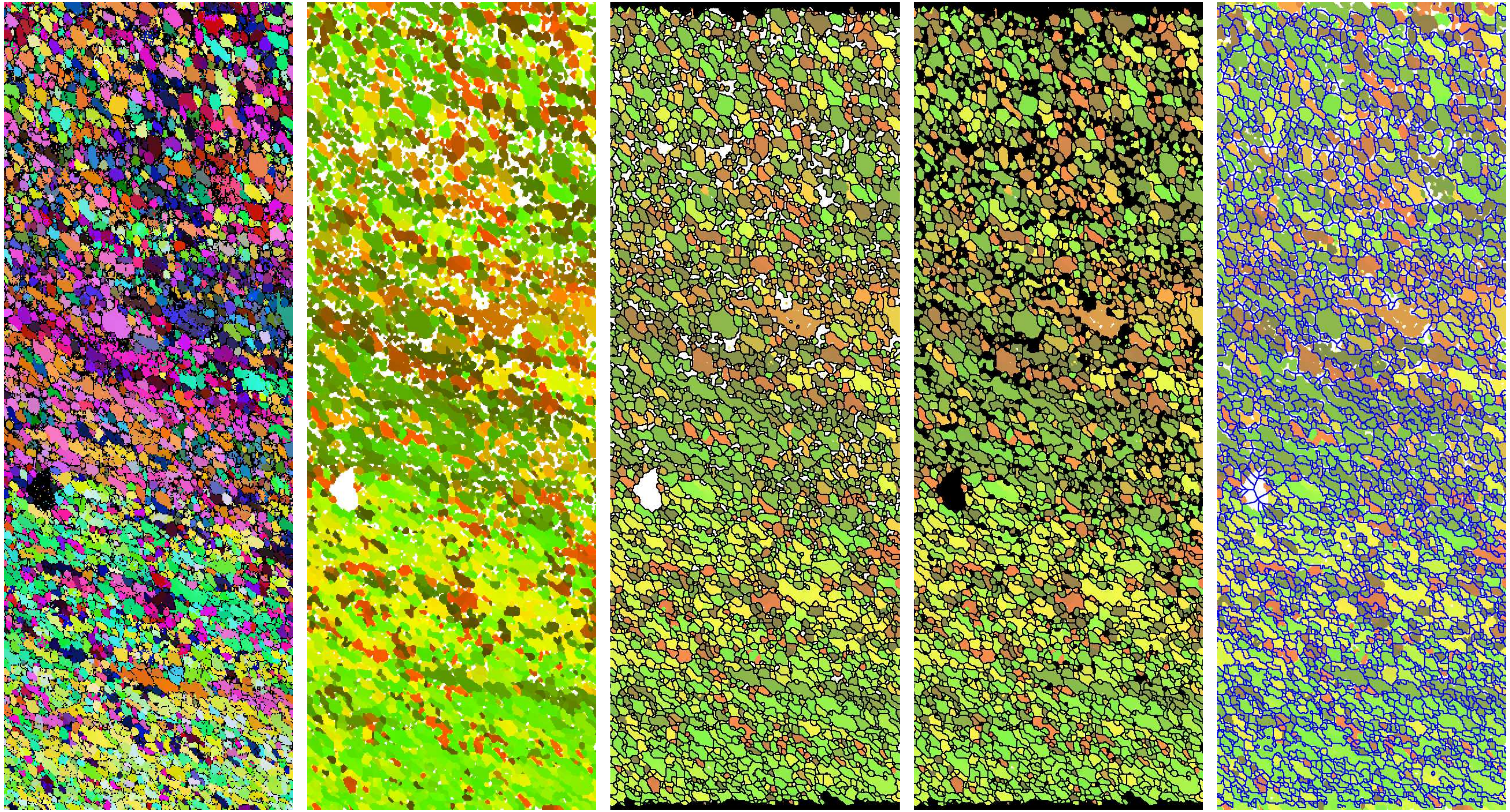
50 µm

ImageJ/Fiji > Process Noise - Outliers:
a) radius 2 color difference 1 bright
b) radius 1 color difference 1 dark

ImageSXM / Lazy grain boundaries
misorstacks mis-45-90 misE2 misH2 misN2
misr1 misr2 misr3 misr4

<< details >>

comparison   mtex - Lazy grain boundary



Euler   azi inc filtered   + misor gb   + misor gb >75%index   + mtex gb

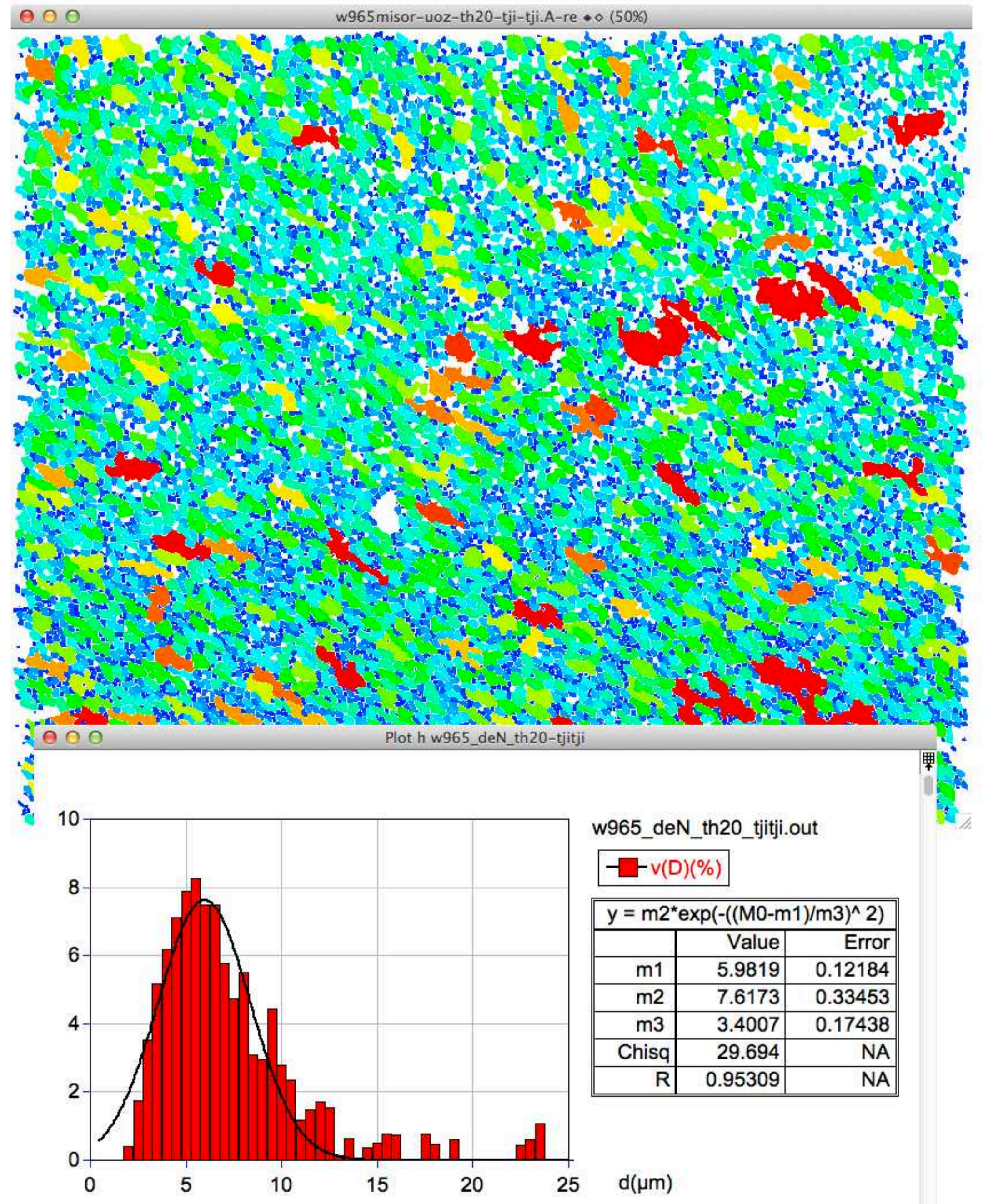
<< details >>

segmenting CIP-type misorientation images

<< details >>

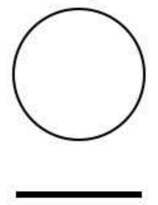
grains from misorientation images

w965_deN.misor-uoz-th20-tji-tji



number of particles: 10203

starting grain size 104 µm



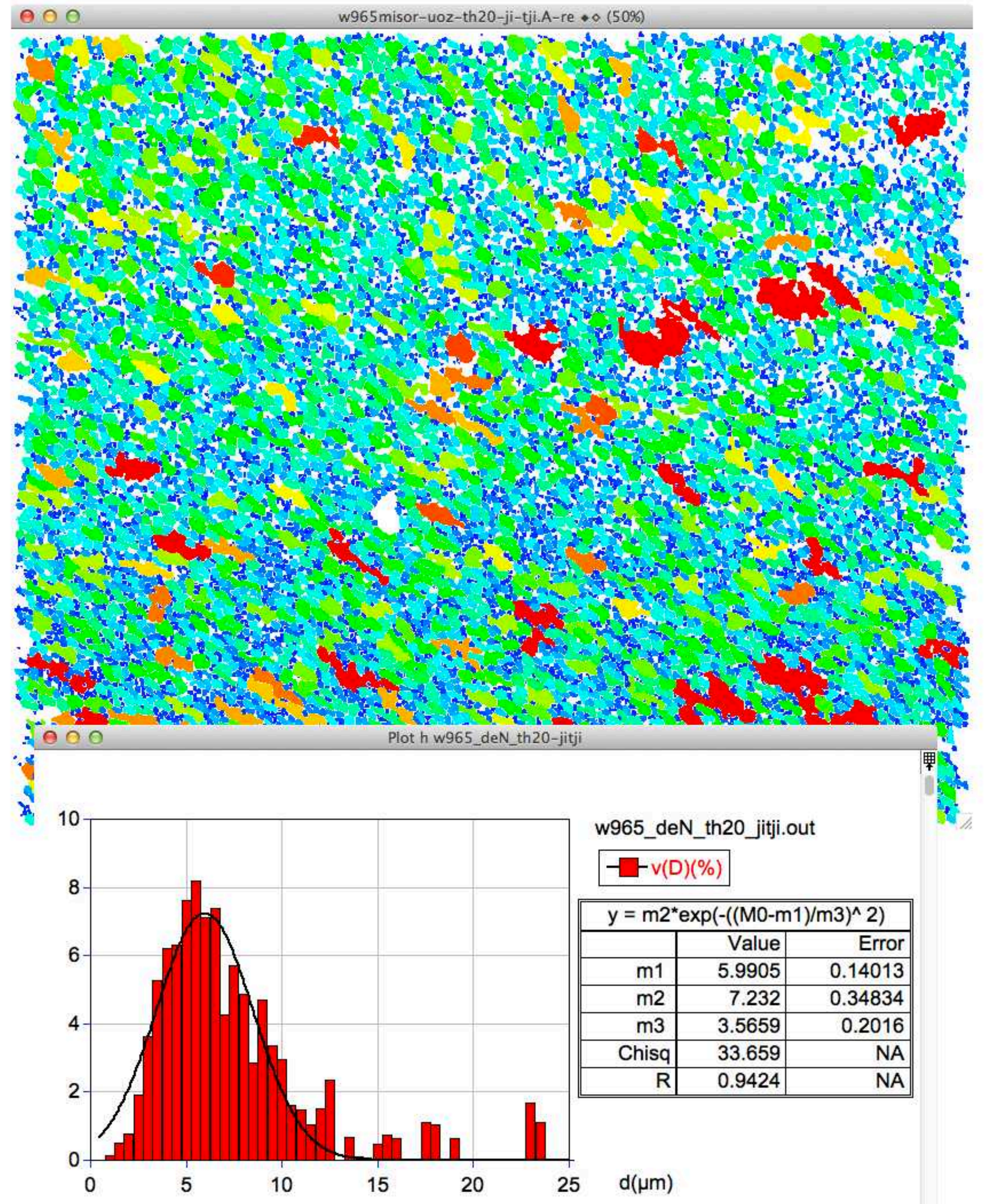
Lazy MapRedirect [A]
map of grains with > 75% indexing

equivalent diameter d_{corr}

0 ≥ 12.5 µm

mode(D) = 5.98 µm

w965_deN. misor-uoz-th20-ji-tji



number of particles: 12516

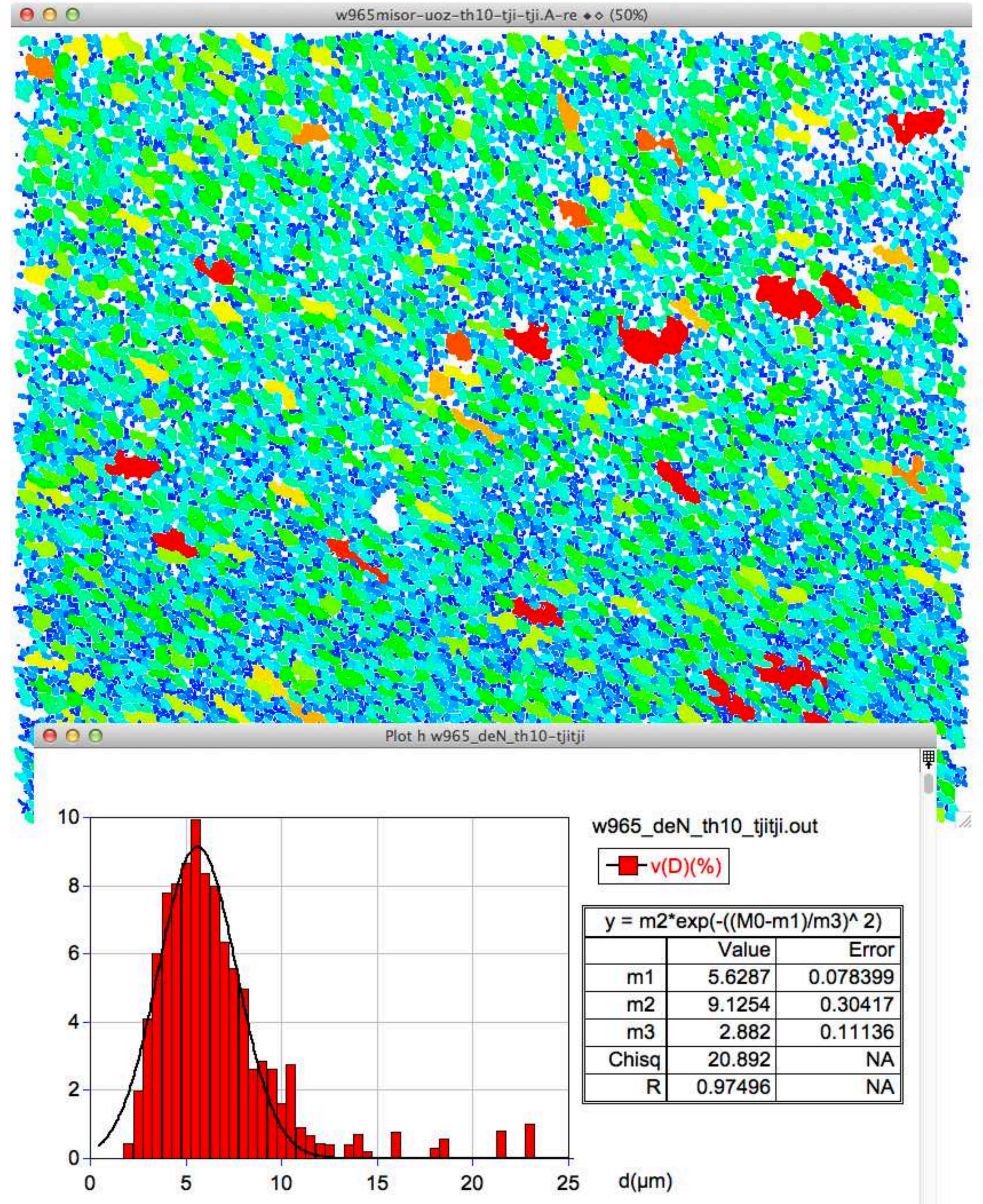
Lazy MapRedirect [A]
map of grains with > 75% indexing

equivalent diameter d_{corr}

0 ≥ 12.5 µm

mode(D) = 5.99 µm

w965_deN. misor-uoz-th10-tji-tji



number of particles: 11179

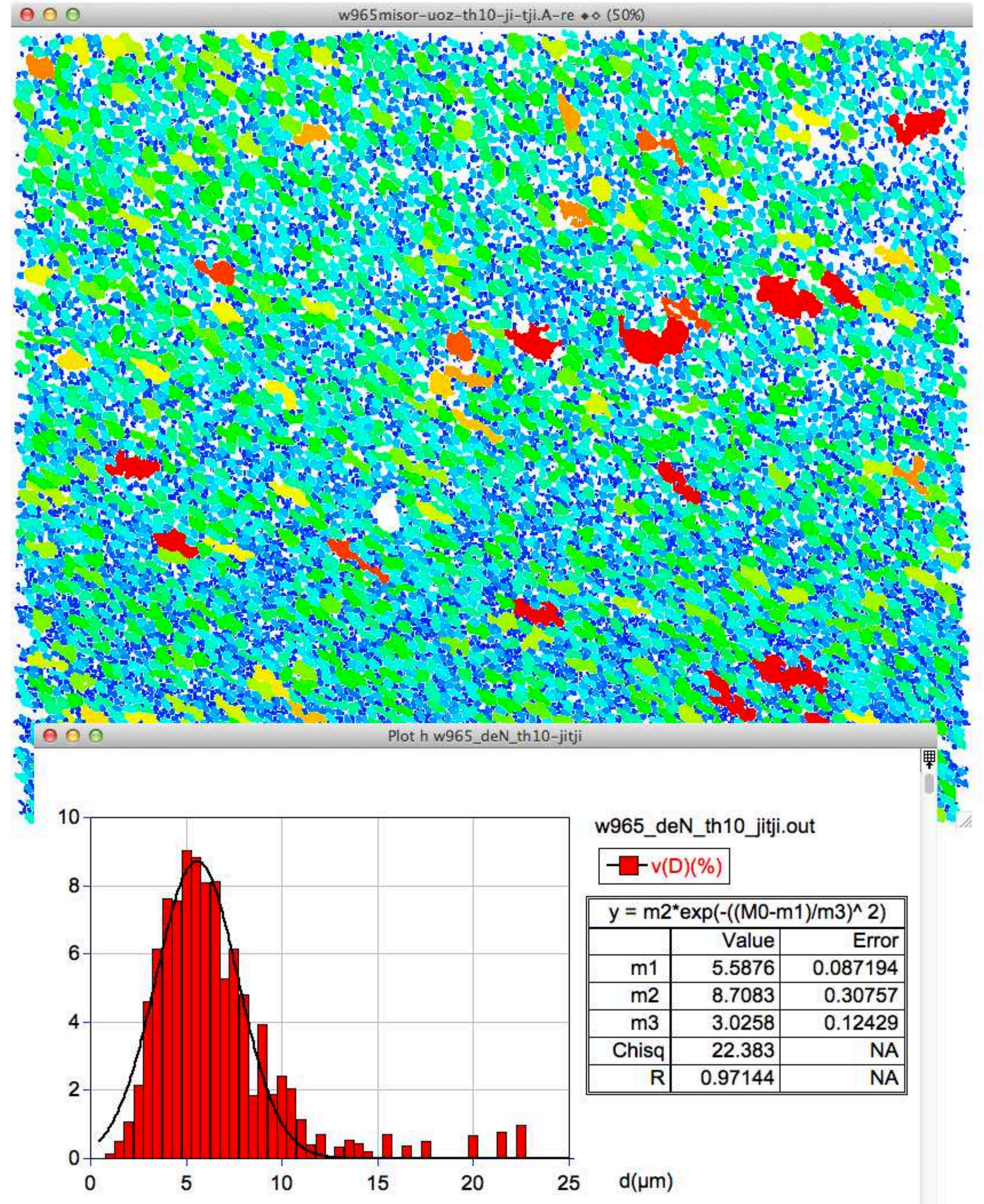
Lazy MapRedirect [A]
map of grains with > 75% indexing

equivalent diameter d_{corr}

0 ≥ 12.5 µm

mode(D) = 5.63 µm

w965_deN. misor-uoz-th10-ji-tji



number of particles: 13886

Lazy MapRedirect [A]
map of grains with > 75% indexing

equivalent diameter d_{corr}

0 ≥ 12.5 µm

mode(D) = 5.59 µm

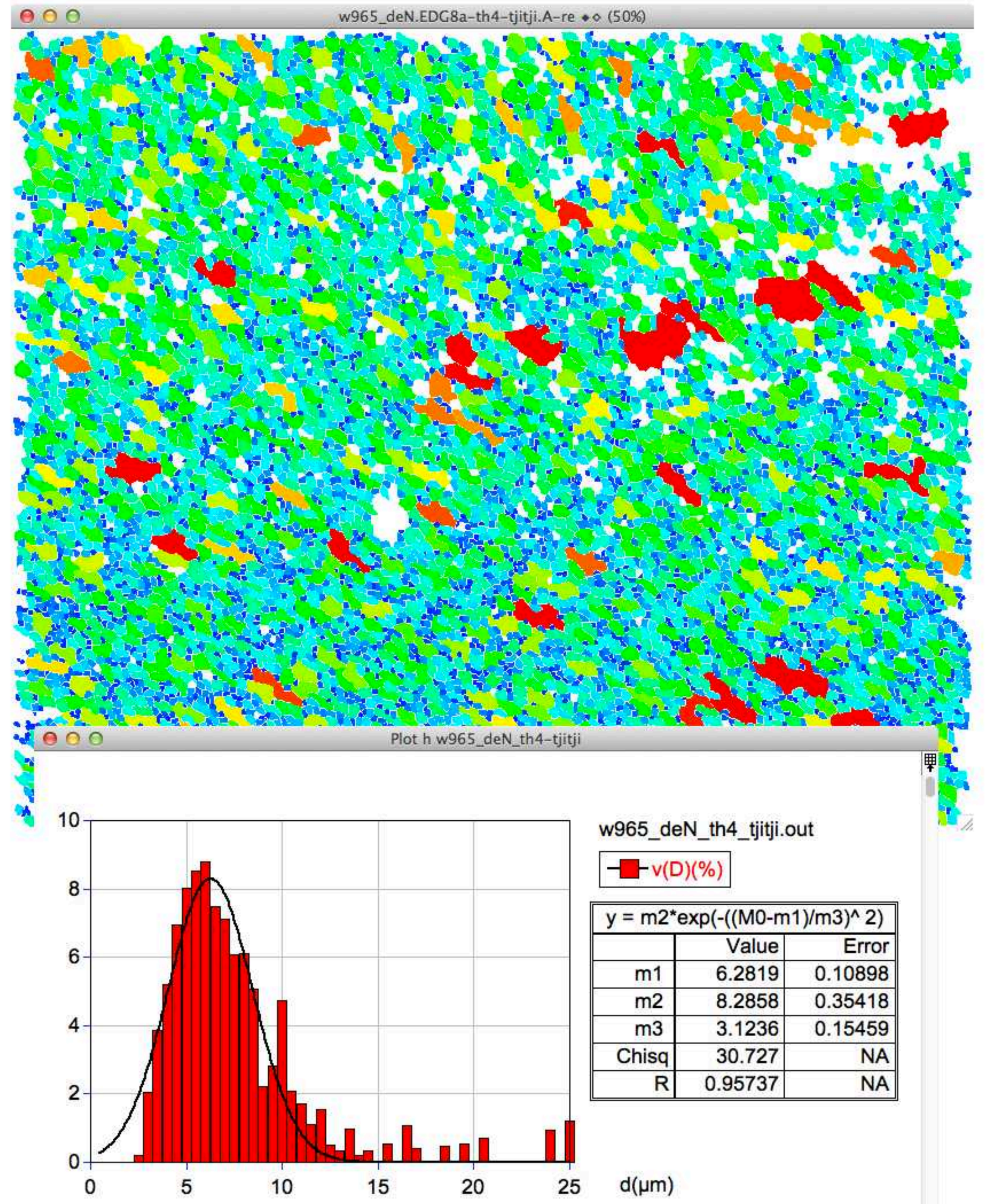
<< details >>

segmenting CIP-type orientation gradient images

<< details >>

grains from orientation gradient images

w965_deN. EDG8a-th04(2°)-tji-tji



number of particles:

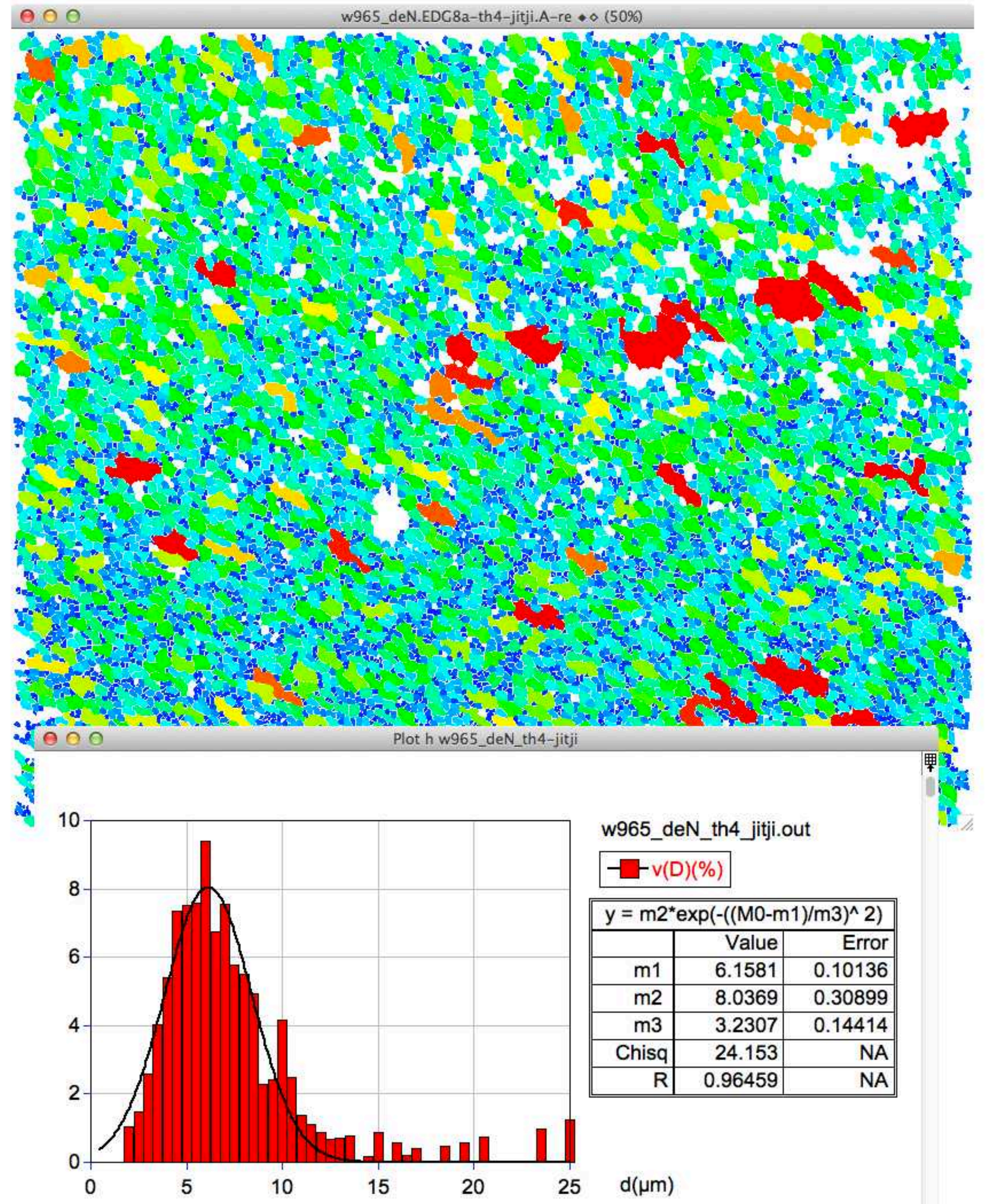
Lazy MapRedirect [A]
map of grains with > 75% indexing

equivalent diameter d_{corr}

0 ≥12.5 µm

mode(D) = 6.28 µm

w965_deN. EDG8a-th04(2°)-ji-tji



number of particles:

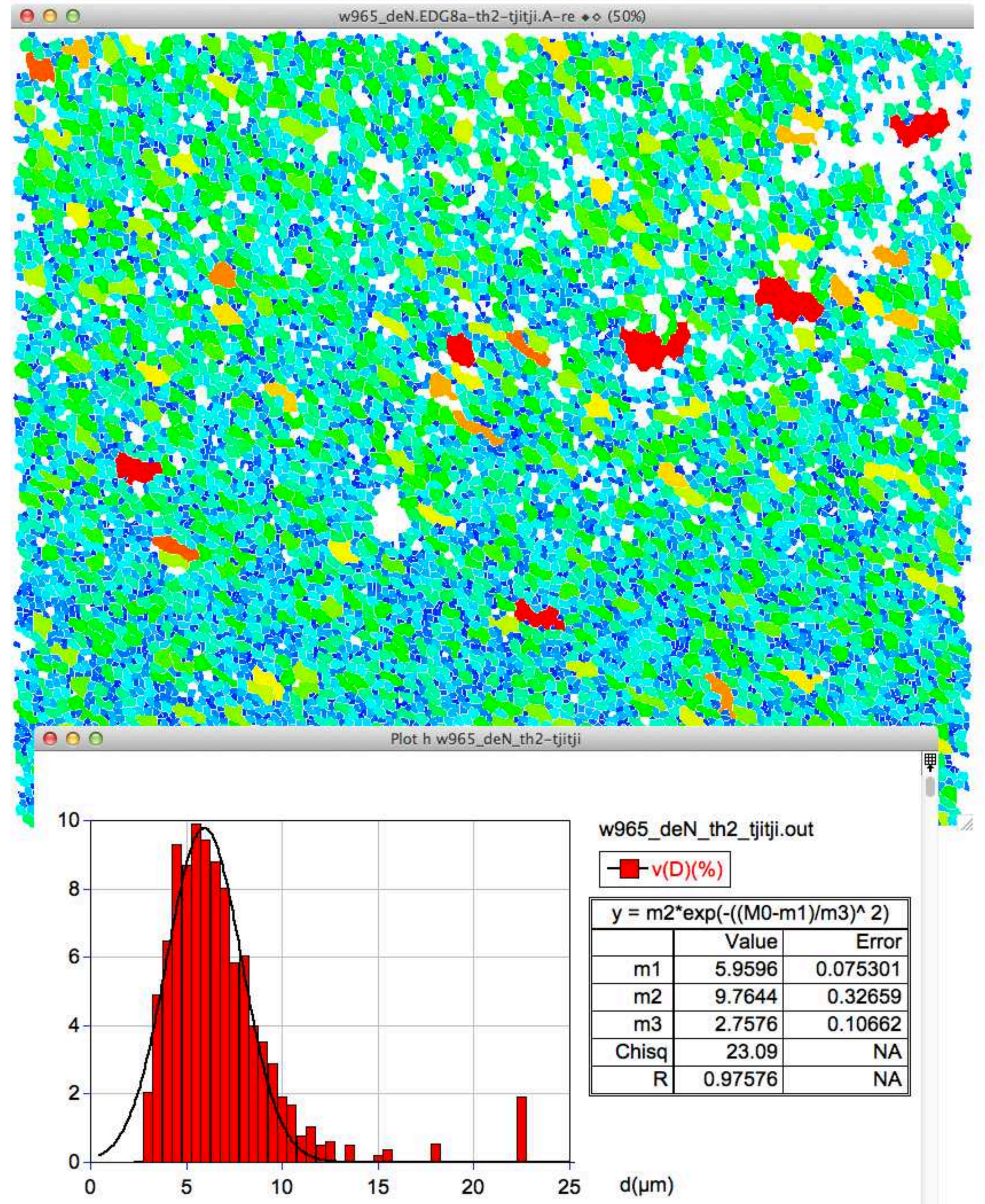
Lazy MapRedirect [A]
map of grains with > 75% indexing

equivalent diameter d_{corr}

0 ≥12.5 µm

mode(D) = 6.16 µm

w965_deN. EDG8a-th02(1°)-tji-tji



number of particles:

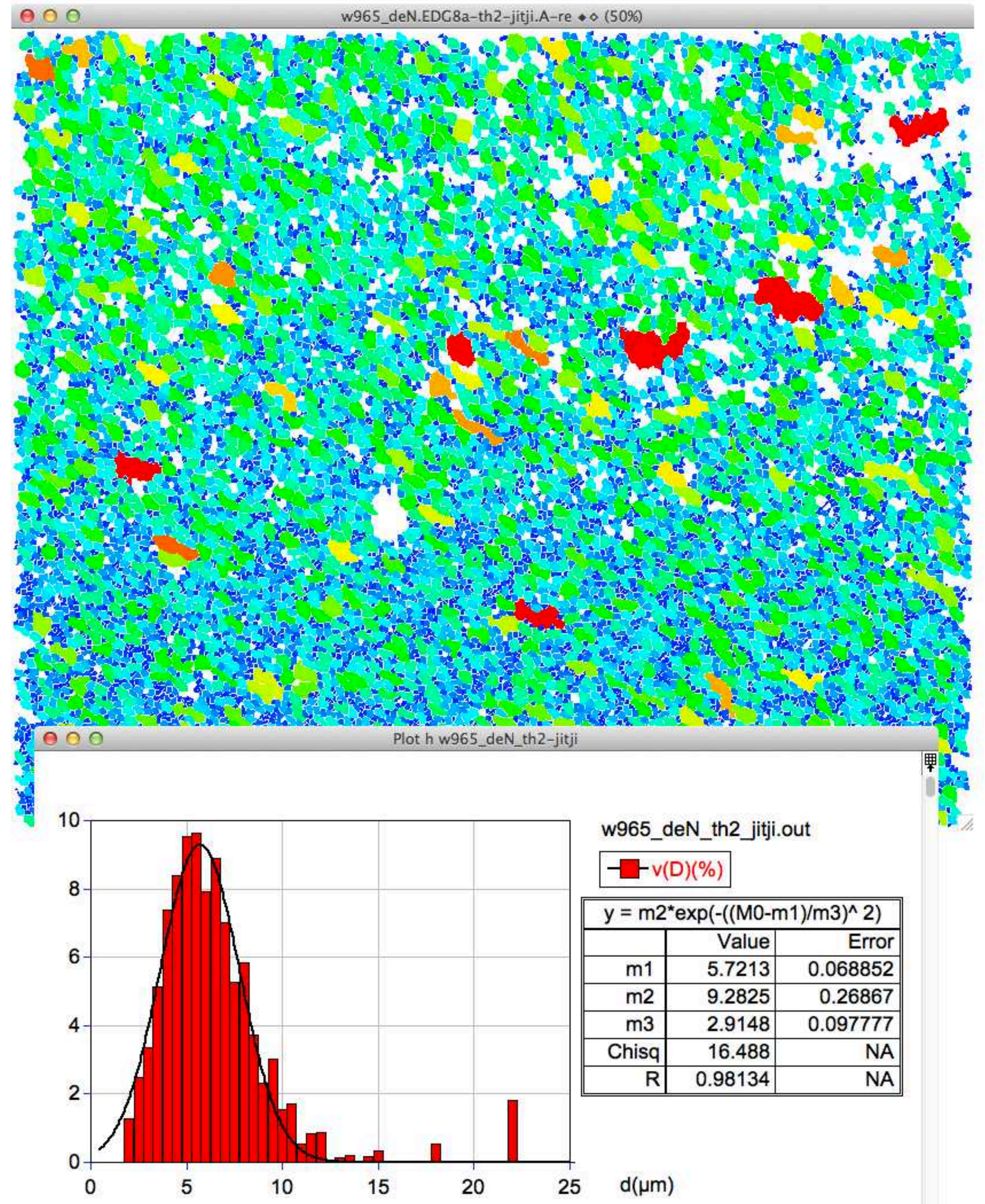
Lazy MapRedirect [A]
map of grains with > 75% indexing

equivalent diameter d_{corr}

0 ≥12.5 µm

mode(D) = 5.96 µm

w965_deN. EDG8a-th02(1°)-ji-tji



number of particles:

Lazy MapRedirect [A]
map of grains with > 75% indexing

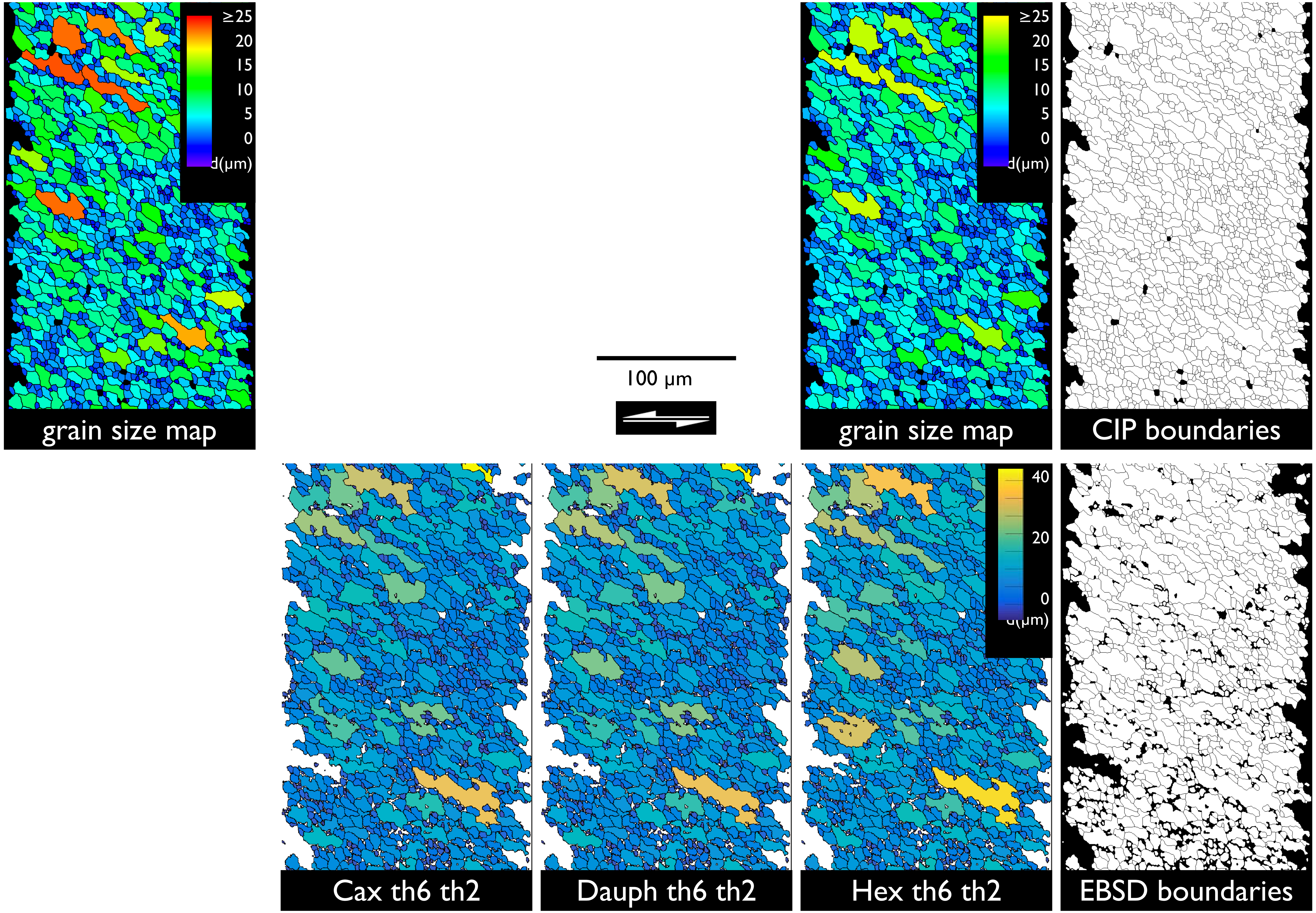
equivalent diameter d_{corr}

0 ≥12.5 µm

mode(D) = 5.72 µm

<< details >>

comparing grain size maps



<< details >>

big difference - small difference ? 2° threshold

hexagonal | Dauphiné | c-axis

w965_40__dauphineThreshold_2_CaxAngleThreshold_2

<< details >>

big difference - small difference ? 4° threshold

hexagonal | Dauphiné | c-axis

<< details >>

w965_40__dauphineThreshold_4_CaxAngleThreshold_2

big difference - small difference ? 6° threshold

hexagonal Dauphiné c-axis

w965_40__dauphineThreshold_6_CaxAngleThreshold_2

<< details >>

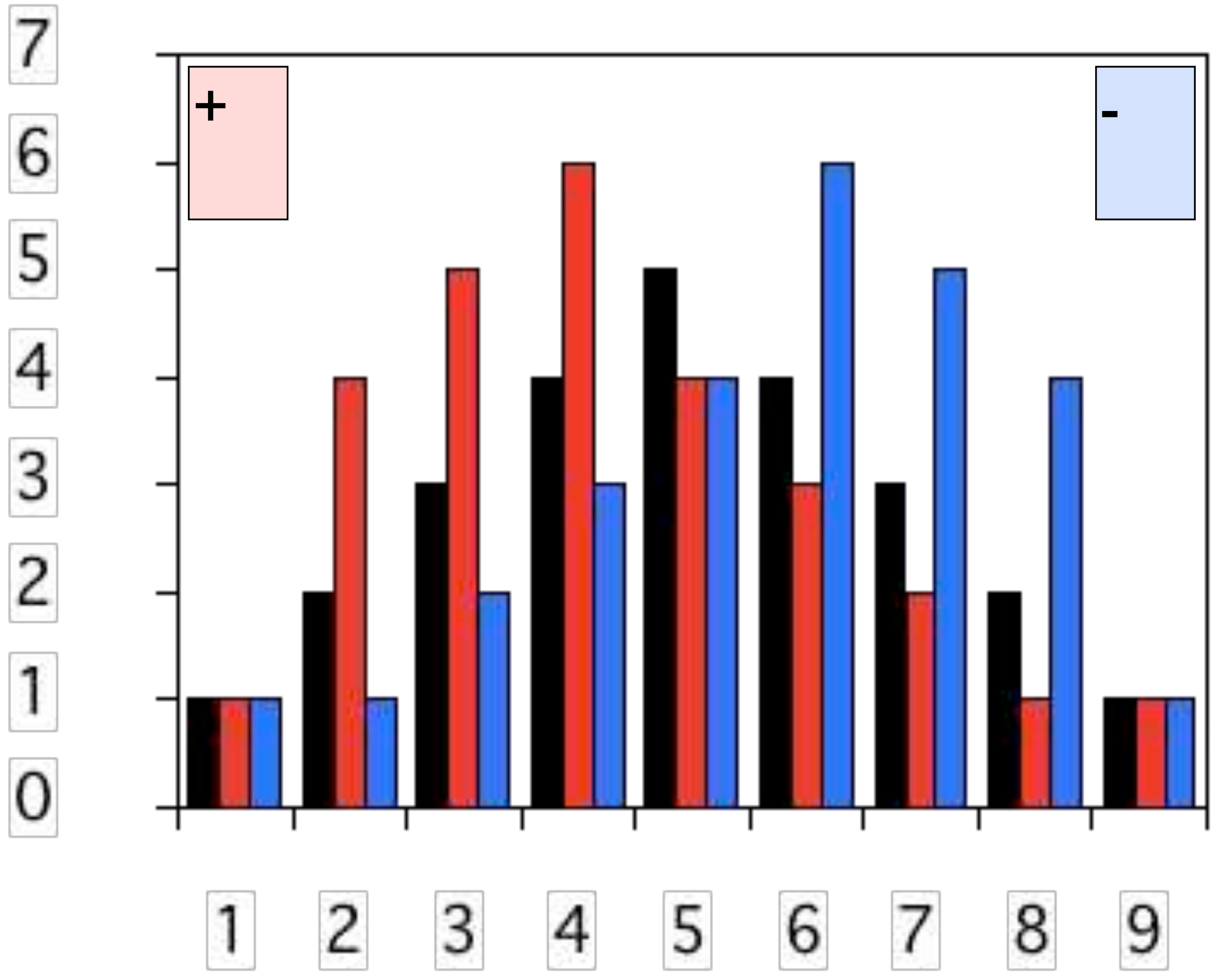
choosing a mean grain size

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	=	$\sqrt{(1/n \cdot \sum x_i^2)}$	≈ area average

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

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



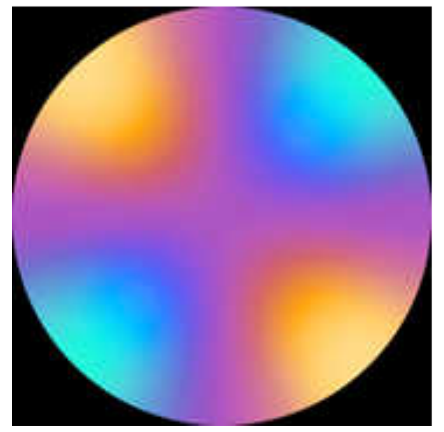
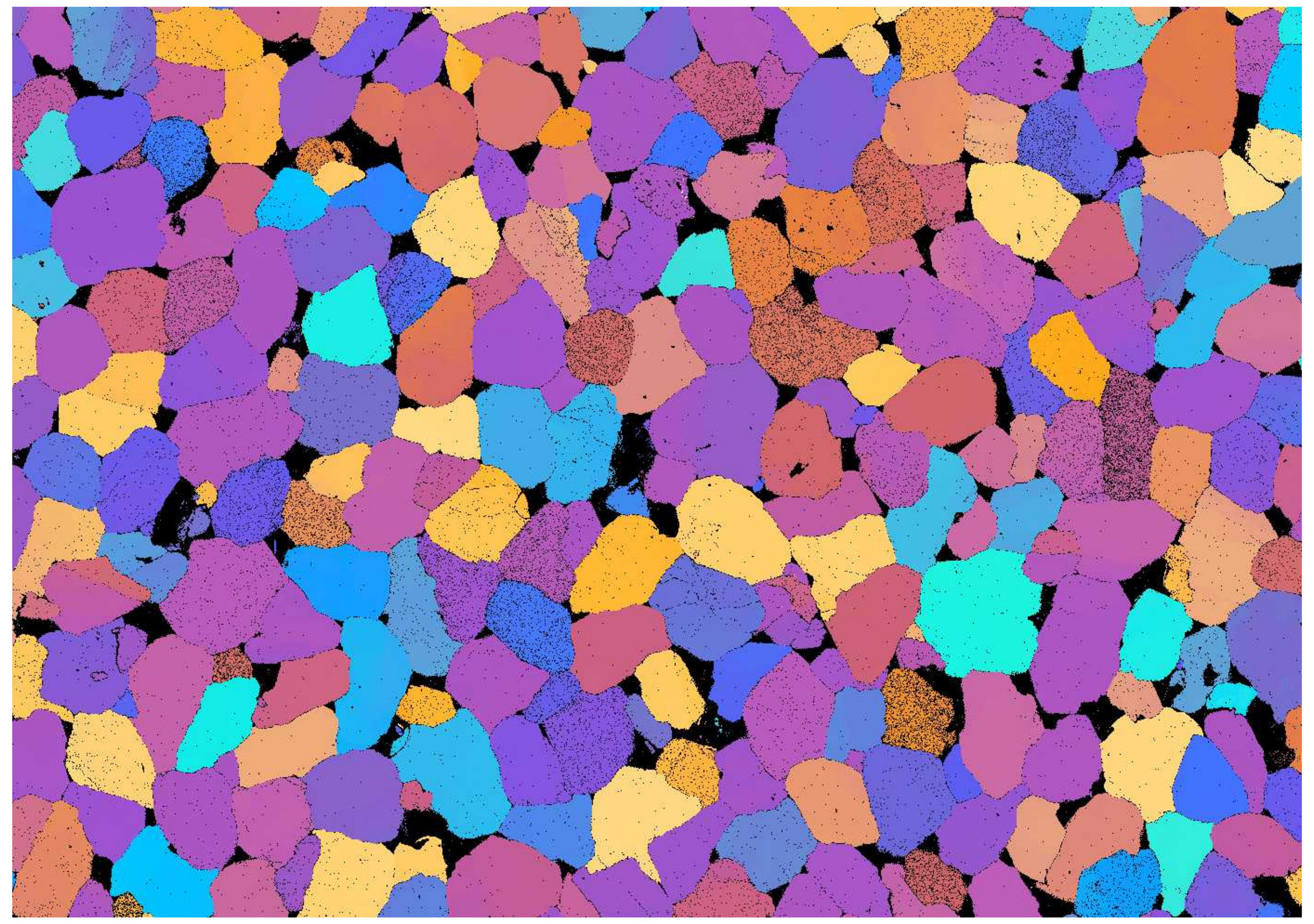
	symm.	+ skew	- skew
$\bar{X}$	5.00	4.33	5.67
Mode	5.00	4.00	6.00
RMS	5.39	4.75	5.99
Skewness	0.00	0.53	-0.53
RMS/$\bar{X}$	108%	110%	106%

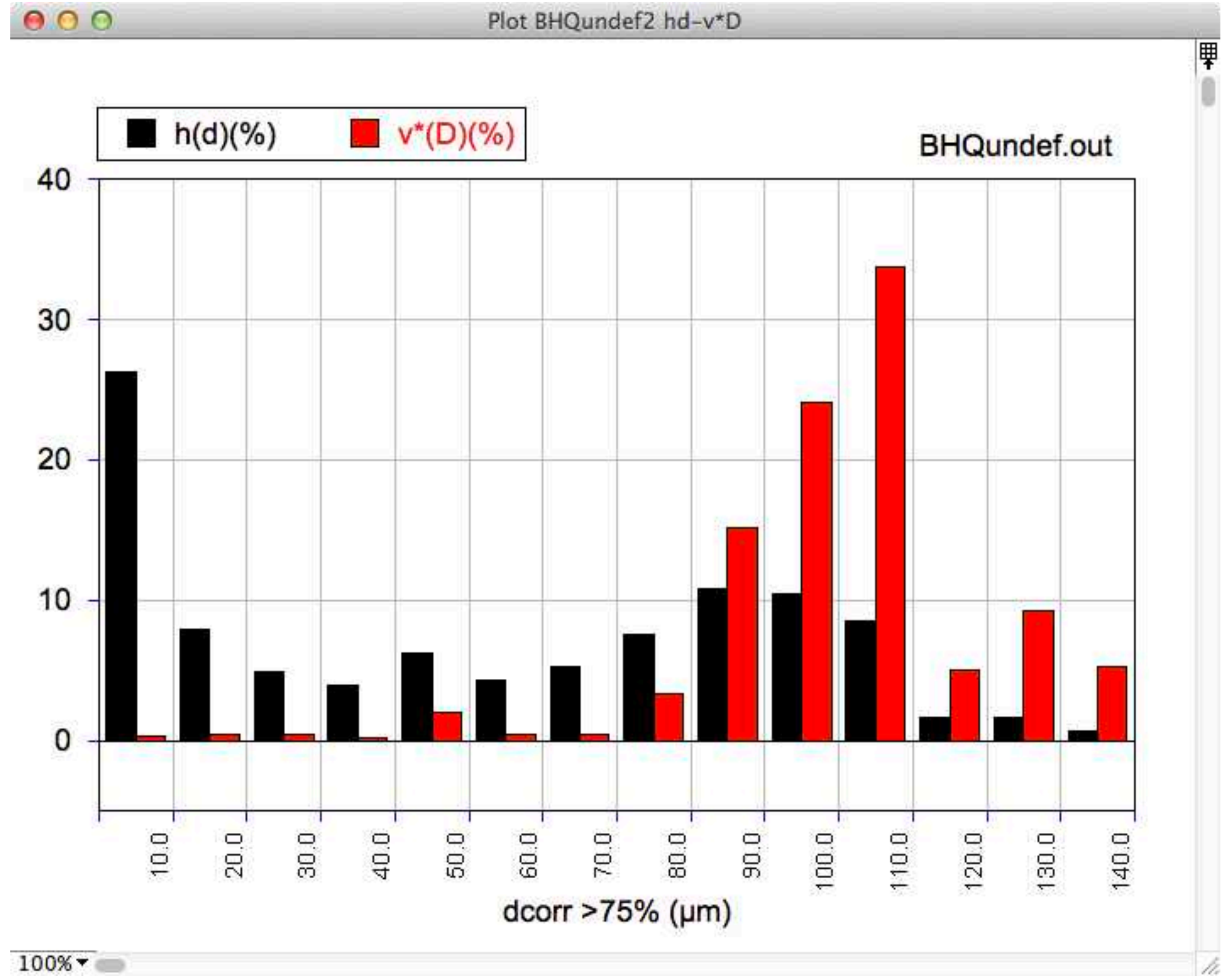
⇒ RMS overestimates mean

<< details >>

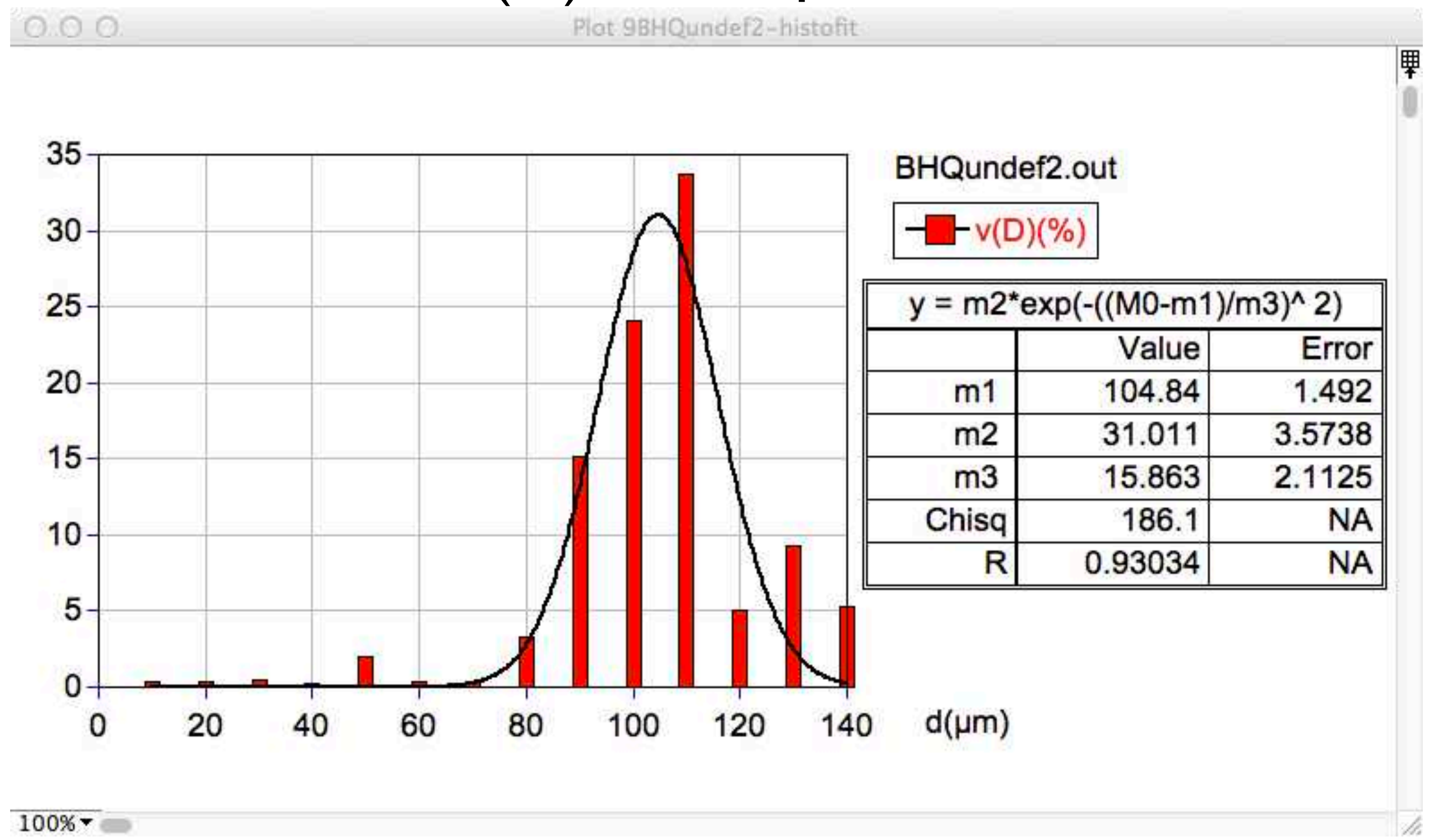
the influence of bin size

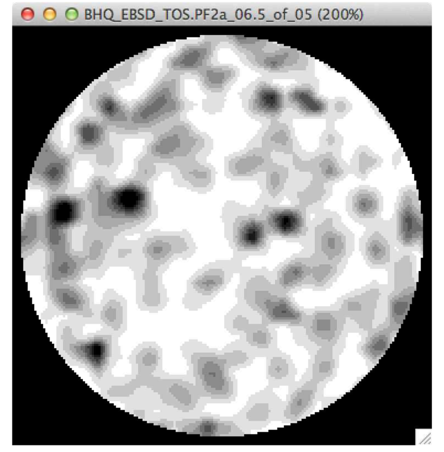
BHQ undeformed EBSD 1μm step size

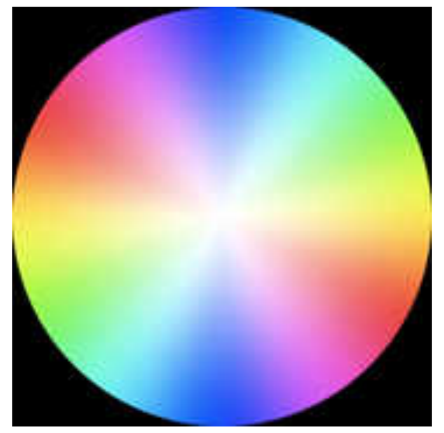
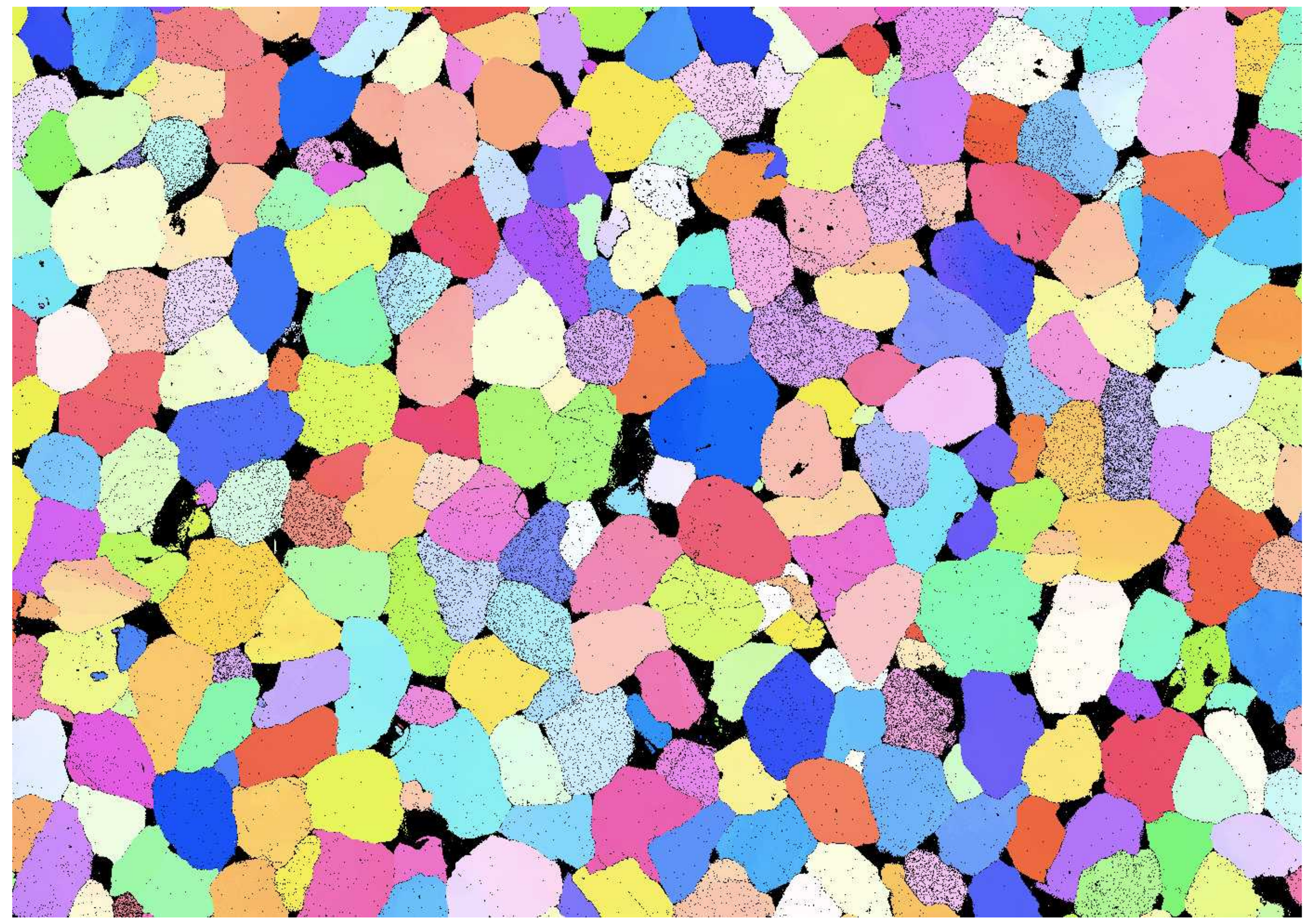



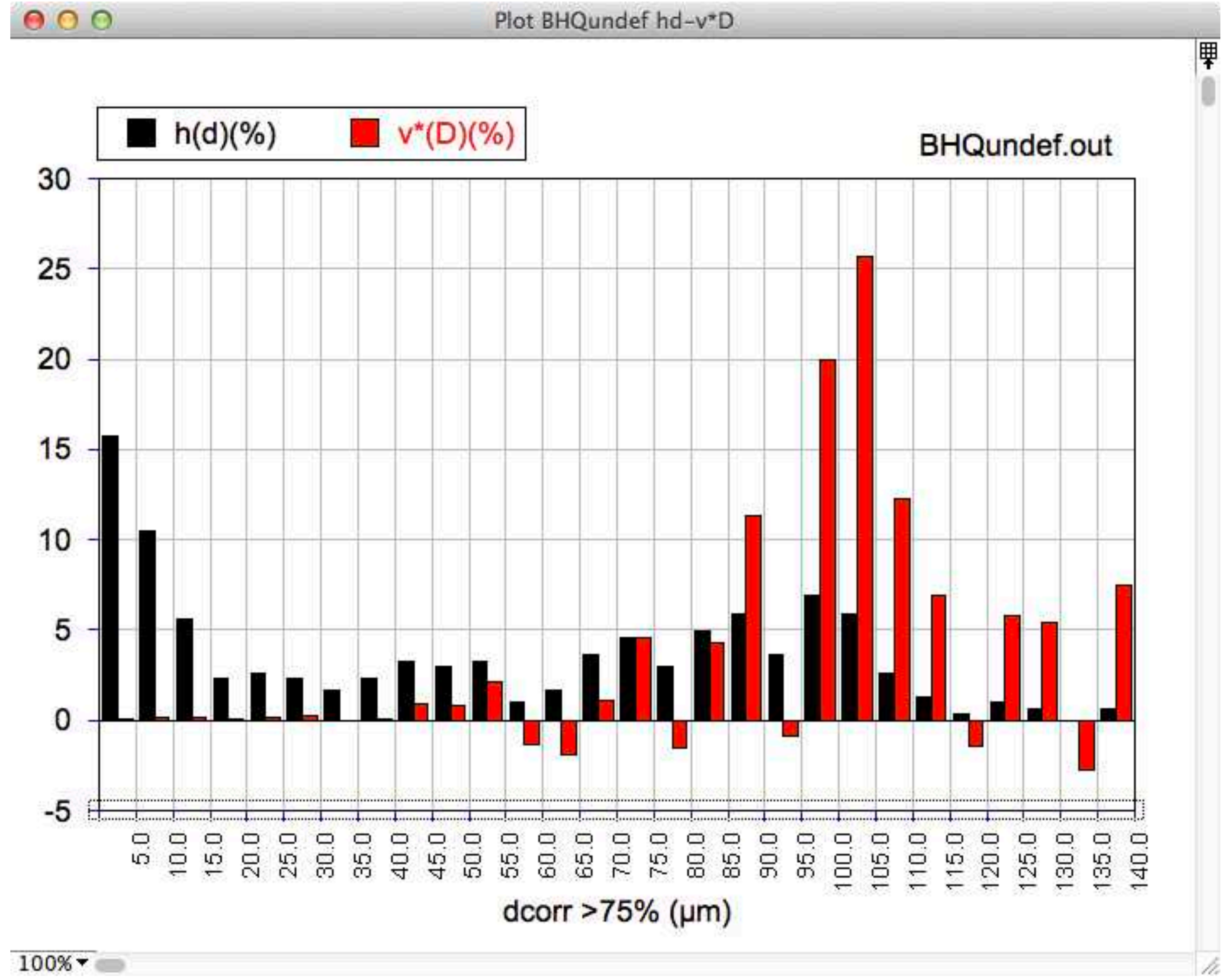


mode(D) = 105 μm

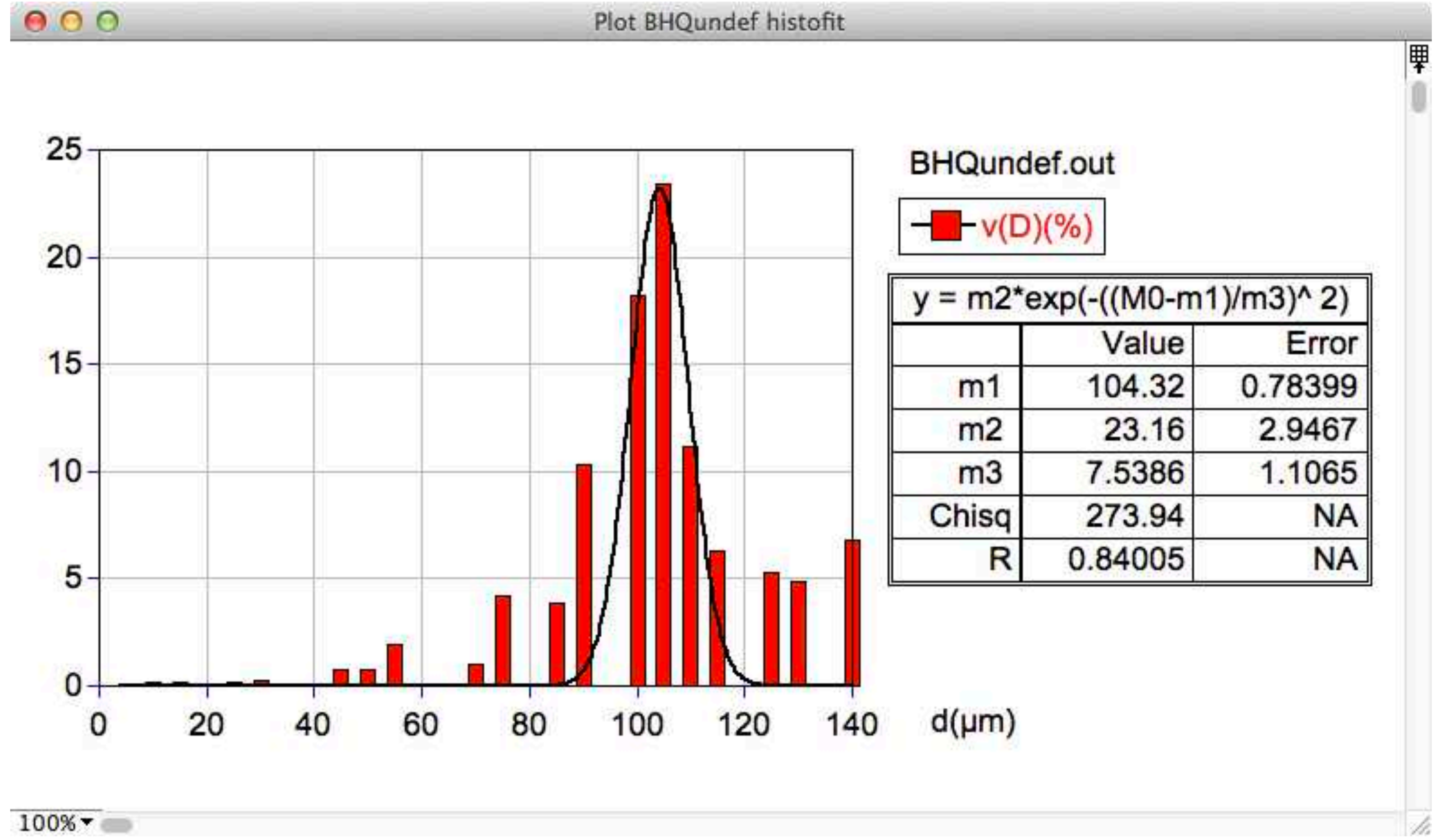






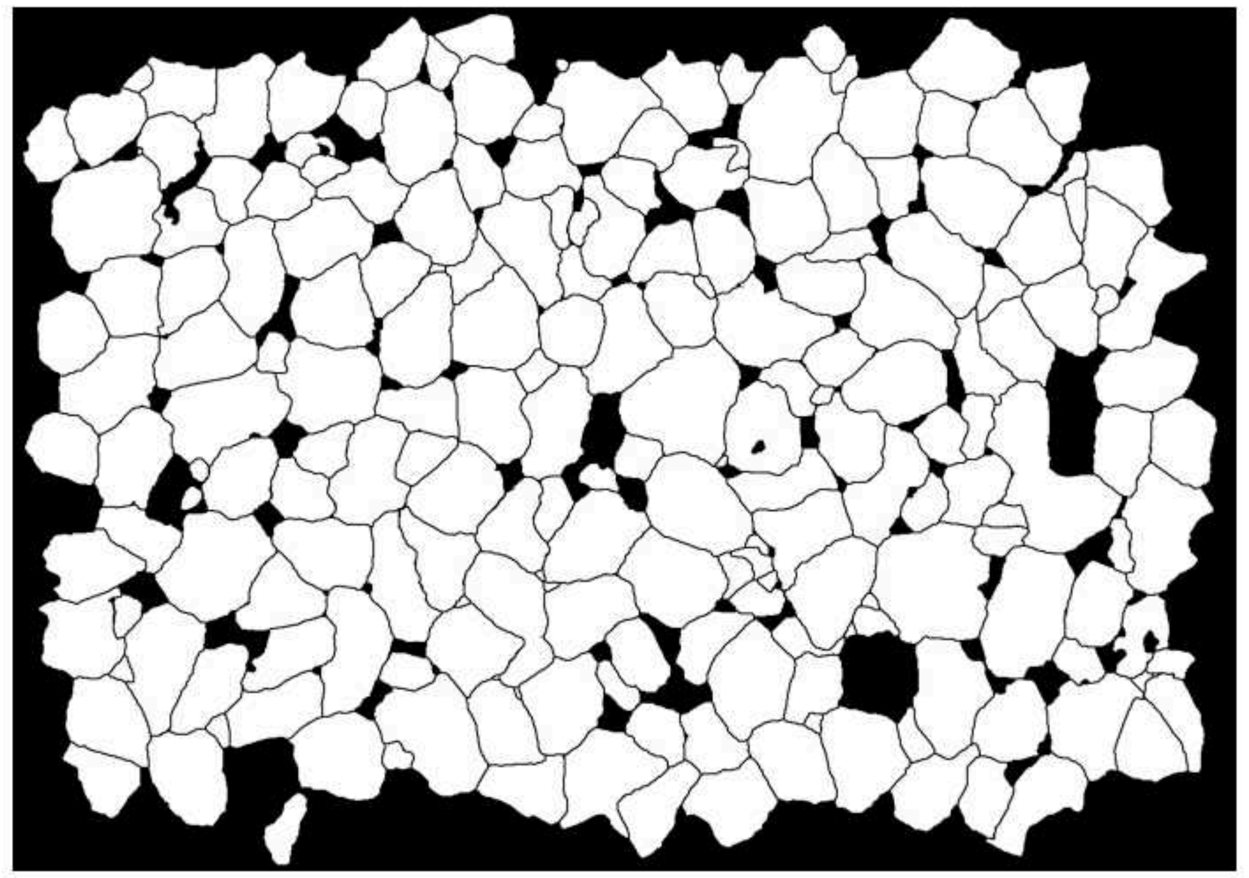
mode(D) = 104 μm

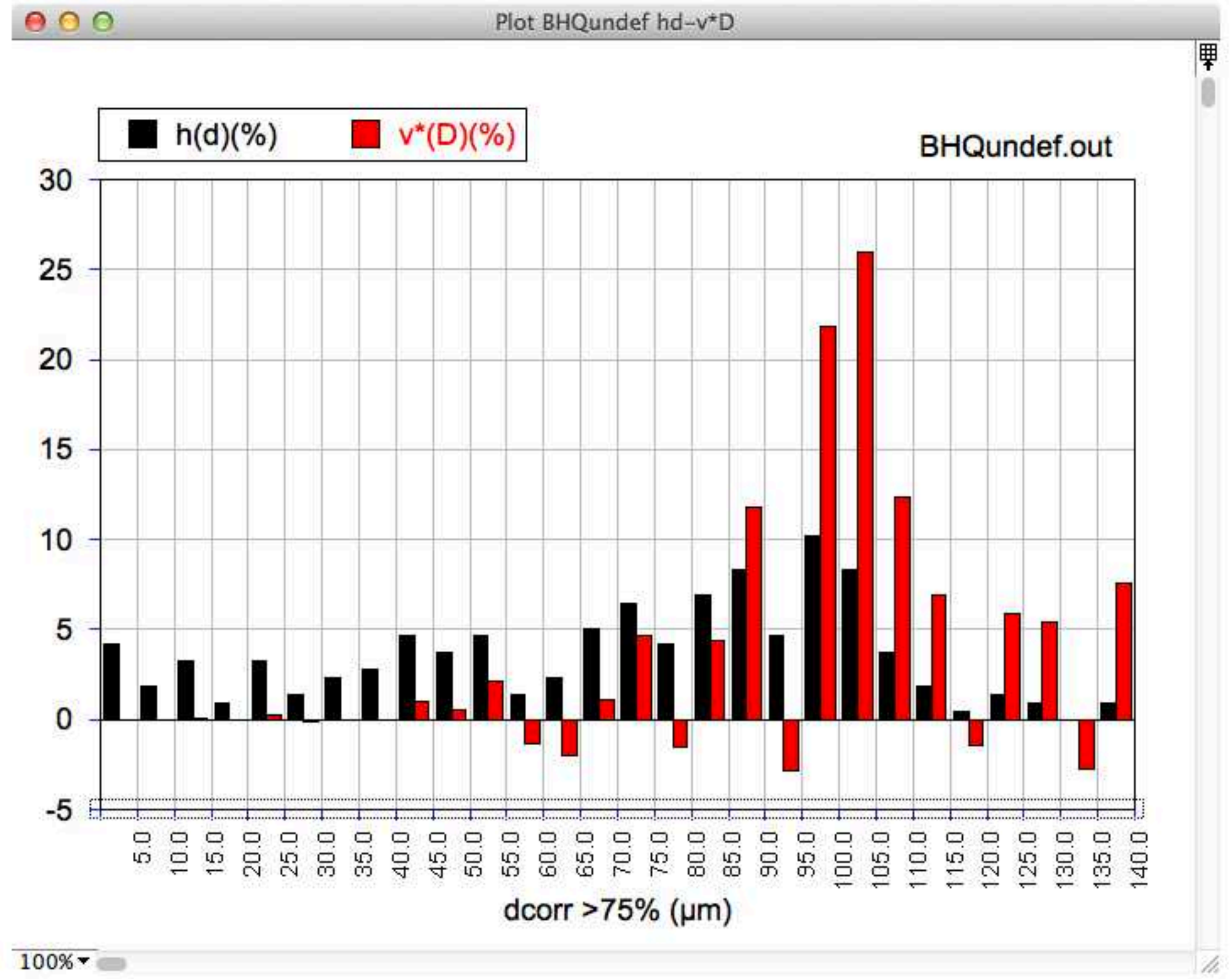


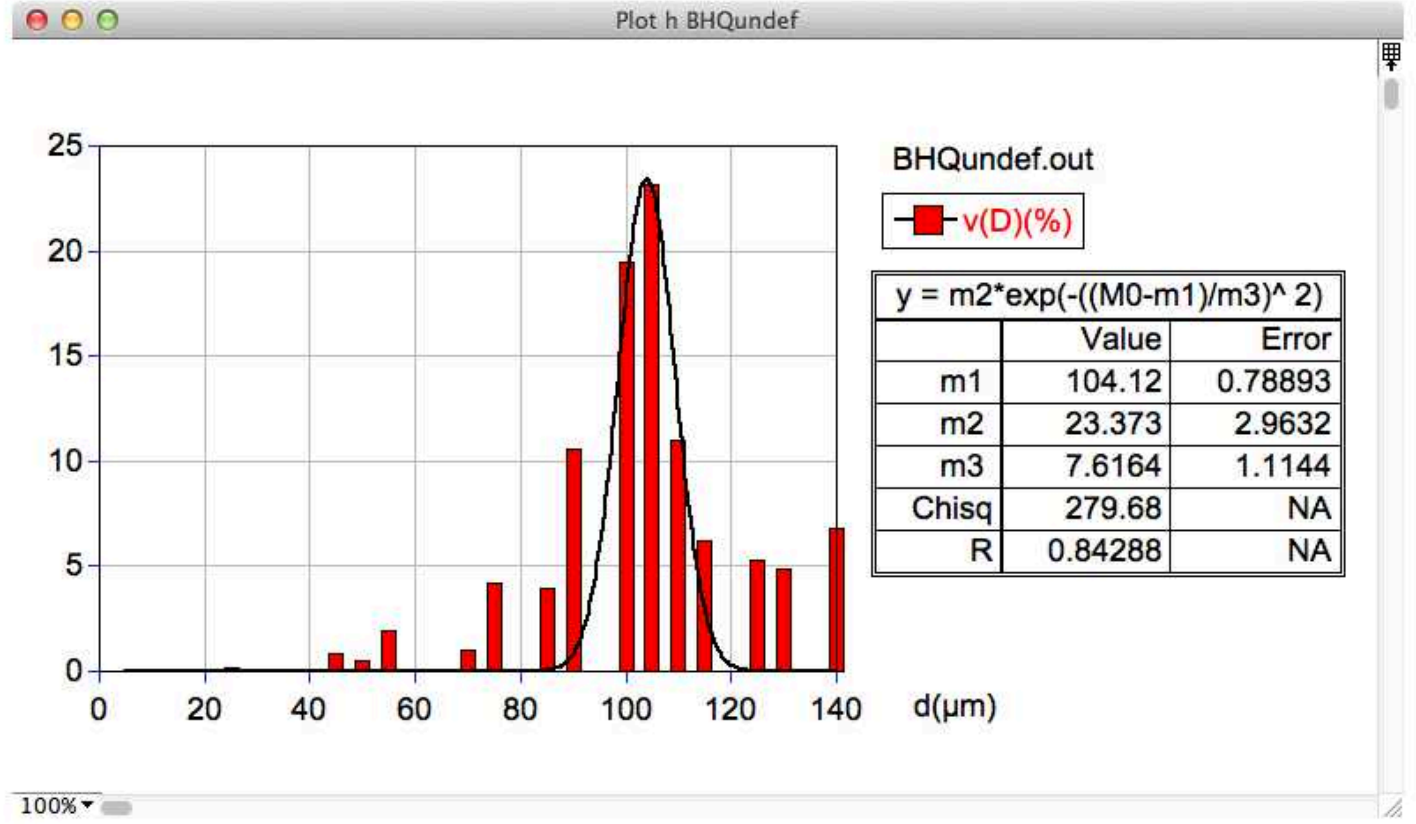
<< details >>

the influence of sample size

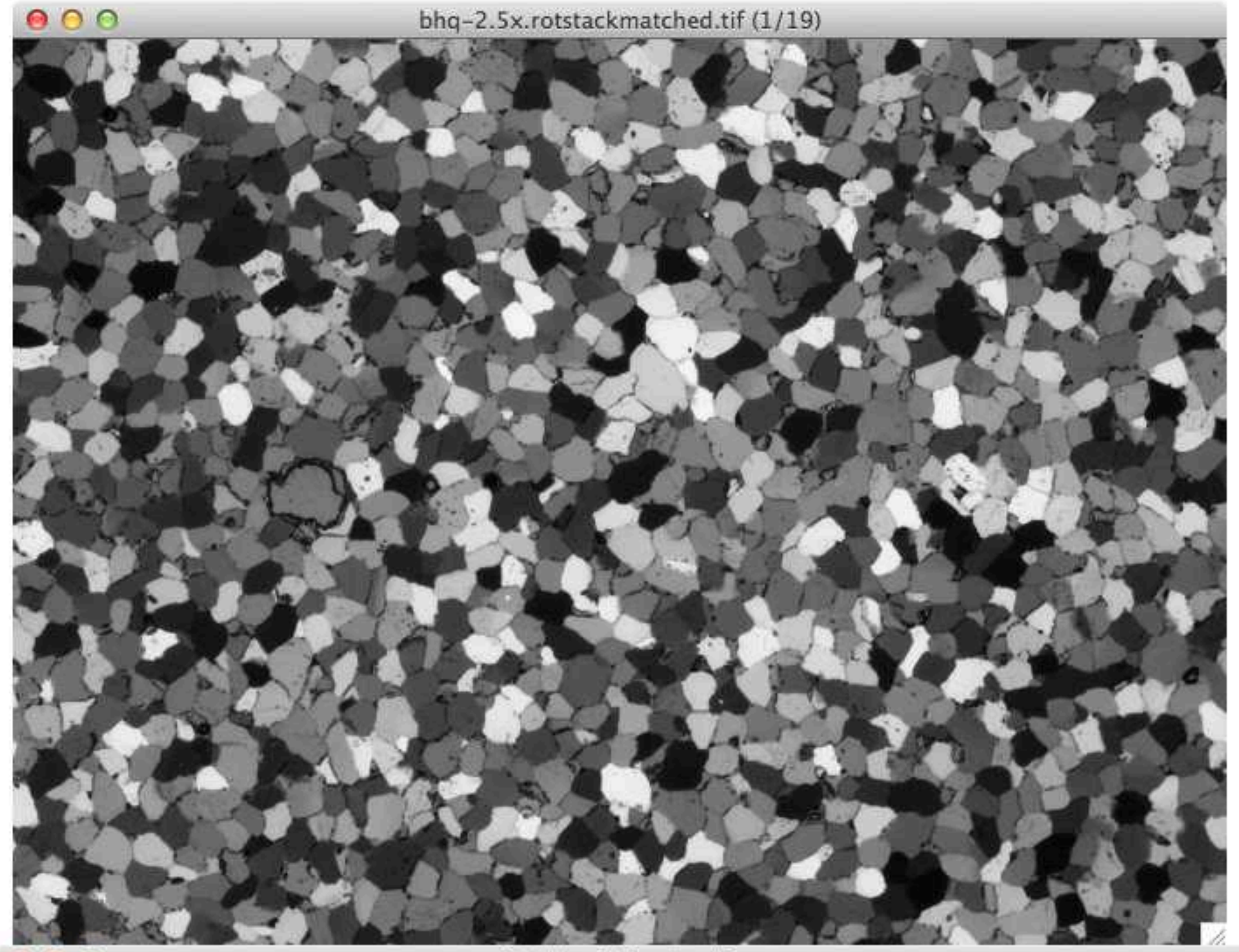
re-done

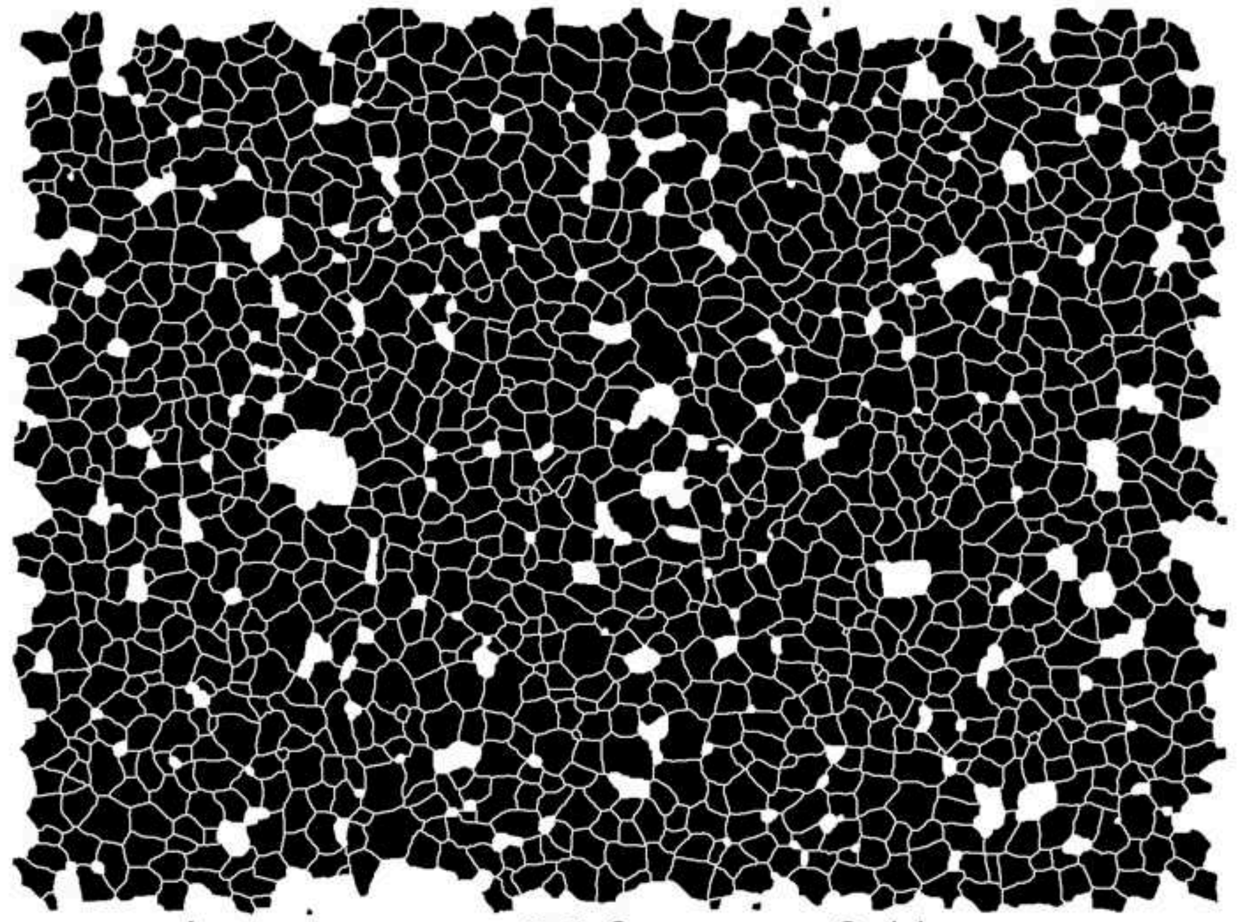




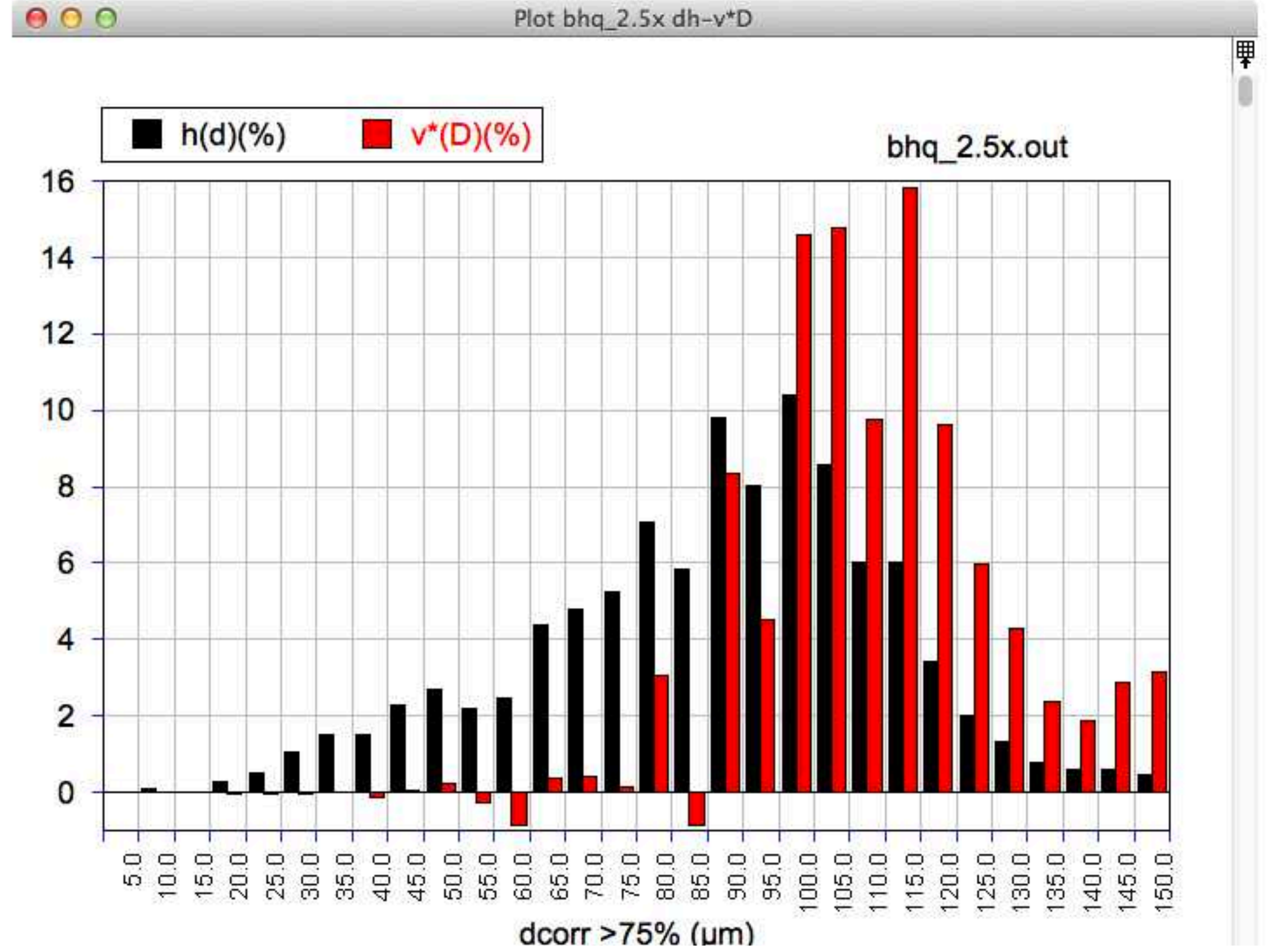


bhq 2.5x LM Axiocam 41 px = 100 µm

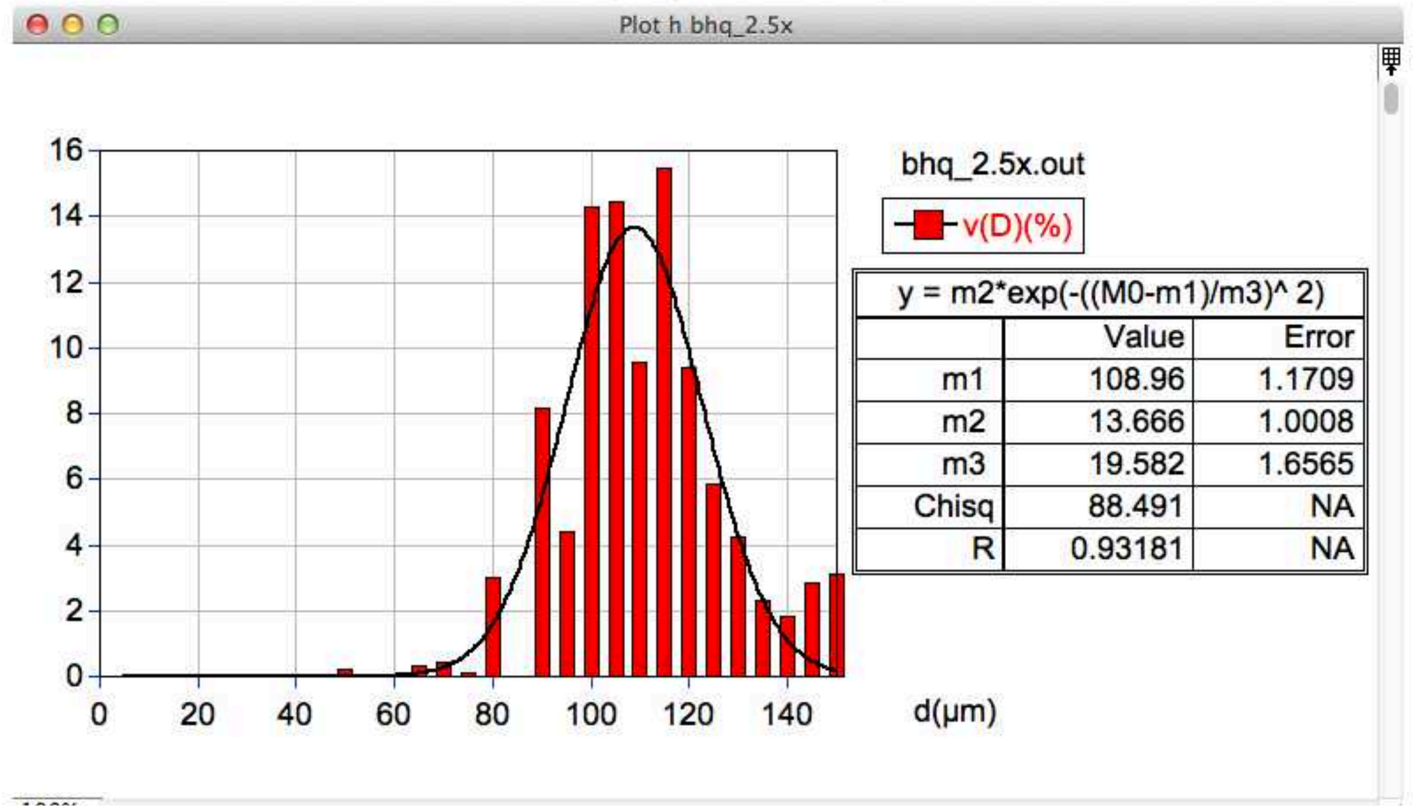




rotstack uuueog-z-mt jitji fix step = 2.44 µm



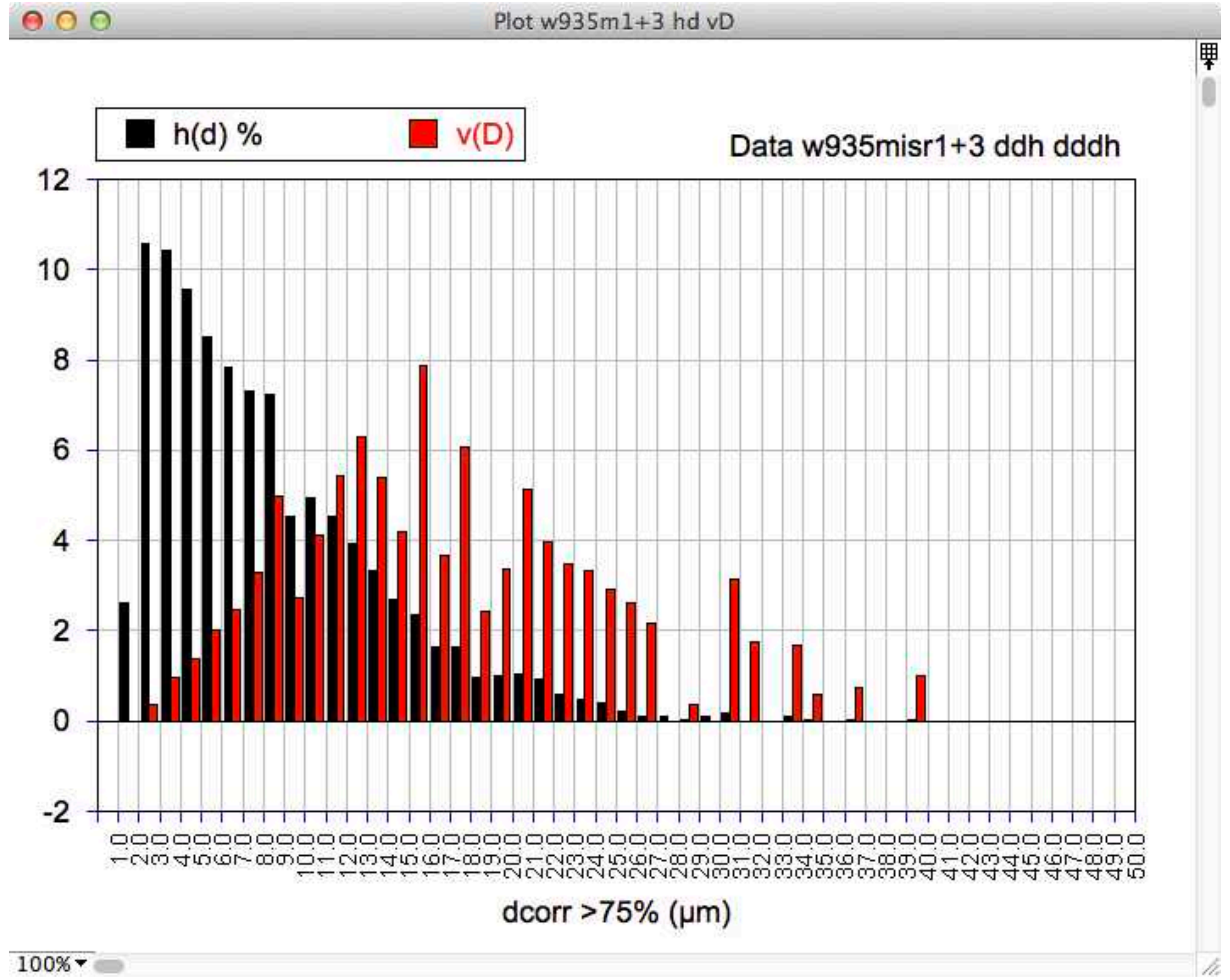
mode(D) = 109 µm

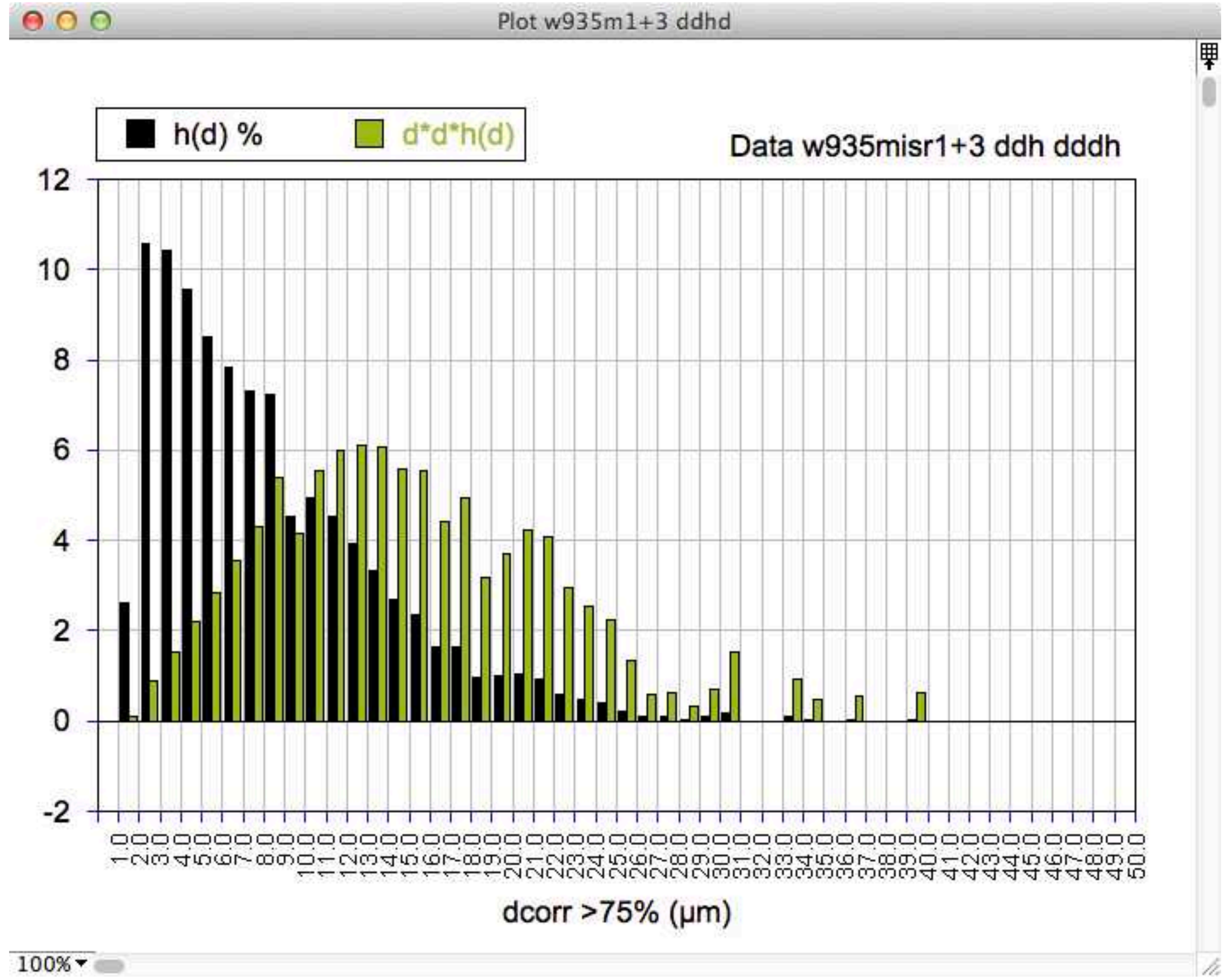


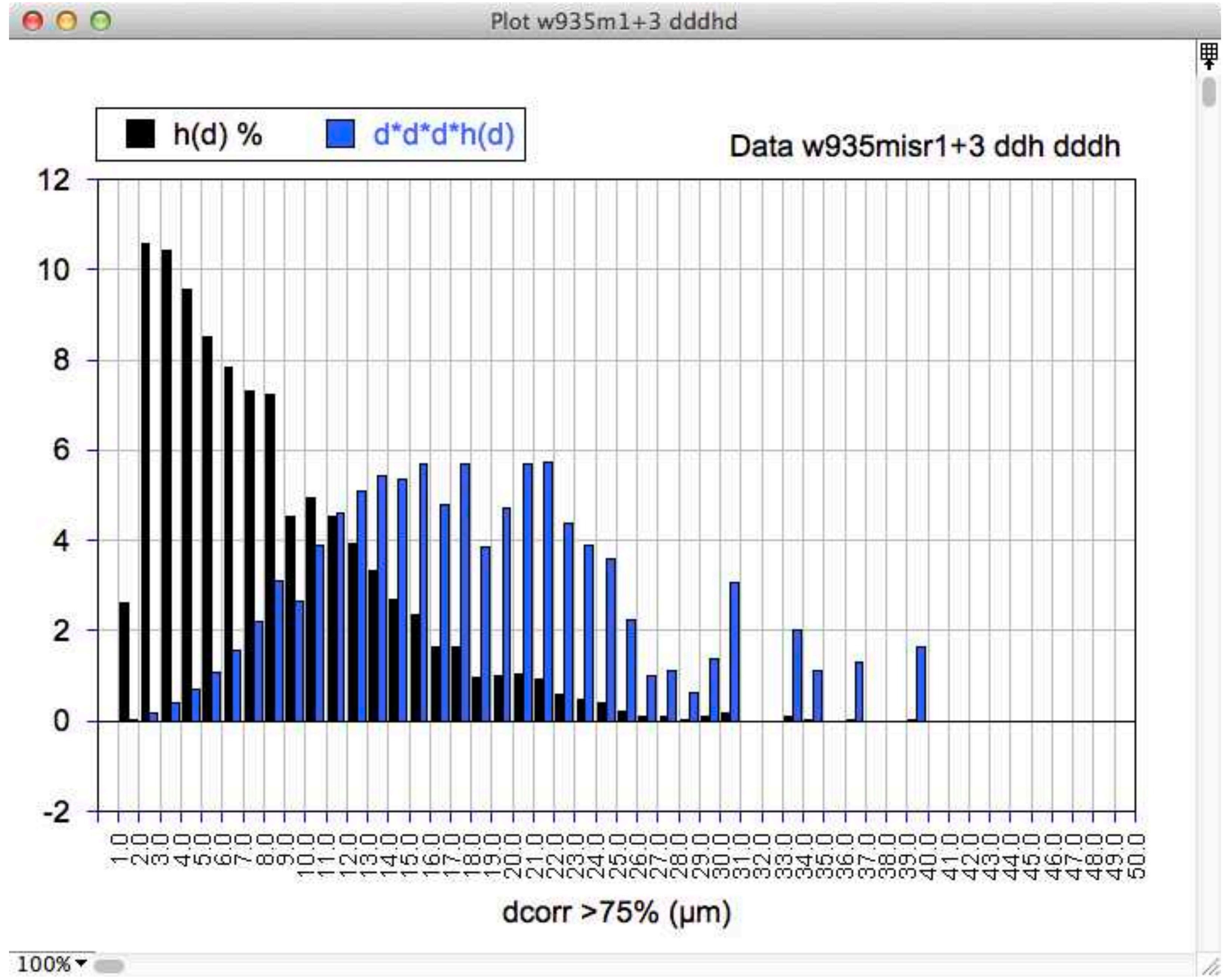
<< details >>

no access to stripstar ?! ... fake it !

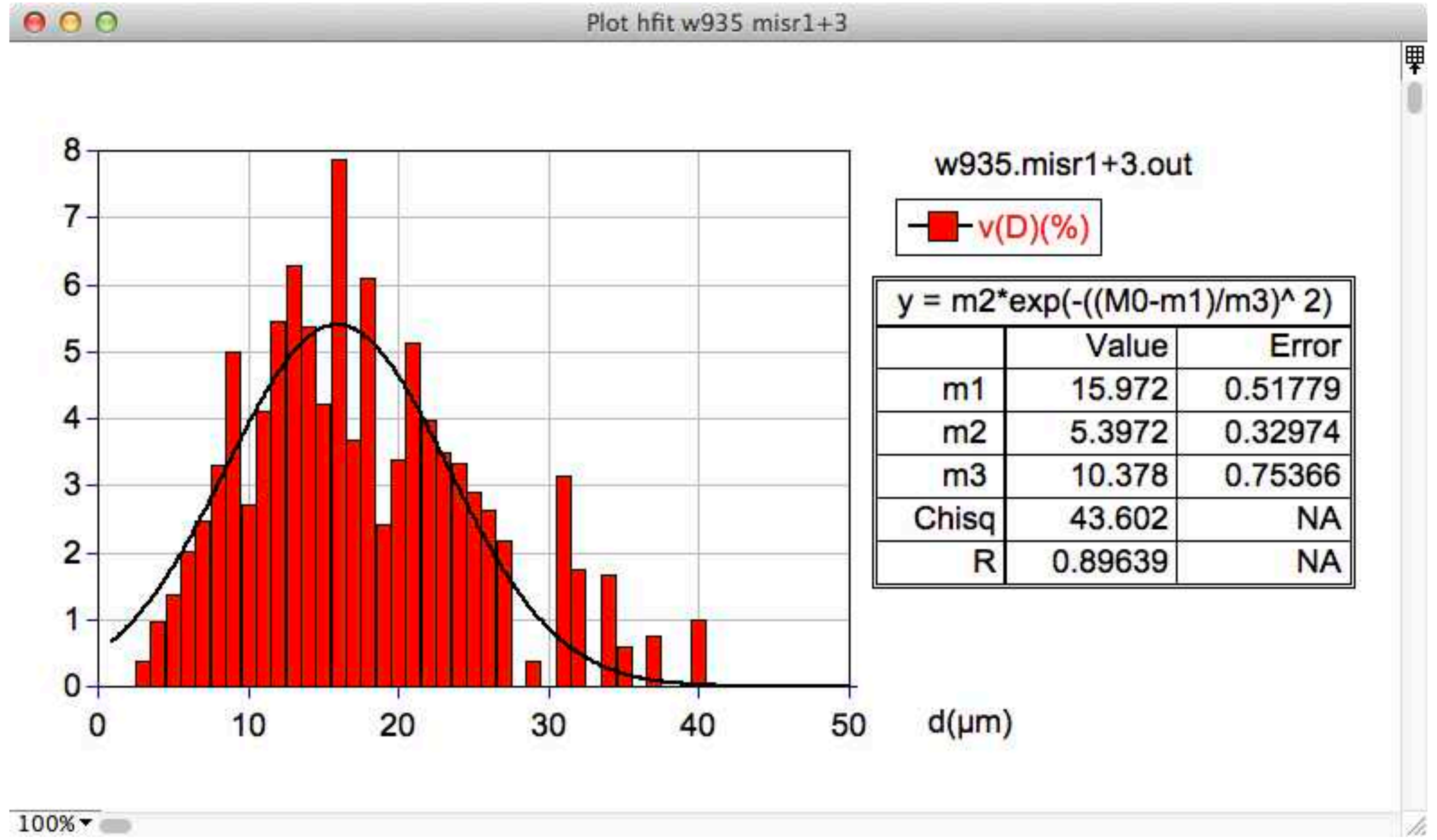
from 2D diameters to 3D:

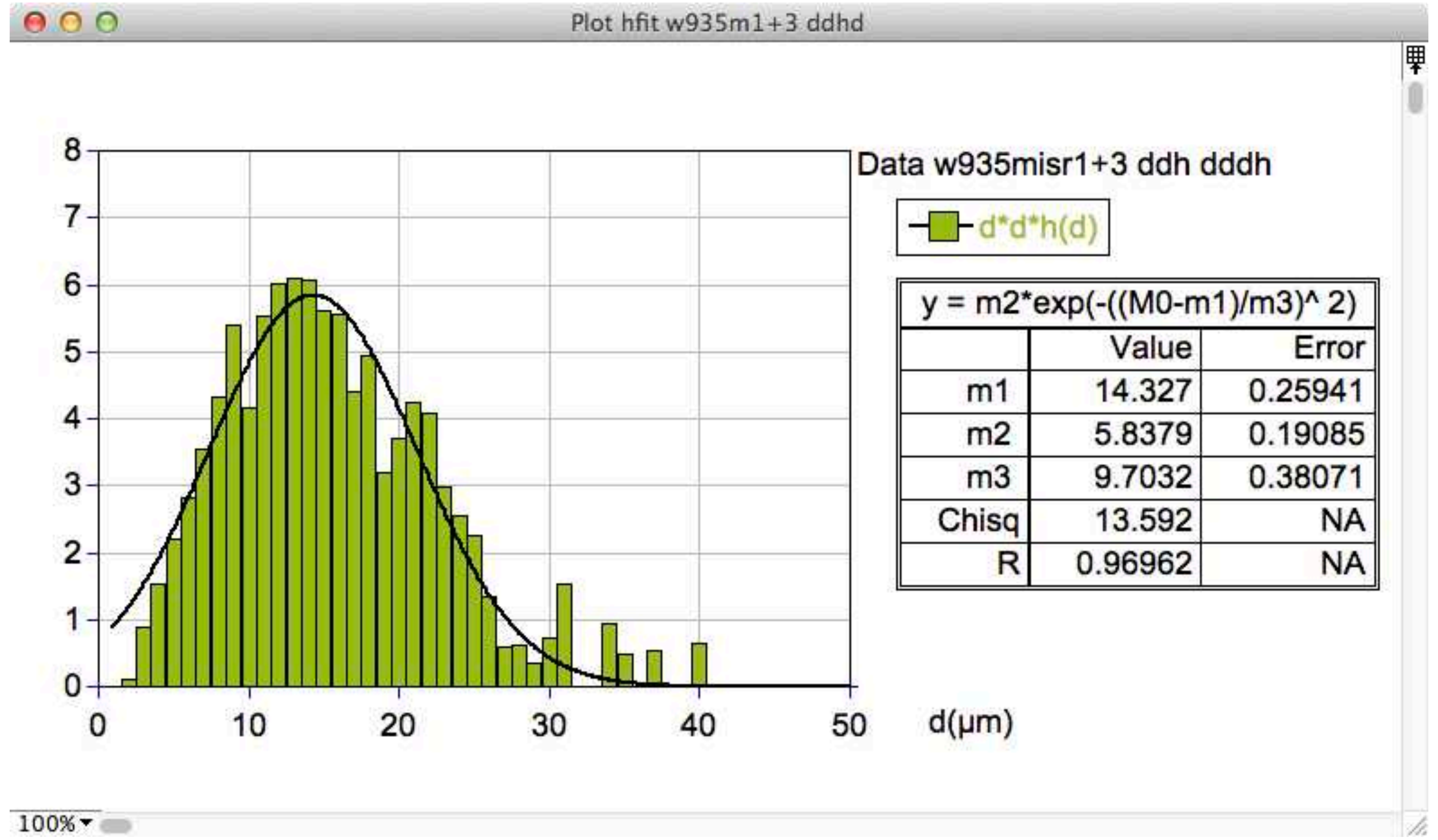


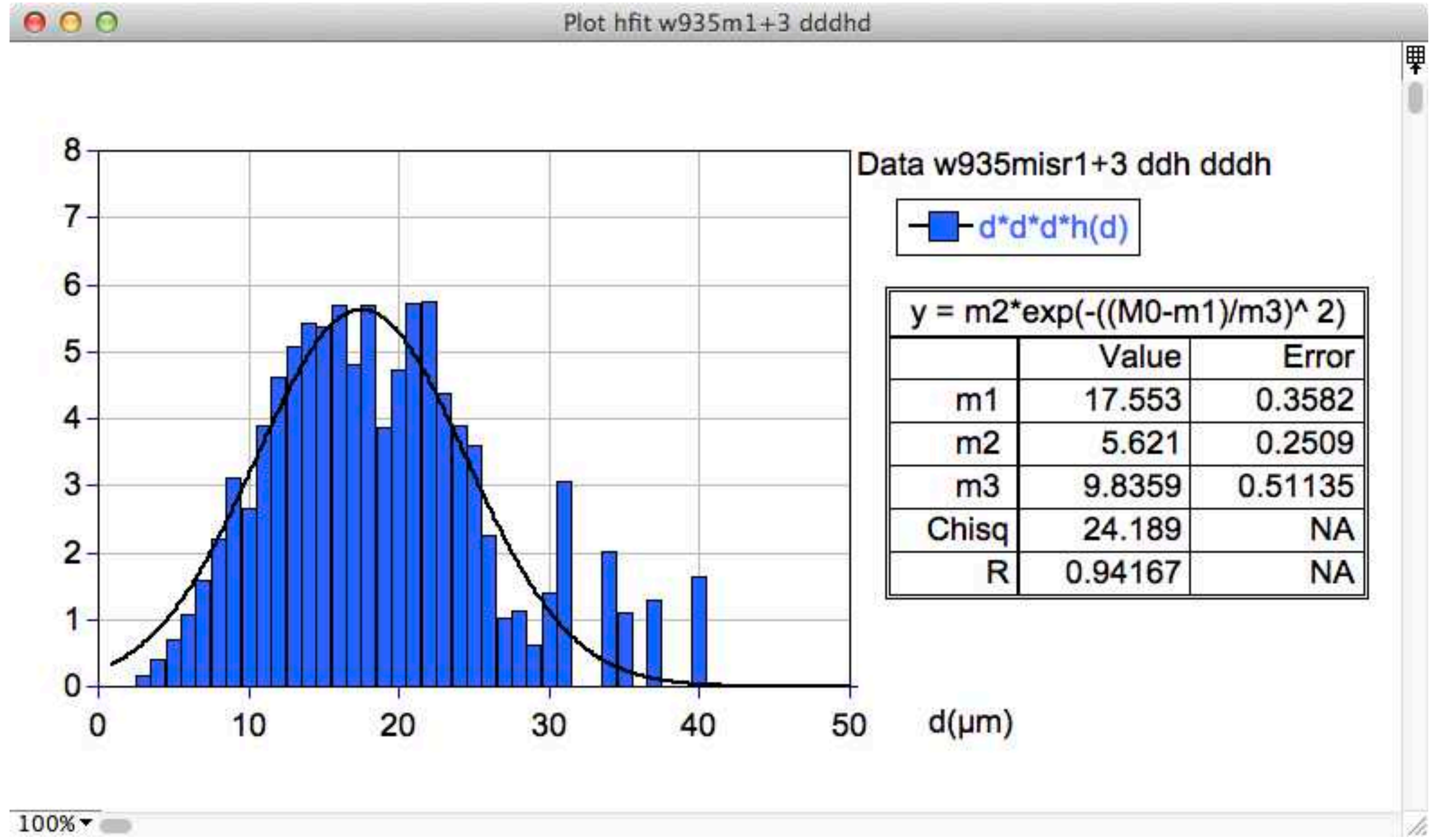




find the mode:







v(D) $d^2 \cdot h(d)$ $d^3 \cdot h(d)$

<< details >>

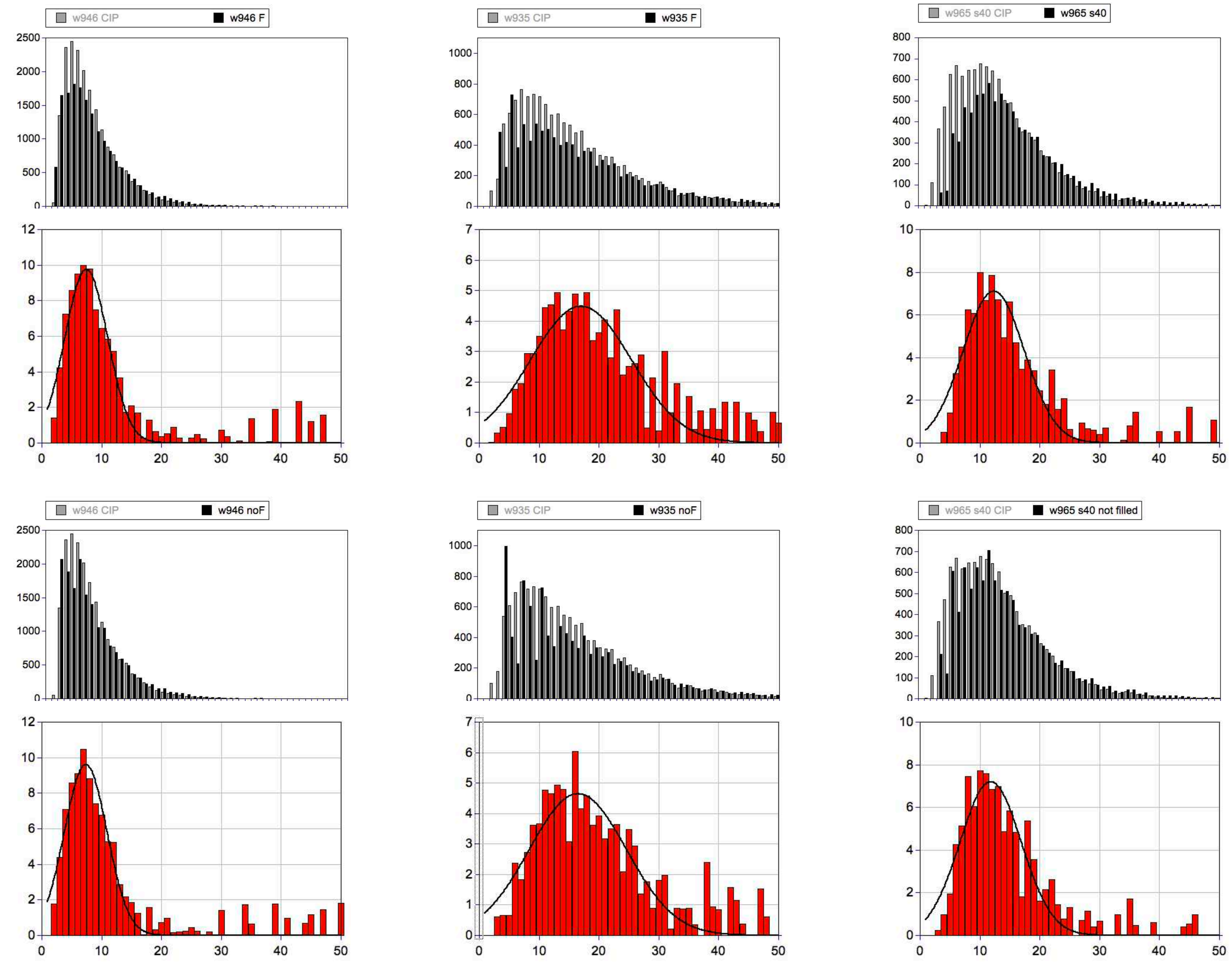
filled - not filled

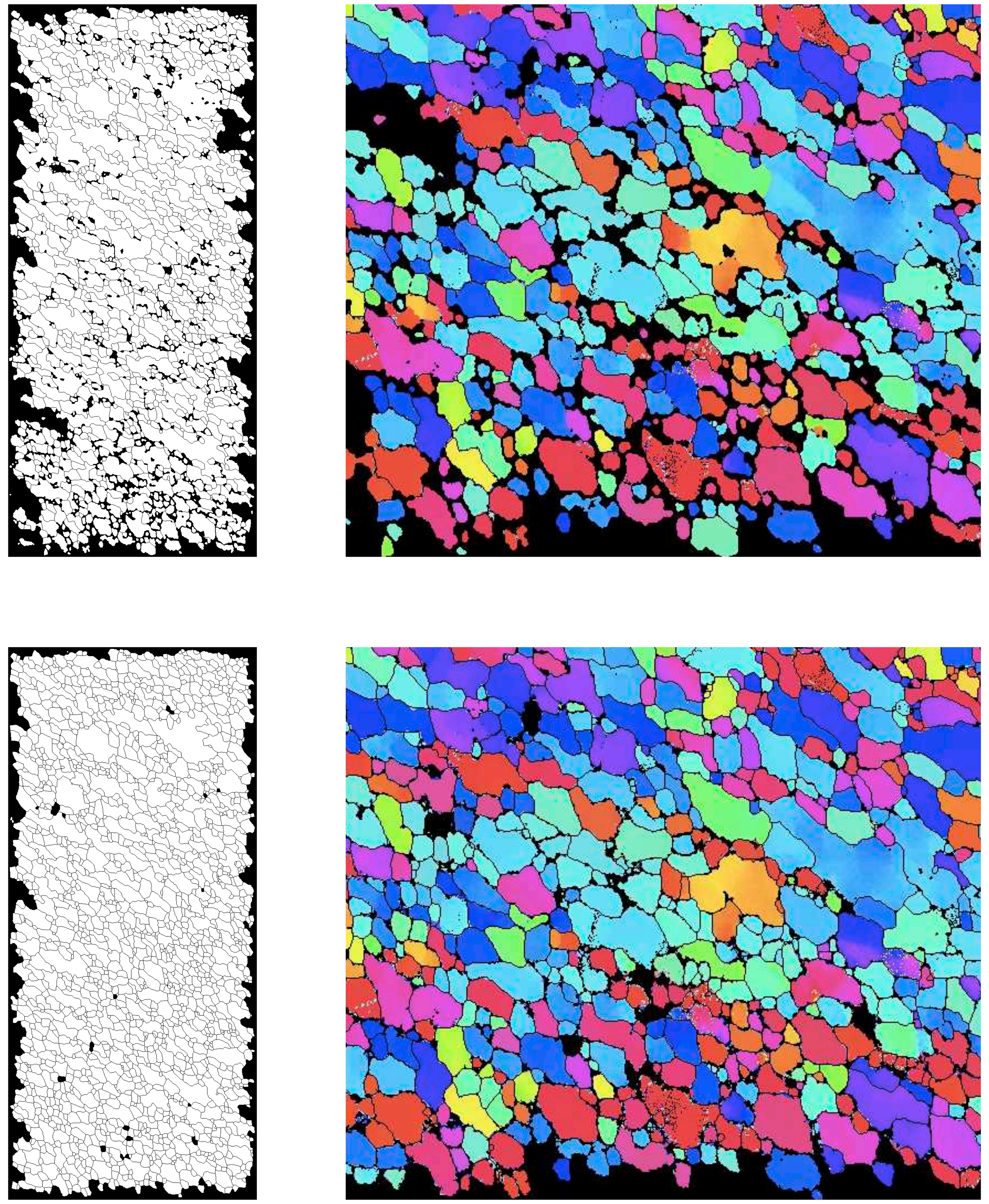
2D not filled

3D not filled

2D filled

3D filled



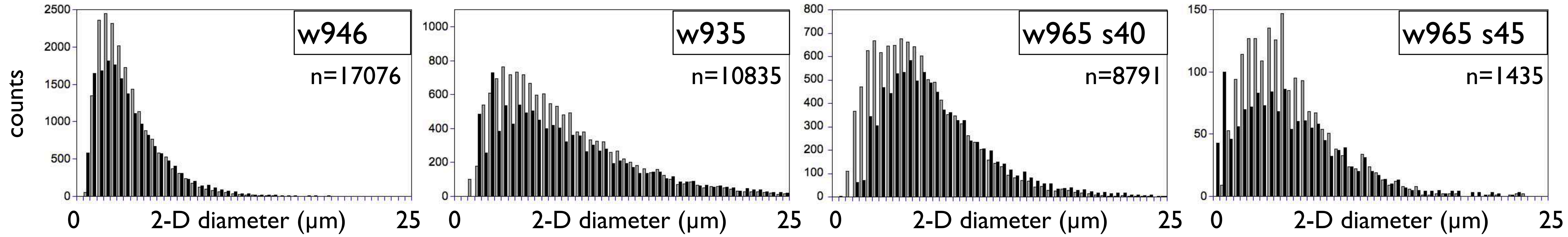


sample	index (%)	n	mode v(D) filled	RMS(d) filled	n	mode v(D) not filled	RMS(d) not filled
w946	98.6	17076	7.4788	4.9373	17209	7.3889	4.8918
w935	95.6	10835	17.058	10.747	10778	16.532	10.509
w965-s40	88.6	8791	12.363	8.9981	9645	11.845	8.3442

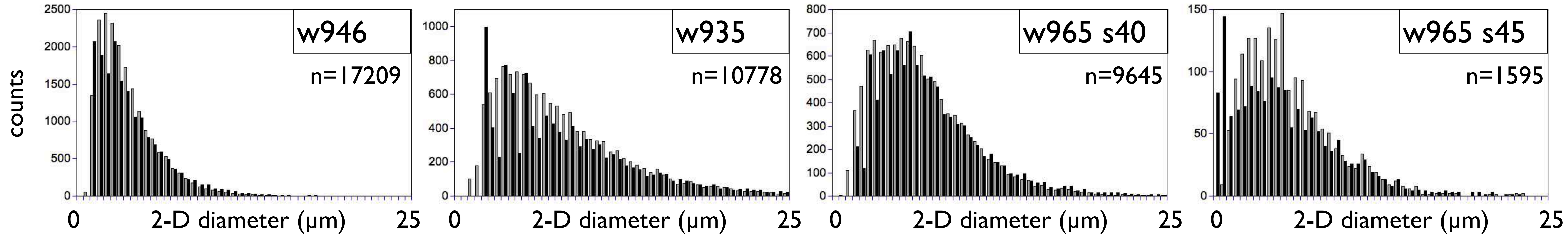
<< details >>

compare segmentations

with grain completion



without grain completion



sample	indexing rate (%)	RMS(d) EBSDc	RMS(d) EBSDnc	RMS CIP	RMS ratio CIP/EBSDc (%)	mode v(D) EBSDc	mode v(D) EBSDnc	mode CIP	mode ratio CIP/EBSDc (%)
w946	94.3	4.9373	4.8918	4.5242	91.6	7.4788	7.3889	6.5284	87.3
w935	92.3	10.747	10.509	9.3815	87.3	17.058	16.532	14.543	85.3
w965-s40	76.9	8.9981	8.3442	7.5841	84.3	12.363	11.845	10.964	88.7
w965-s45	89.0	7.4375	6.9302	6.6653	89.6	11.374	10.925	10.05	88.4

Comparison of segmentations.
Frequency distributions h(d) are shown for regime 2 and 3. EBSD segmentations are plotted in black, corresponding CIP segmentation in gray.

(a) EBSD segmentation with grain completion
(b) EBSD segmentation without grain completion.
(c) Table with RMS of h(d) and modes of v(D), where d = 2-D diameter of area equivalent circle, D = 3-D diameter of volume equivalent sphere. Subscript 'c' = with grain completion, as in (a), subscript 'nc' = without grain completion, as in (b). RMS ratio CIP/EBSDc (%) = ratio of RMS values found by CIP versus EBSDc. Mode ratio CIP/EBSDc (%) = ratio of modes found by CIP versus EBSDc.

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... and in case you missed it ... here is the Abstract

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Complete grain boundaries from incomplete EBSD maps: the influence of segmentation on grain size determinations

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Grain size analyses are carried out for a number of reasons, for example, the dynamically recrystallized grain size of quartz is used to assess the flow stresses during deformation. Typically a thin section or polished surface is used. If the expected grain size is large enough (10 μm or larger), the images can be obtained on a light microscope, if the grain size is smaller, the SEM is used. The grain boundaries are traced (the process is called segmentation and can be done manually or via image processing) and the size of the cross sectional areas (segments) is determined. From the resulting size distributions, 'the grain size' or 'average grain size', usually a mean diameter or similar, is derived.

When carrying out such grain size analyses, a number of aspects are critical for the reproducibility of the result: the resolution of the imaging equipment (light microscope or SEM), the type of images that are used for segmentation (cross polarized, partial or full orientation images, CIP versus EBSD), the segmentation procedure (algorithm) itself, the quality of the segmentation and the mathematical definition and calculation of 'the average grain size'. The quality of the segmentation depends very strongly on the criteria that are used for identifying grain boundaries (for example, angles of misorientation versus shape considerations), on pre- and post-processing (filtering) and on the quality of the recorded images (most notably on the indexing ratio).

In this contribution, we consider experimentally deformed Black Hills quartzite with dynamically re-crystallized grain sizes in the range of 2 - 15 μm. We compare two basic methods of segmentations of EBSD maps (orientation based versus shape based) and explore how the choice of methods influences the result of the grain size analysis. We also compare different measures for grain size (mean versus mode versus RMS, and 2D versus 3D) in order to determine which of the definitions of 'average grain size yields the most stable results.

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EBSD data acquisition, image processing and segmentation

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
#	Sample	Voltage (kV)	Probe current (nA)	Pressure (Pa)	Aperture (µm)	WD (mm)	Magn.	Speed (Hz)	Time (h:m)	Reflectors / Bands	Mean MAD	Hough resol.	Binning	Step size (µm)	Map size (µm · µm)	Hit rate (%)
	undeformed material:															
	BHQ	20	5.3	35	120	9.48	200x	40.5	9:19	48 / 9	0.58	120	4x4	1.0	1388 · 980	91.4
	scanned sites of experiments:															
1a	w940	20	n.a.	2	120	14.5	250x	22.6	17:50	75 / 9	0.89	70	2x2	0.5	500 · 725	44.1
1b	w1092	20	n.a.	28	120	14.47	250x	22.8	18:45	75 / 10	0.90	110	2x2	0.5	550 · 700	92.8
1b	w1092-s30	20	n.a.	n.a.	n.a.	14.7	n.a.	11.2	10:48	75 / 9	0.81	70	2x2	0.5	241.5 · 452	77.3
2a	w1086	20	3.0	20	120	14.6	150x	22.6	5:54	75 / 9	0.90	70	2x2	0.5	600 · 200	72.0
2b	w946	20	n.a.	28	120	13.49	300x	22.8	18:16	75 / 10	0.62	110	2x2	0.5	750 · 485	94.3
3a	w1010-s34	20	9.0	25	120	14.3	200x	40.3	3:02	75 / 9	0.78	70	4x4	1.0	430 · 980	82.1
3a	w1010-s36	20	9.0	25	120	14.3	200x	11.4	2:51	75 / 9	0.84	70	2x2	1.0	500 · 830	78.5
3b	w935	20	n.a.	28	120	13.35	200x	22.8	15:58	75 / 10	0.57	110	2x2	0.9988	1275.5 ·1025.8	93.1
3b	w965-s40	20	6.0	25	120	15.0	150x	40.3	14:28	75 / 9	0.82	70	4x4	1.0	840 · 700	76.9
3b	w965-s45	20	3.0	20	120	148	250x	22.6	14:00	75 / 10	0.75	70	2x2	0.25	180 · 400	89.0

1	2	3	4	5	6	7	8	9	10	11	12
#	Map	Source	Cropped size (px)	Hit rate raw (%)	Hit rate deN (%)	Step size (µm)	Images used	Magn.	Pixel size (µm)	Procedure	Definition (°)
	BHQ	EBSD	1388 · 980	91.4	94.5	1.0	8 misors	1	1	LGB interactive	n.a.
	bhq 2.5x	CIP	1388 · 1040	-	-	2.439	nopol	1	2.439	visual boundaries	n.a.
1a	w940	EBSD	1000 · 500	86.5	95.6	0.50	8 misors	2	0.25	euoz-th25-itjitji-x-1y-1	1.2
1b	w1092	EBSD	1100 · 1400	76.0	89.8	0.50	8 misors	2	0.25	eoz-th50mjtji	2.5
1b	w1092-s30	EBSD	483 · 904	77.3	92.9	0.50	8 misors	2	0.25	eoz-th50mjitji	2.5
2a	w1086	EBSD	1200 · 400	72.0	81.0	0.50	8 misors	2	0.25	eoz-th25-er5-mmmjitji	1.2
2b	w946	EBSD	1500 · 970	94.3	98.6	0.50	8 misors	2	0.25	eoz-th50itji	2.5
3a	w1010-s34	EBSD	450 · 980	82.1	91.2	1.00	8 misors	2	0.50	eoz-th50i-tjitji	2.5
3a	w1010-s36	EBSD	500 · 830	78.5	90.0	1.00	8 misors	2	0.50	eoz-th50i-tjitji	2.5
3b	w935	EBSD	1277 ·1027	92.3	95.6	0.9988	8 misors	2	0.4994	eoz-th32i-e5dH-mjitji	1.5
3b	w965-s40	EBSD	840 · 700	76.9	88.6	1.00	8 misors	4	0.25	ueuoz-th50er5-ttjitji	2.5
3b	w965-s45	EBSD	720 · 1600	89.0	94.8	0.25	8 misors	1	0.25	eoz+m-th40-e5dG-mjitji	2.0

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Grain size measurements

1	2	3	4	5	6	7	8
Map	Number of grains	Mode v(D)	Standard deviation	μ + σ	μ + 2σ	μ + 3σ	RMS(d)
undeformed Black Hills Quartzite							
BHQ undef. EBSD	216	104.1200	5.3856	109.51	114.89	120.28	77.214
BHQ undef. CIP	1146	103.9600	13.847	117.81	131.65	145.50	89.964
(a) all maps							
1a-w940	5914	5.2979	1.9958	7.2937	9.2895	11.29	4.1186
1b-w1092	34115	4.0942	1.4439	5.5381	6.9820	8.43	3.4025
1b-w1092-s30	9871	4.0790	1.4839	5.5629	7.0467	8.53	3.3308
2a-w1086	4377	5.7705	2.1522	7.9227	10.075	12.23	4.9579
2b-w946	19279	6.5284	2.9552	9.4836	12.439	15.39	4.5242
3a-w1010-s34	6441	9.0813	3.4139	12.495	15.909	19.32	7.9589
3a-w1010-s36	5792	9.2756	3.4170	12.693	16.110	19.53	8.3934
3b-w935	13354	14.5430	6.5298	21.073	27.603	34.13	9.3815
3b-w965-s40	10910	10.9640	4.3534	15.317	19.671	24.02	7.5841
3b-w965-s45	1860	10.0500	4.3044	14.354	18.659	22.96	6.6653
(b) dependence on grain kernel average misorientation (gKAM)							
1b-w1092 high gKAM	19391	3.9213	1.3561	5.2774	6.6335	7.99	3.2697
1b-w1092 low gKAM	14725	4.2960	1.5167	5.8127	7.3295	8.85	3.5699
2b-w946 high gKAM	13406	5.6628	2.4508	8.1136	10.564	13.02	4.0418
2b-w946 low gKAM	6396	7.7984	3.1009	10.899	14.000	17.10	5.4014
3b-w935 high gKAM	7898	13.0990	5.8398	18.939	24.779	30.62	8.6666
3b-w935 low gKAM	6220	16.2140	7.1071	23.321	30.428	37.54	10.267
(c) texture dependence							
1b-w1092 all (center strip)	25553	4.2660	1.4415	5.7075	7.1490	8.59	3.4041
1b-w1092 B-domain	11647	4.6881	1.8084	6.4965	8.3048	10.11	3.4741
1b-w1092 Y-domain	2289	4.1495	1.2075	5.3570	6.5646	7.77	3.2928
2b-w946 all	19280	6.5776	2.9357	9.5133	12.449	15.38	4.5241
2b-w946 B-domain	7425	7.2038	3.3556	10.559	13.915	17.27	4.7579
2b-w946 Y-domain	5634	6.5537	2.8060	9.3597	12.166	14.97	4.4397
3b-w965 all	10910	11.0140	4.3210	15.335	19.656	23.98	7.5828
3b-w965 B-domain	2203	11.5460	4.8128	16.359	21.172	25.98	7.8153
3b-w965 Y-domain	7385	11.0500	4.2983	15.348	19.647	23.94	7.6113
3b-w935 all	13359	14.6840	6.8181	21.502	28.320	35.14	9.3800
3b-w935 B-domain	2817	14.1530	6.8712	21.024	27.895	34.77	9.1574
3b-w935 Y-domain	7702	15.972	7.0684	22.413	29.482	36.55	9.5594

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