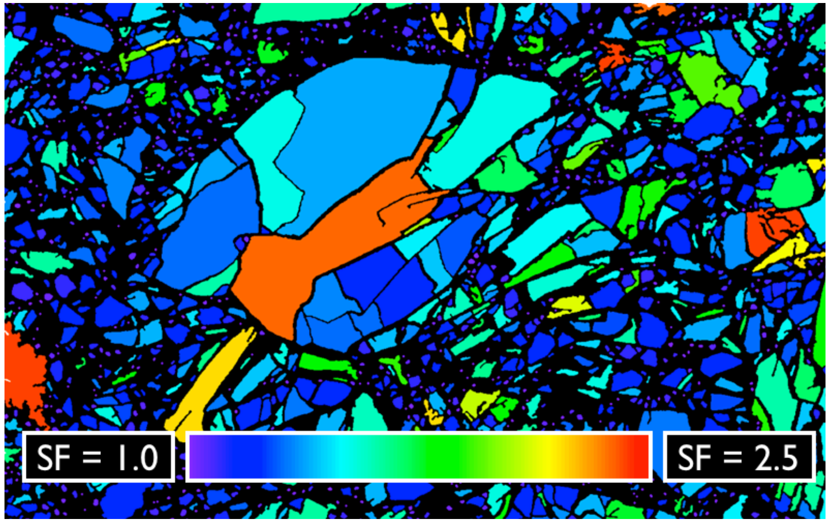
TSK19 HALLE

Workshop 2

Tuesday, March, 7, 2022



Selected topics in image analysis of deformed rocks

(3)

Shape analysis
Grain size distributions
Spatial distributions

renee.heilbronner@unibas.ch

Schedule

Renée – Lectures

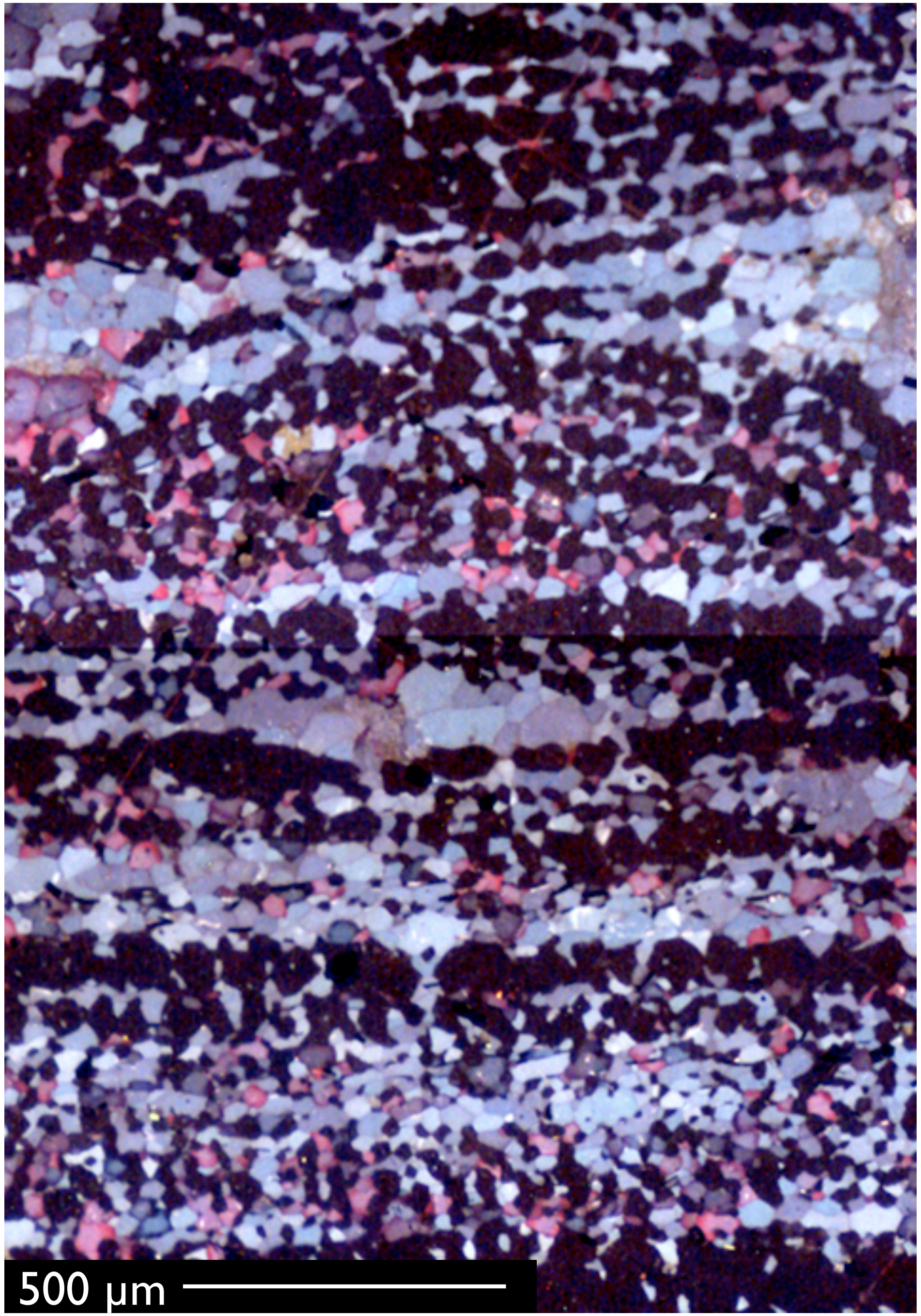
10:00-10:30 shape analysis
10:30-11:00 discussion & break
11:00-11:30 grainsize
11:30-12:00 discussion & break
12:00-12:30 phase distributions & correlations
12:30-14:00 discussion & lunch

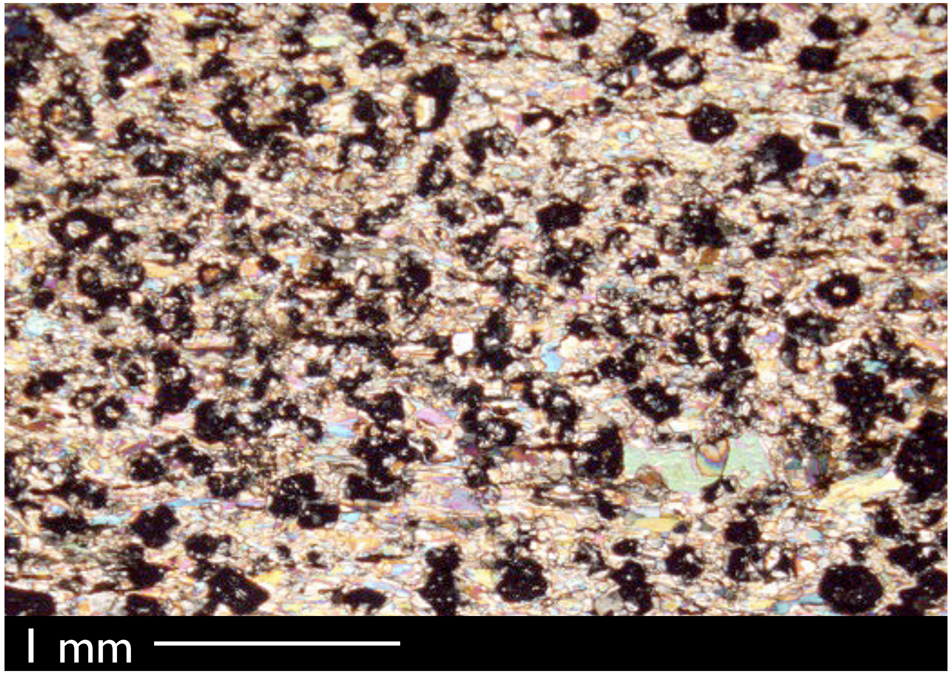
Rüdiger – Lab

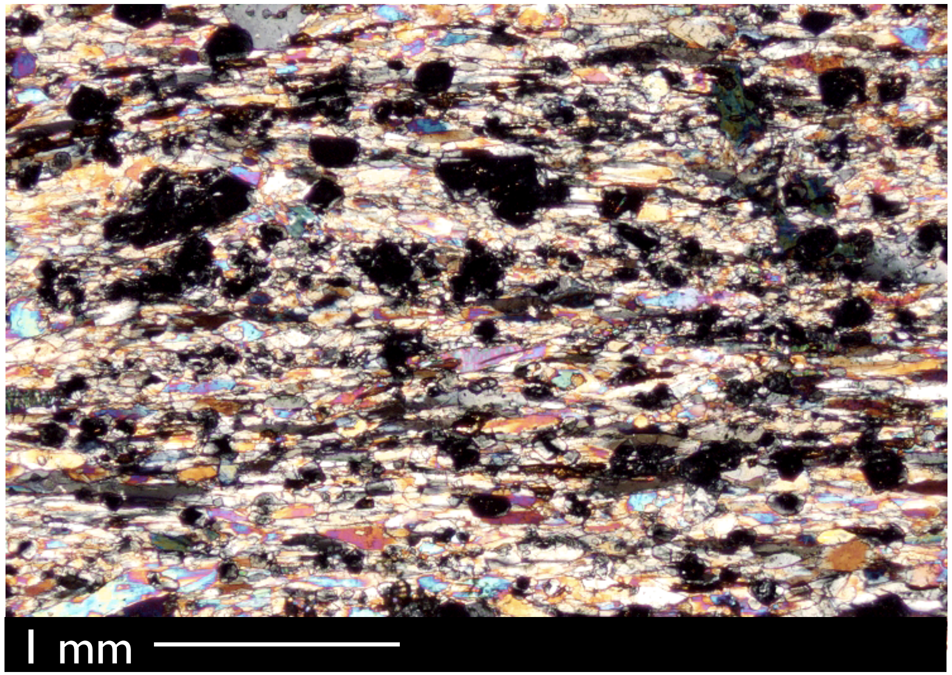
14:00-15:30 using Fiji / imageJ
15:30-16:00 break
16:00-17:00 playtime (with your own data)

I
spatial distributions

spatial dispersion





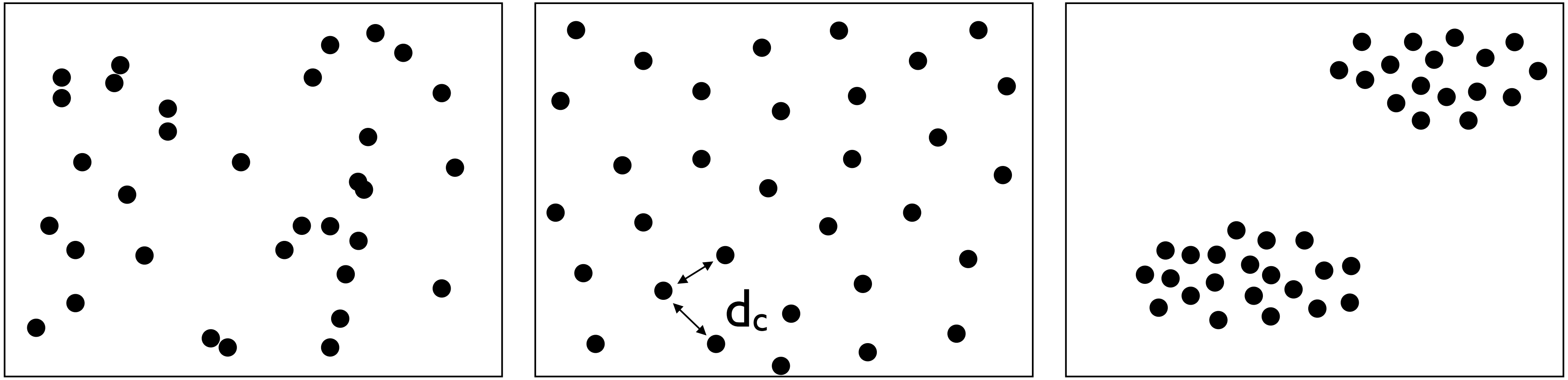


spatial distributions

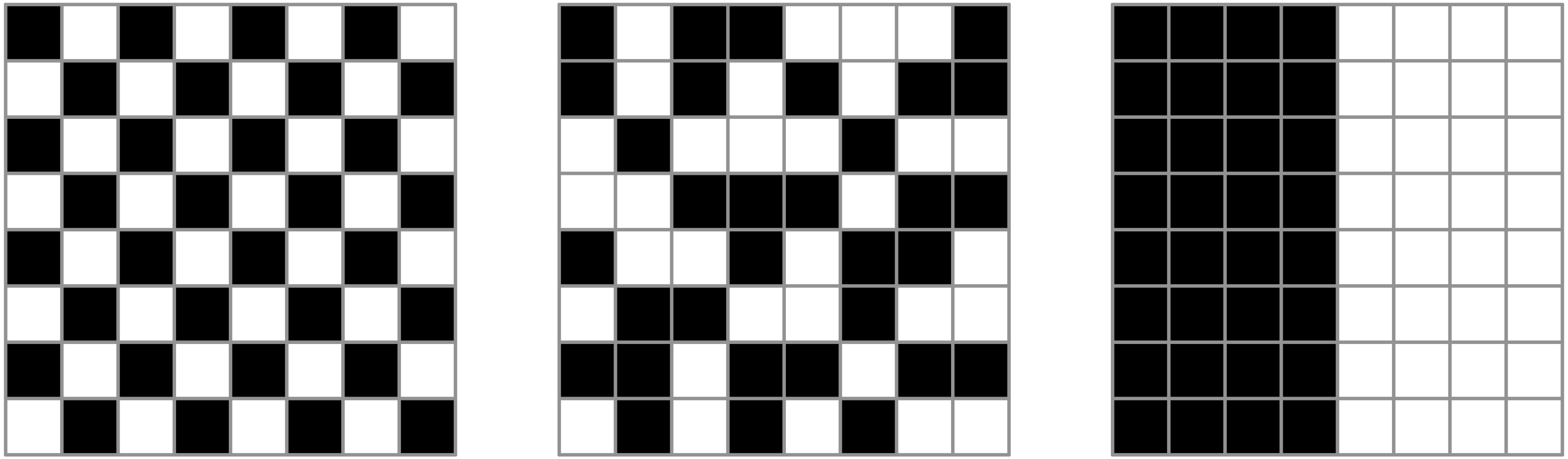
- random
- clustered
- ordered ('anti-clustered')

spatial distributions

spatially dispersed center points

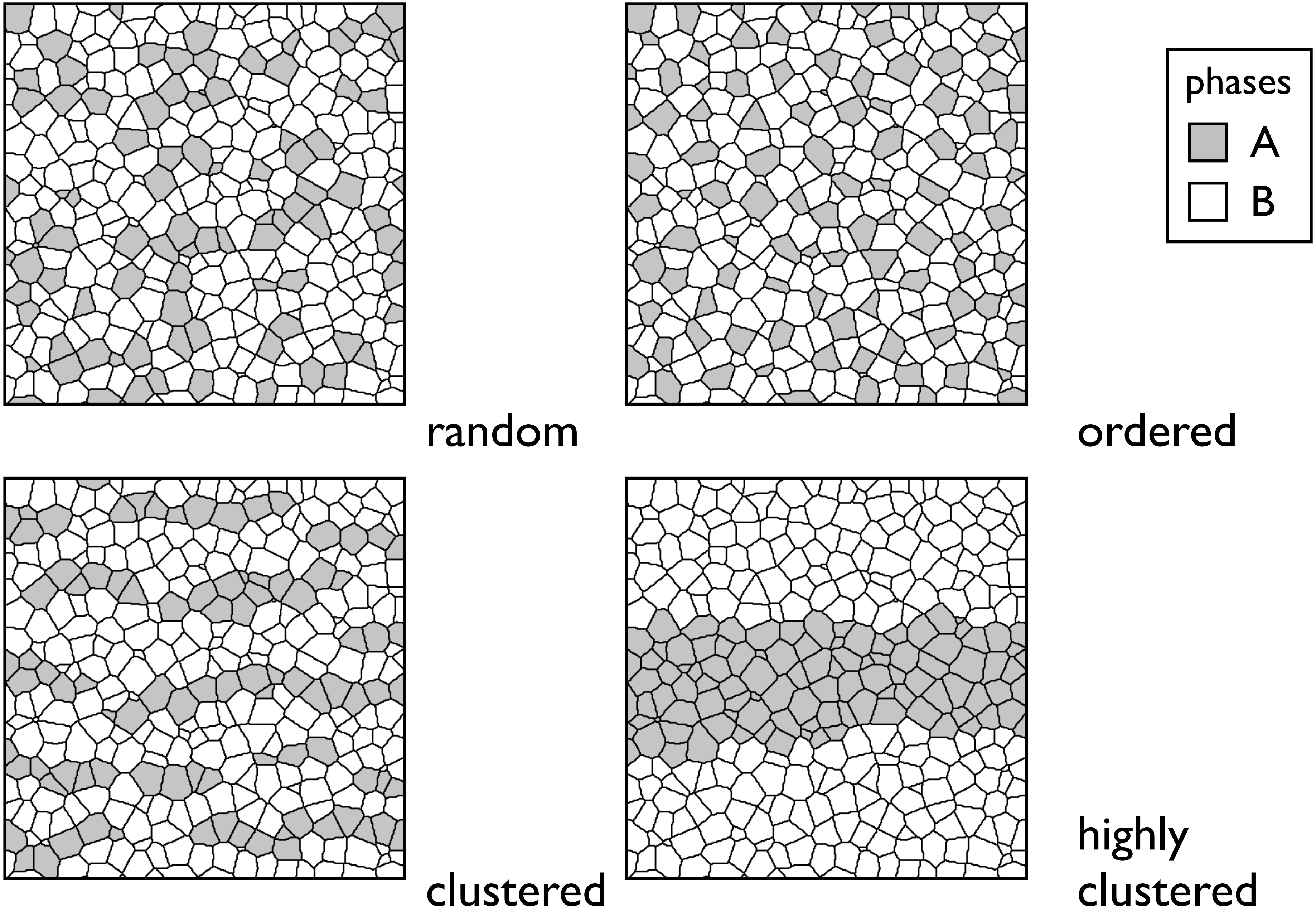


chessboard model

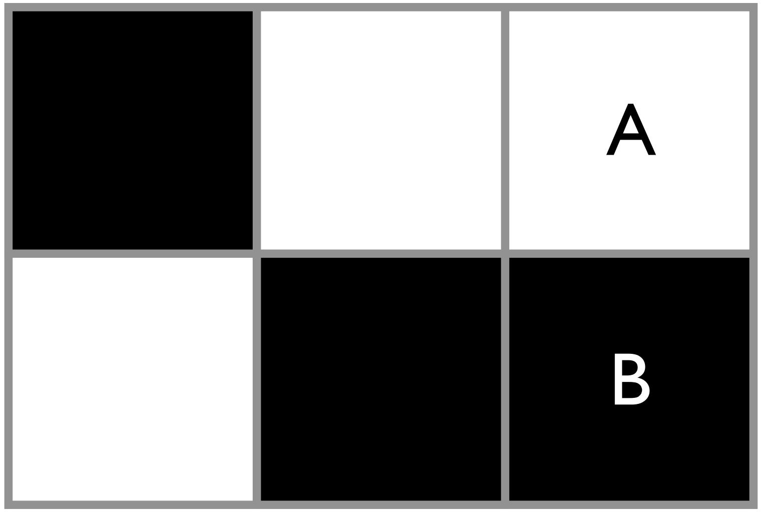


ordered random clustered

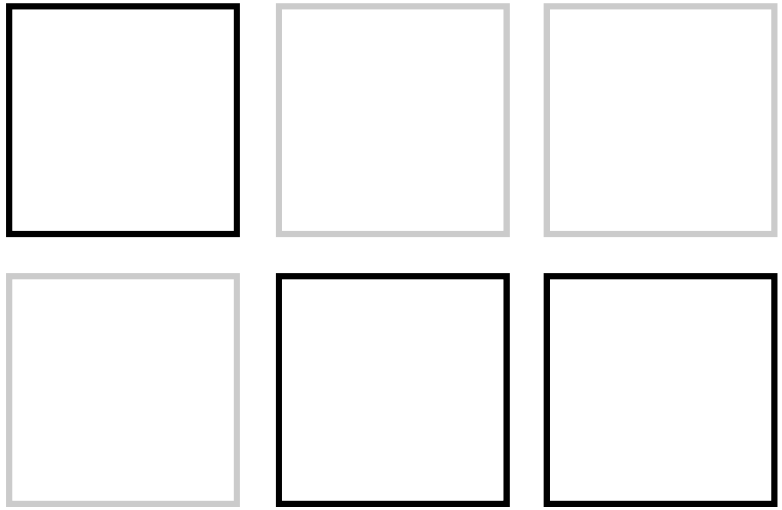
spatial distribution



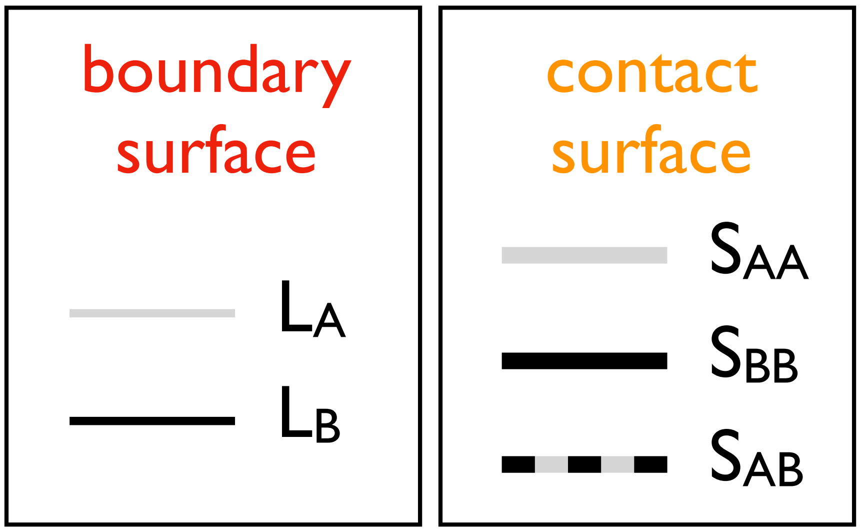
phases, boundaries and contacts

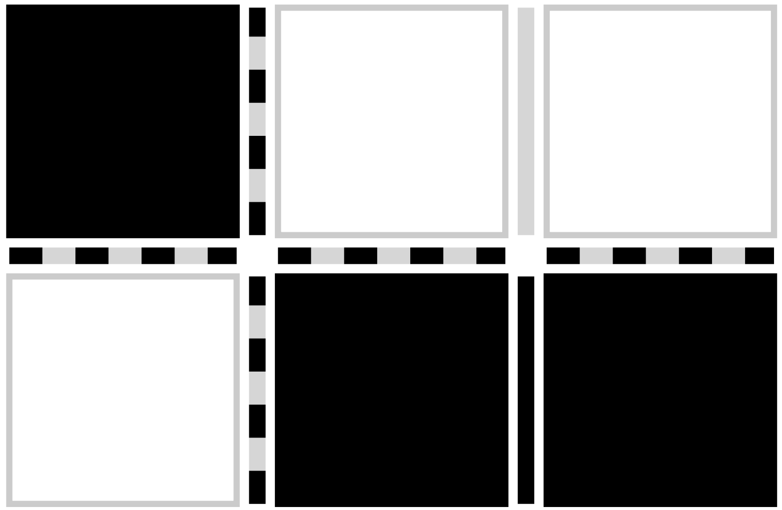


2 types of grains



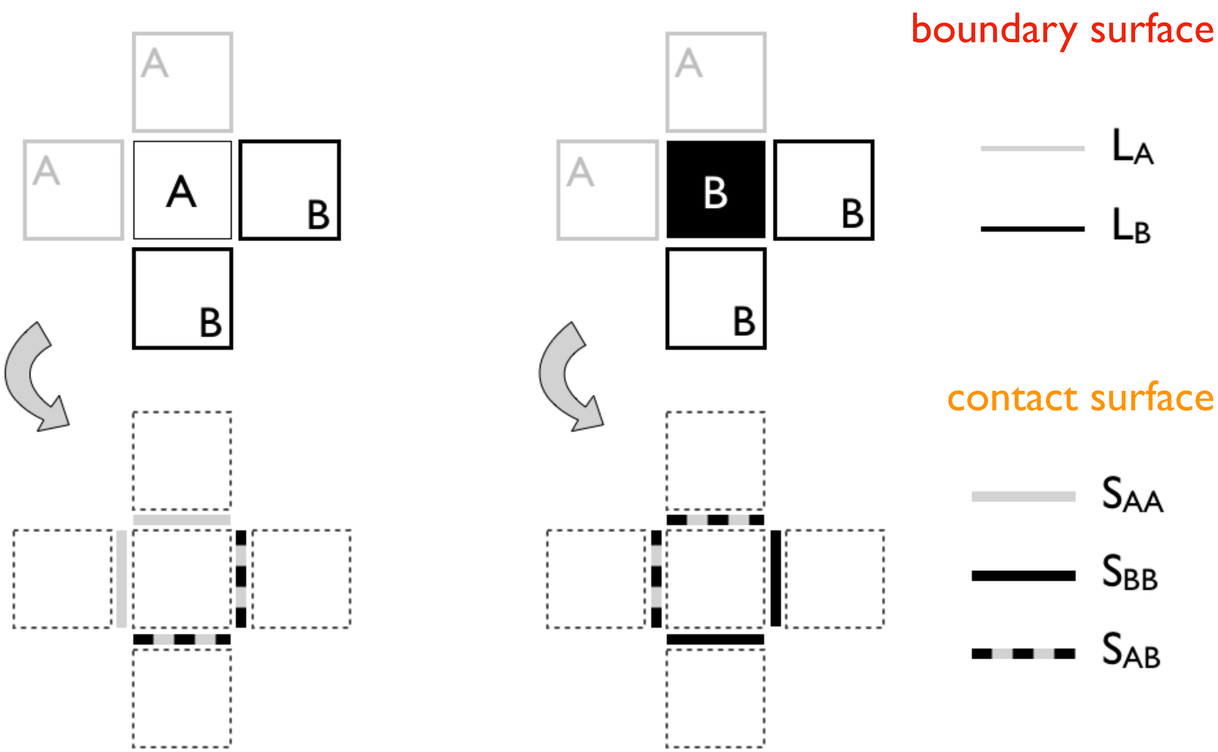
2 types of grain boundary surface





3 types of grain contact surface

conceptual model



For any given grain A, B:

the chance pA, pB, of sharing a boundary surface with a grain A or B is proportional to:

- volume fraction[1)] of A, B

or

- surface fraction[2)] of A, B

$$AA = pA \cdot pA = pA^2$$

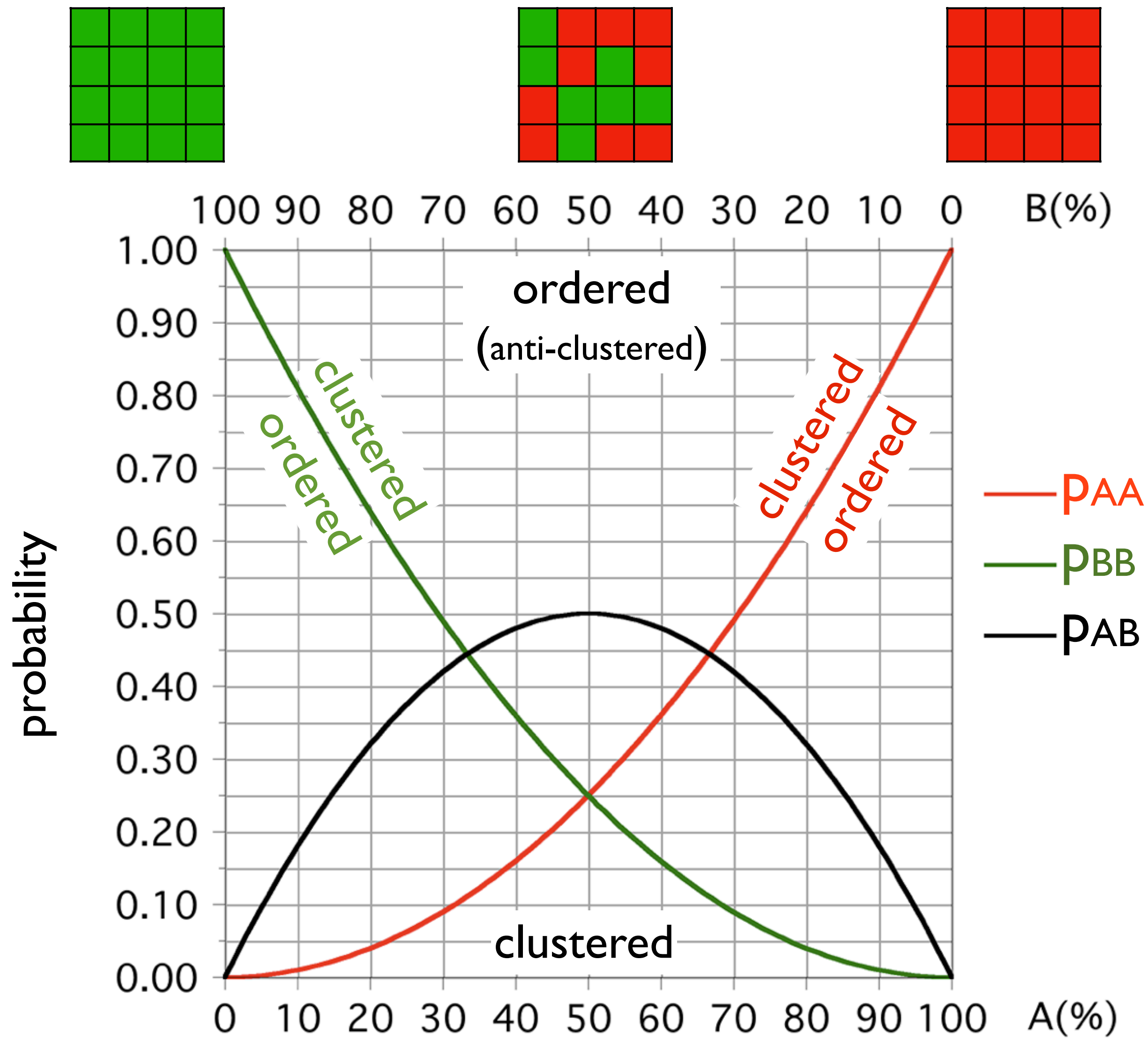
$$BB = pB \cdot pB = (1-pA)^2$$

$$AB = BA = pA \cdot pB + pB \cdot pA = 2 \cdot pA \cdot (1-pA)$$

1) = area(phase) / (total cross sectional area)

2) = outline(phase) / (total boundary length)

binomial distribution



$AA = pA \cdot pA = pA^2$

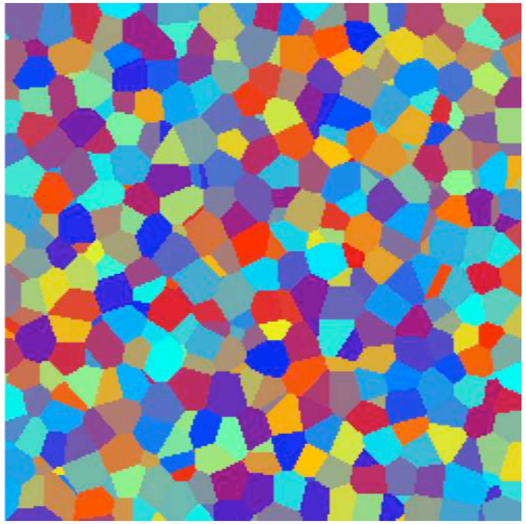
$BB = pB \cdot pB = (1-pA)^2$

$AB = BA = pA \cdot pB + pB \cdot pA = 2 \cdot pA \cdot (1-pA)$

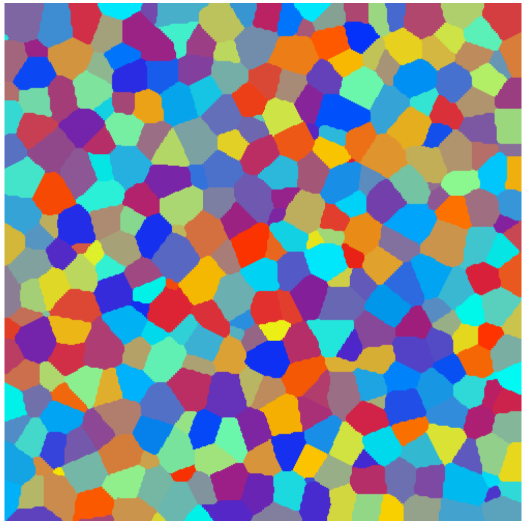
spatial distributions

- grains in matrix
- grains in crystalline aggregate

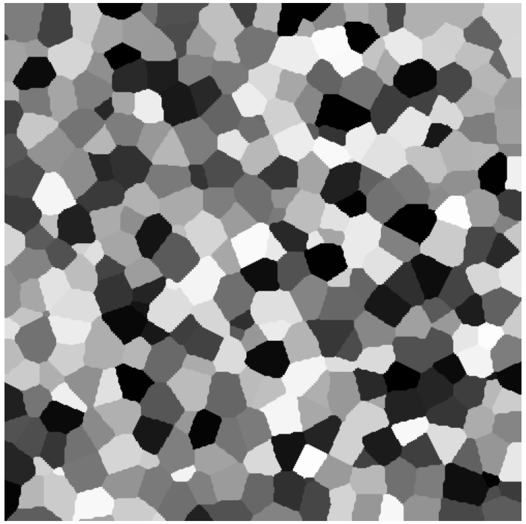
making random Voronois



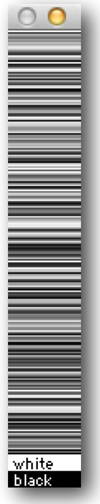
5050anti5_z5.tif

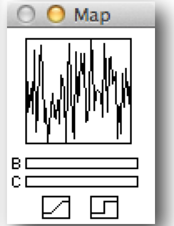


5050anti5Prep

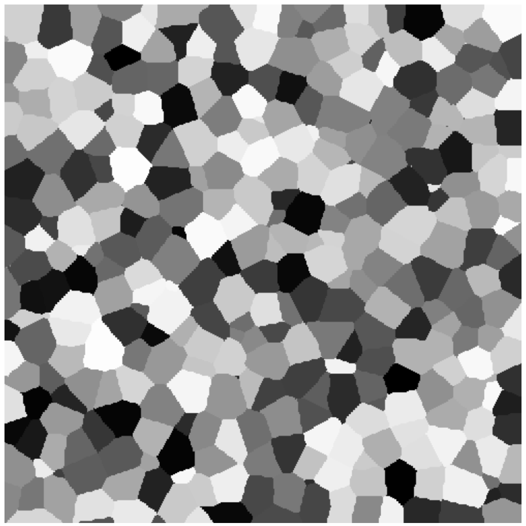


5050anti5Prep (R)

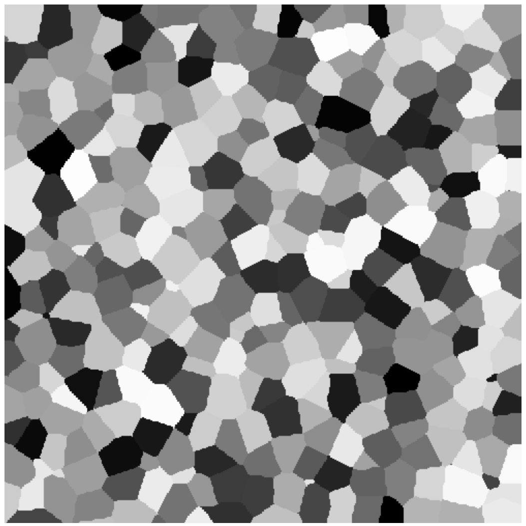




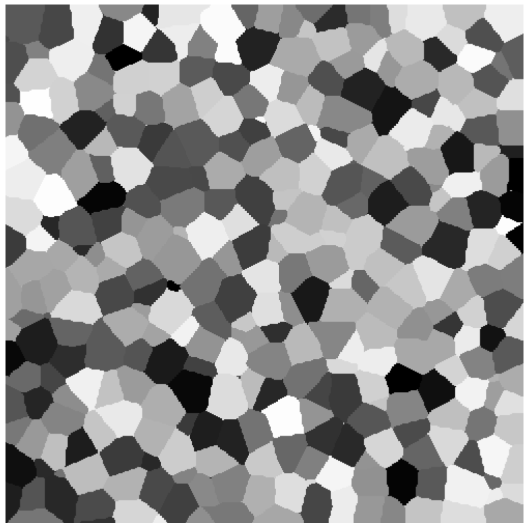
re-apply random Palette



5050anti5Prep R1



5050anti5Prep R2

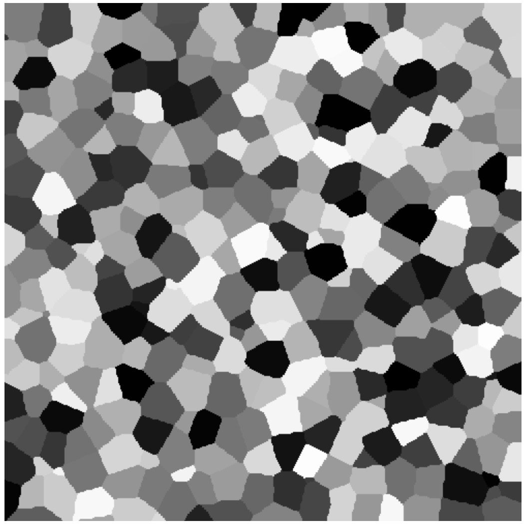


5050anti5Prep R3

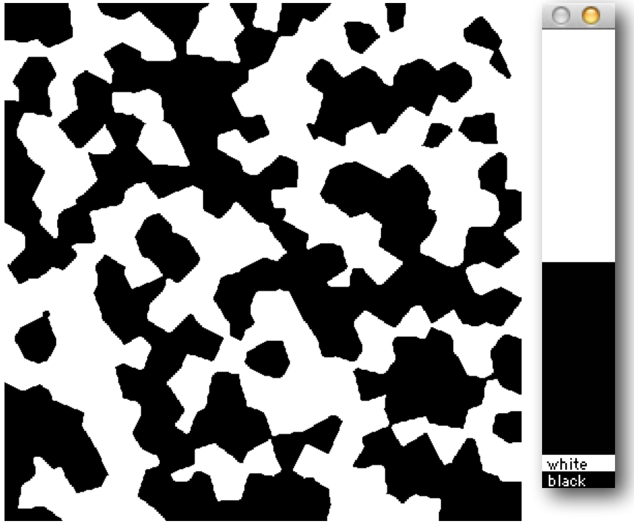
etc.

used random Palette on 5050anti5Prep R = processed R of 5050anti5_z5.tif

making random Voronois (continued)

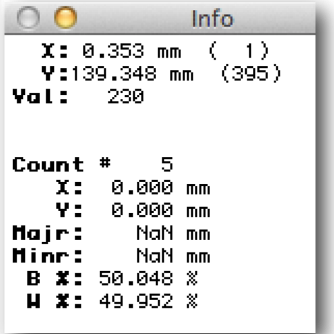


5050anti5Prep (R)

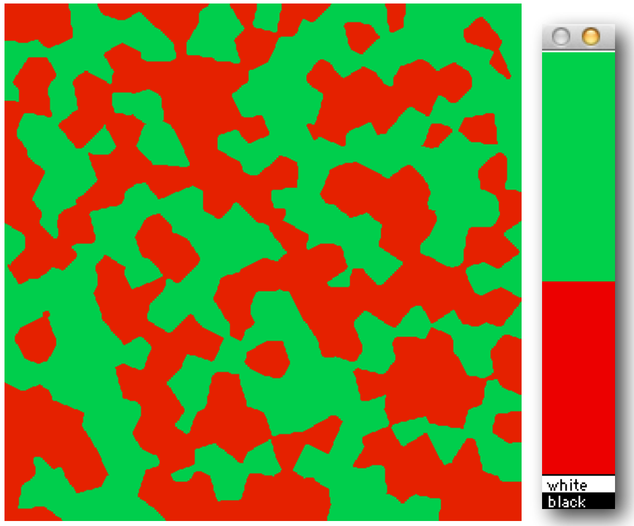


5050anti5Prep (R)

threshold = 139

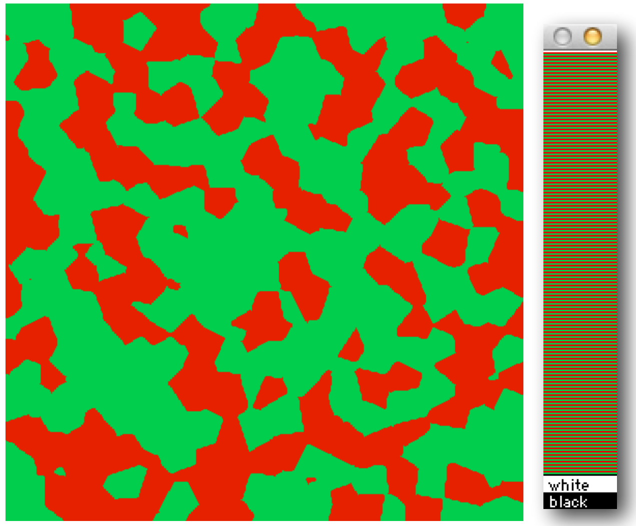


⇒



R 50.0% G 50.0%

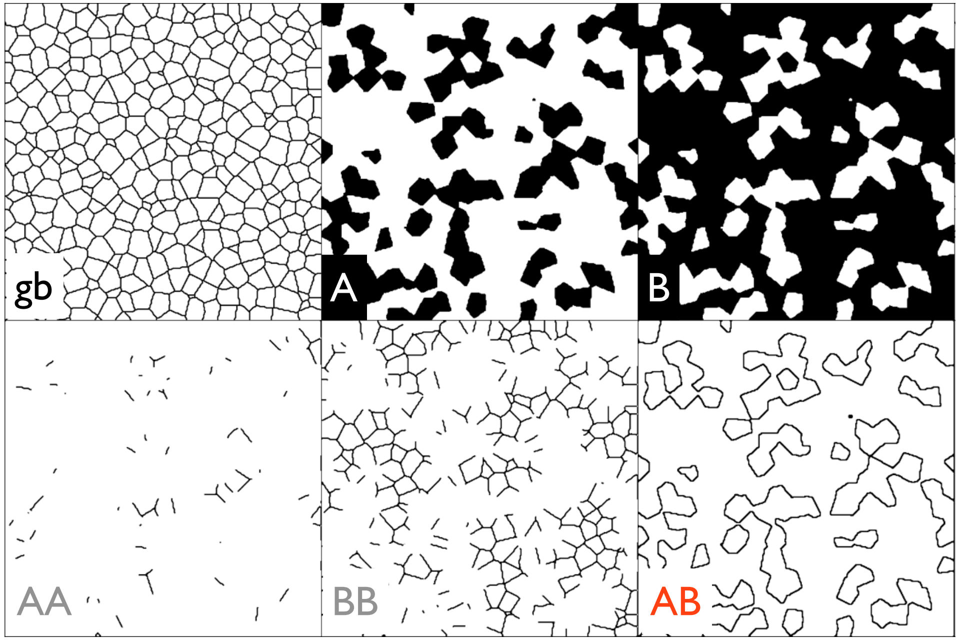
≠

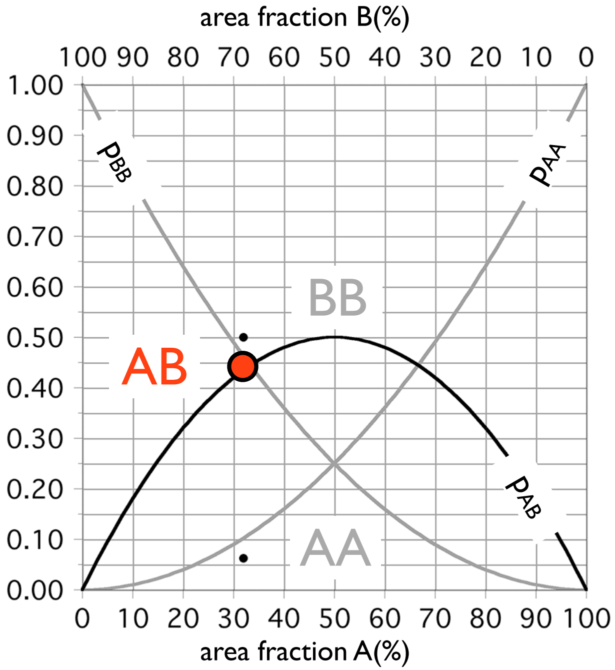


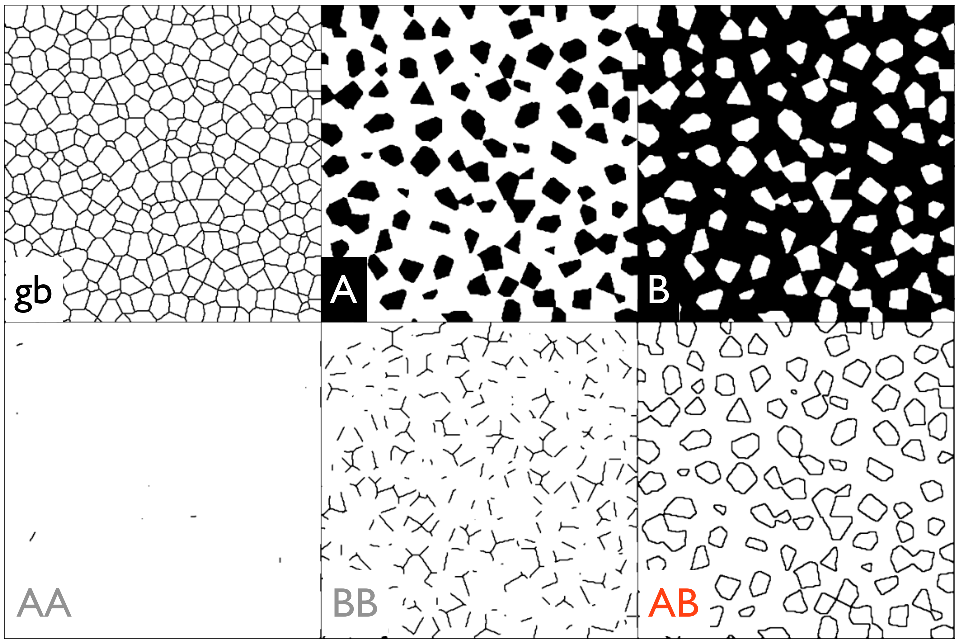
R 46.8% G 52.2%

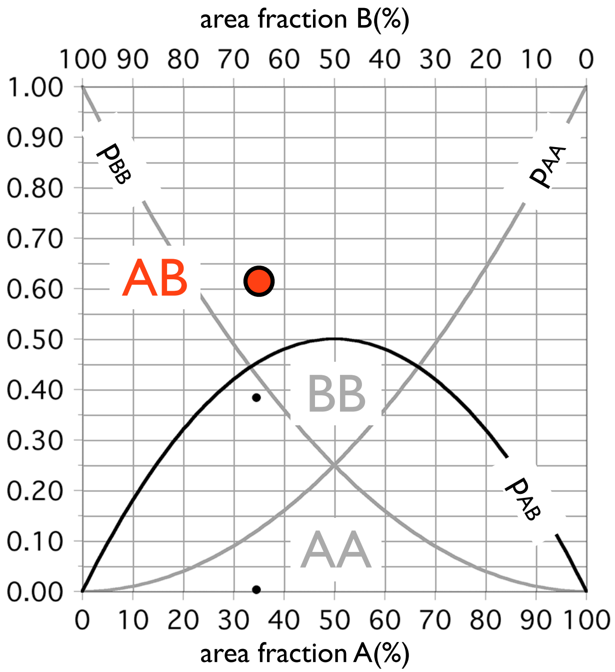
threshold 5050anti5Prep instead of using macro [6], ⇒ control percentage

distributions and contact probabilities

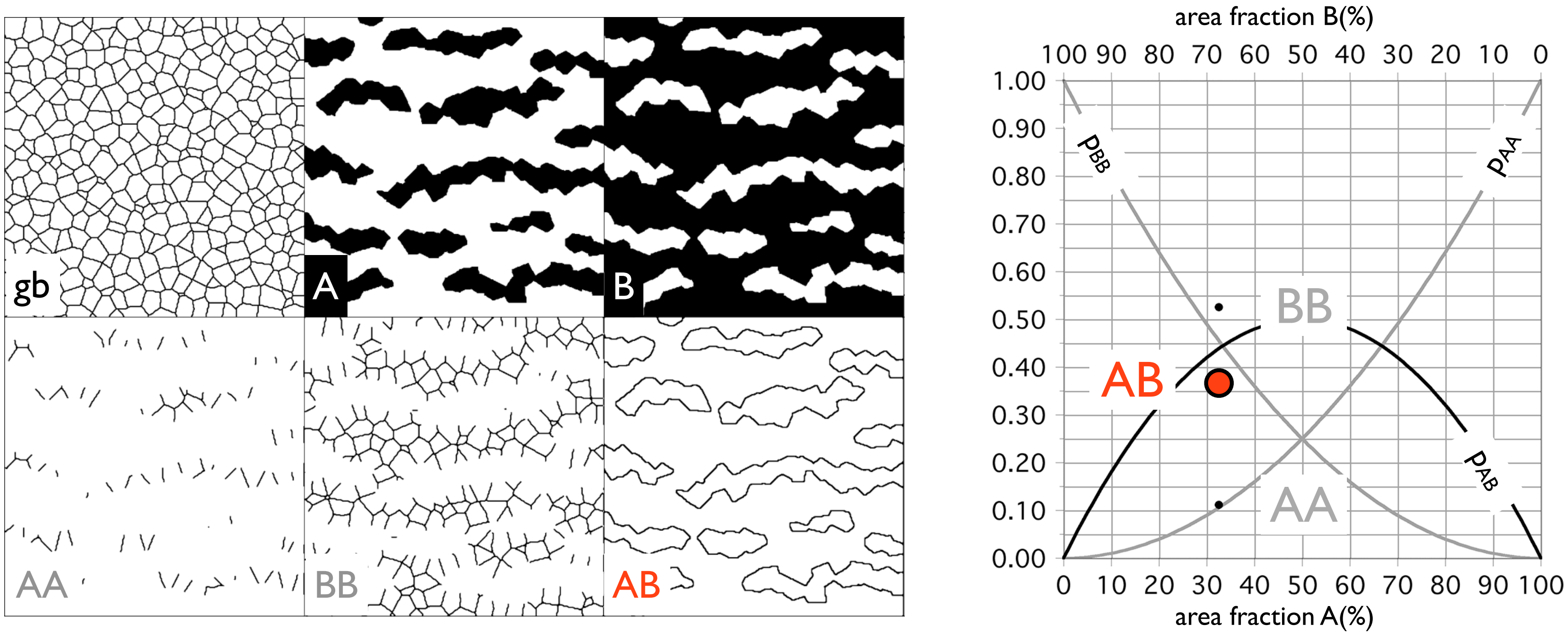


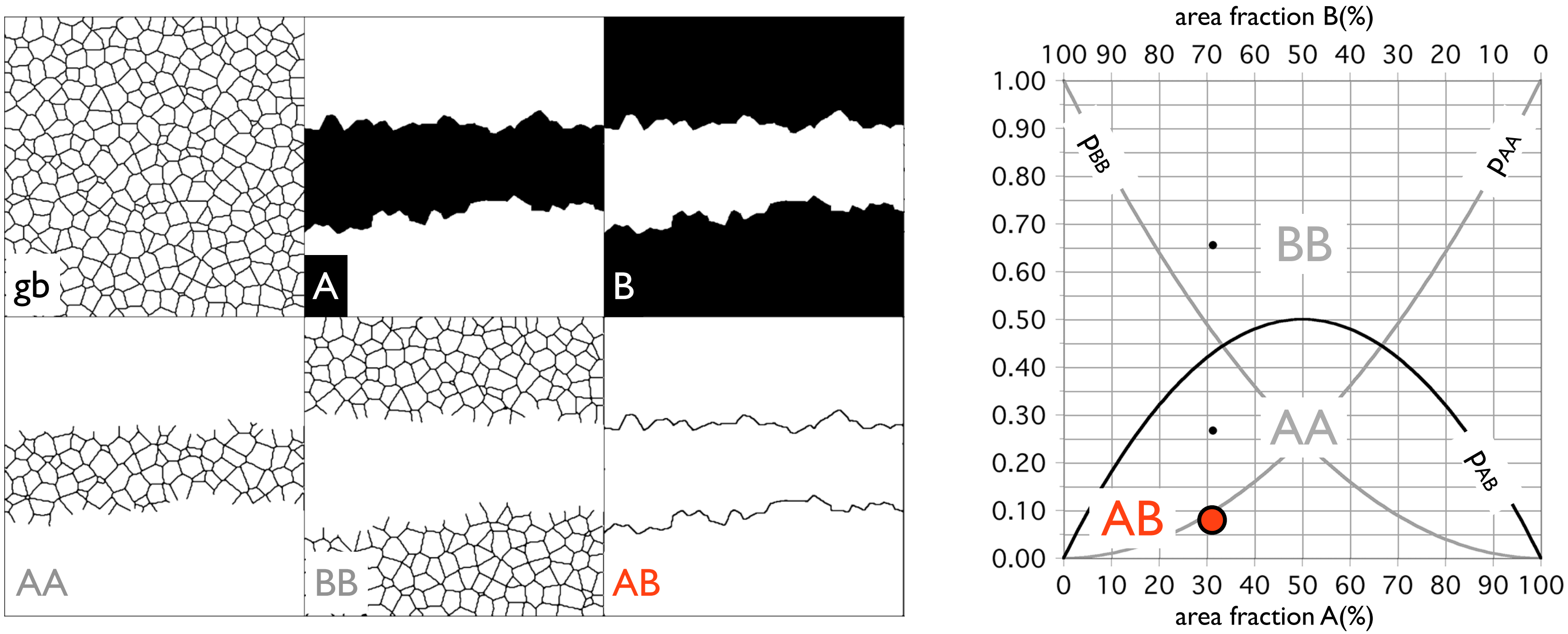




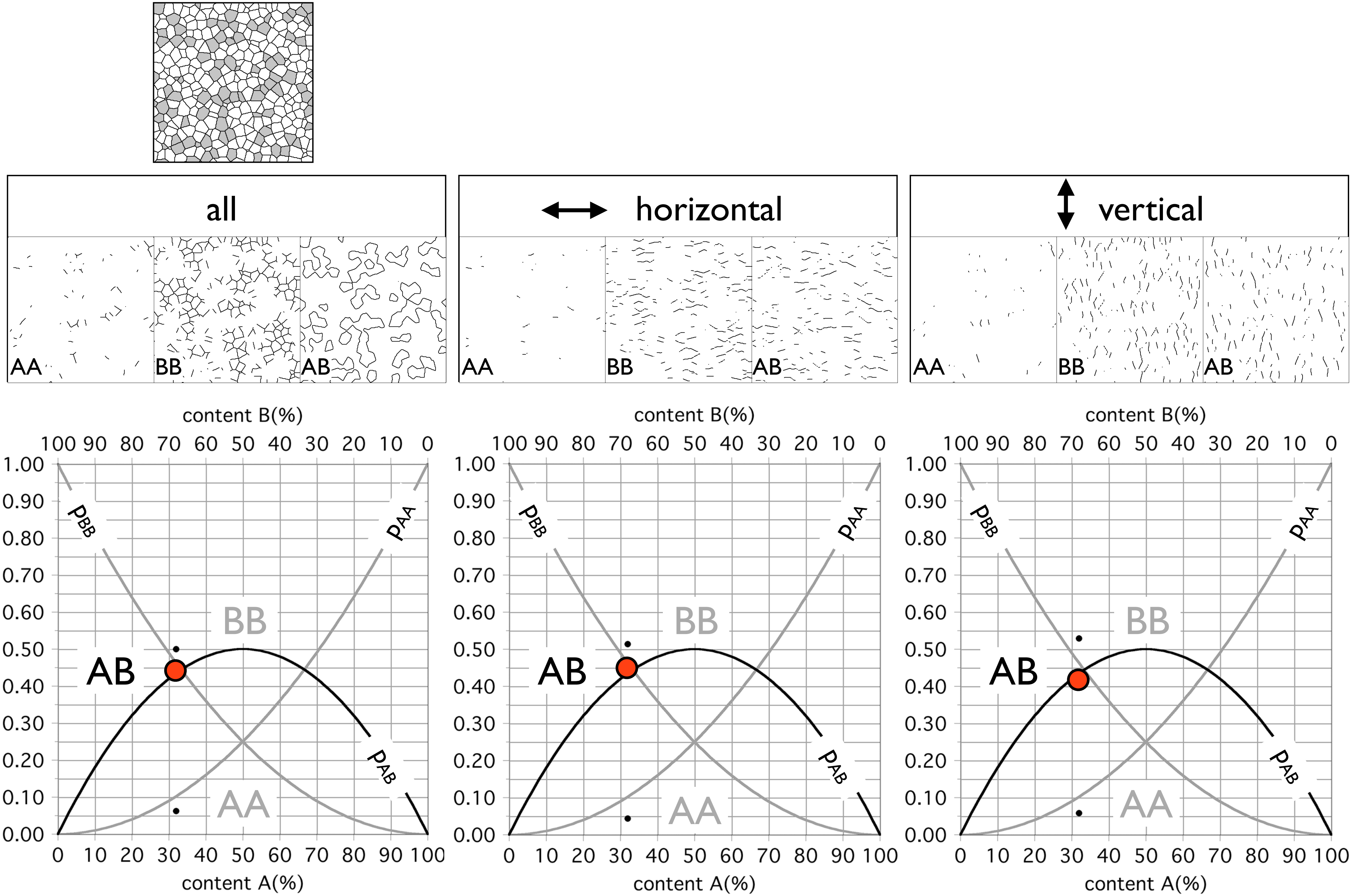


distributions and contact probabilities

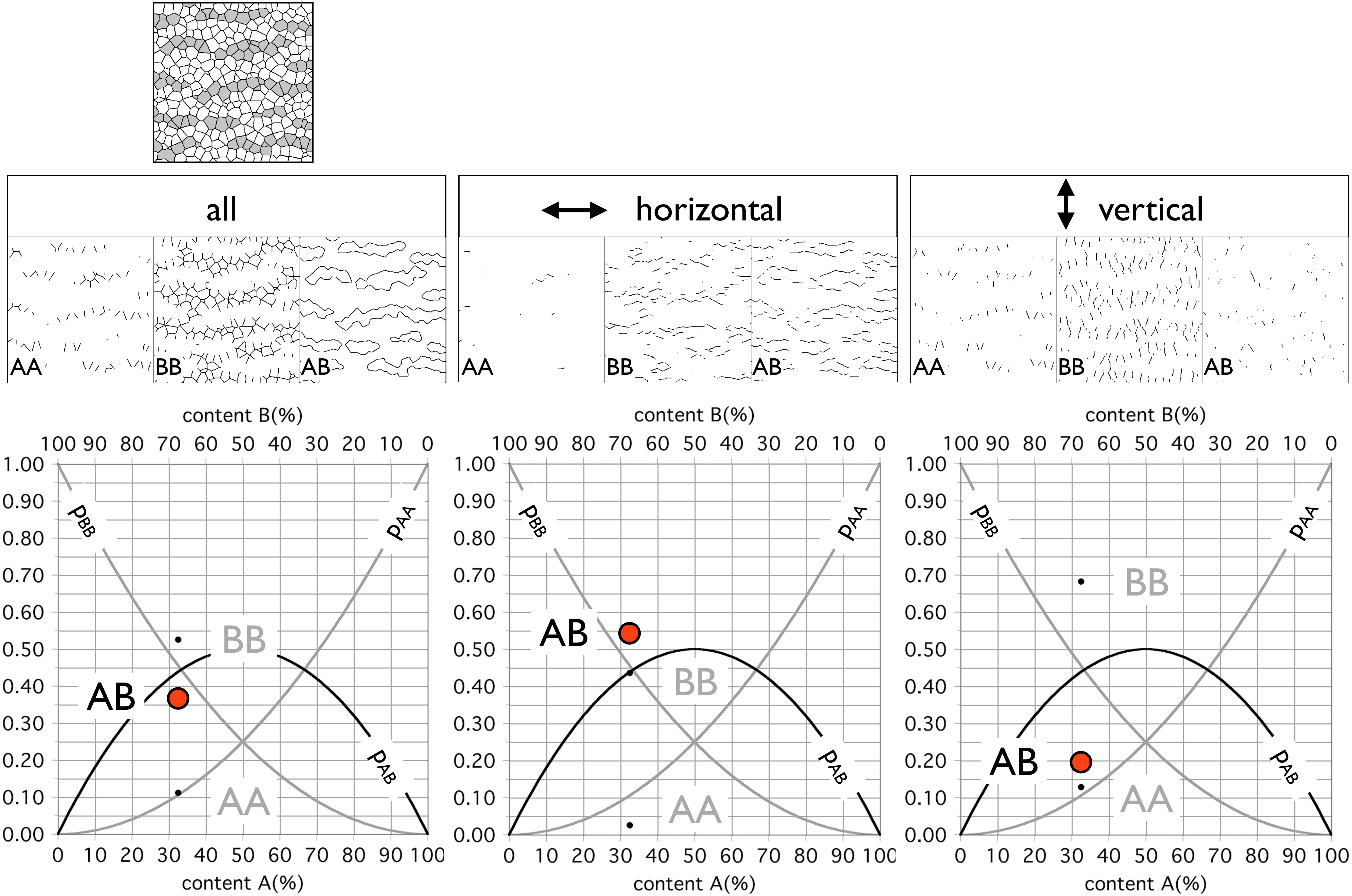




isotropic random distribution

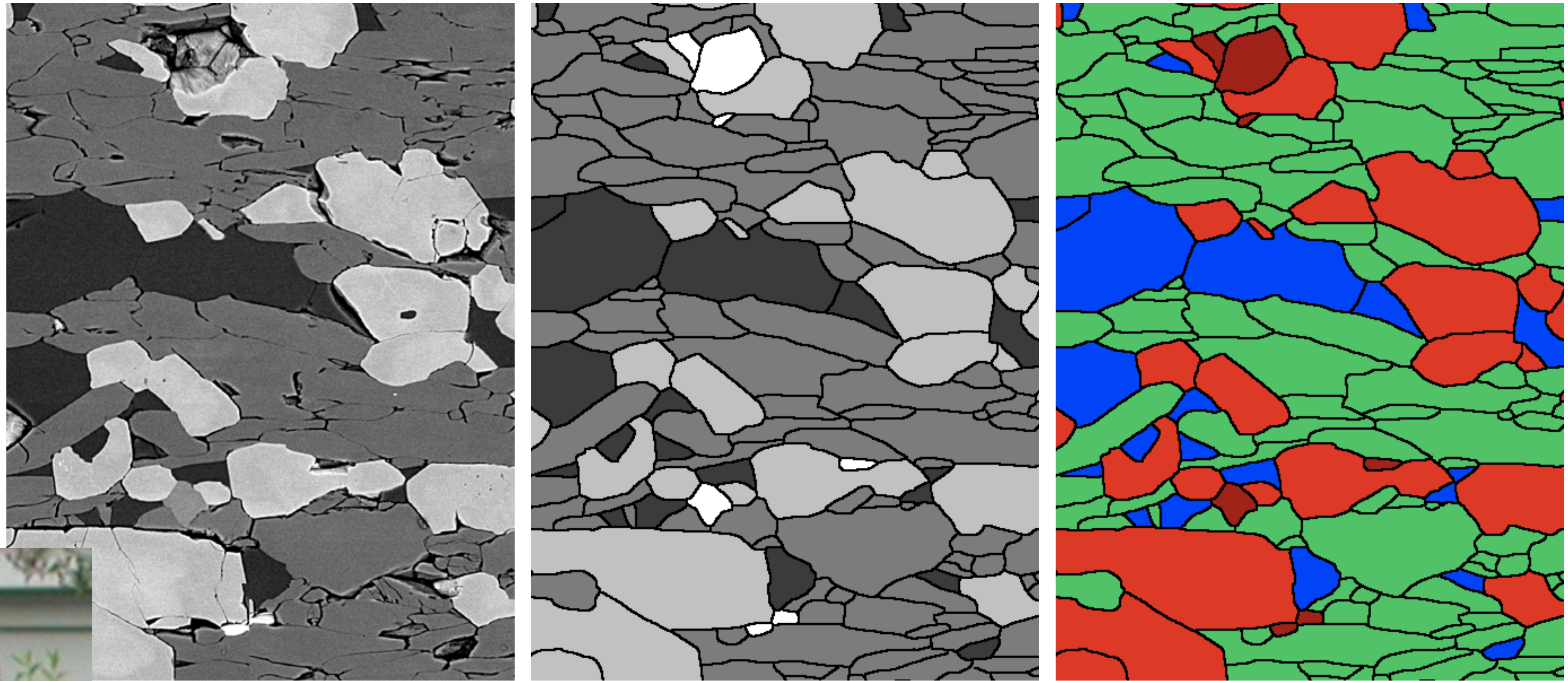


anisotropic random distribution



practical application

Meluzina eclogite

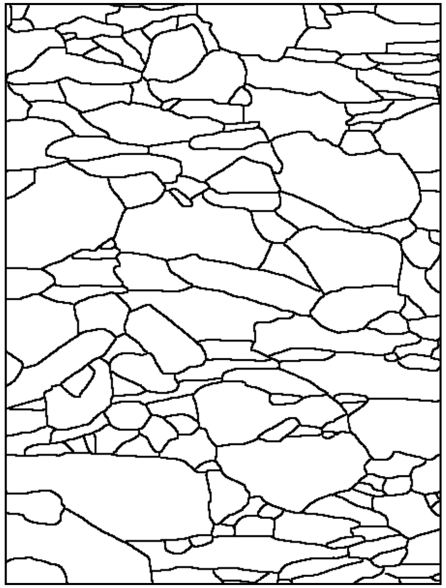


unidentified
garnet
omphacite
quartz

unidentified
garnet
omphacite
quartz

James Mackenzie

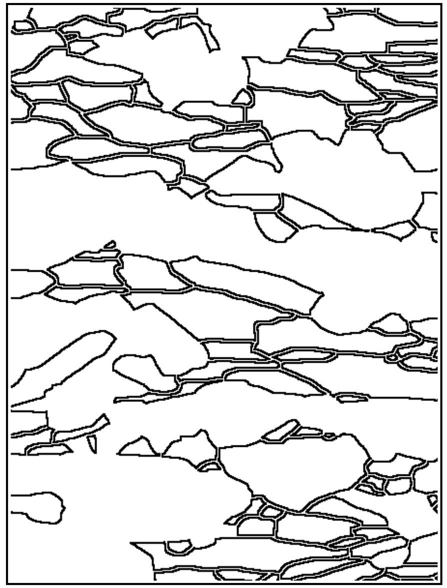
deriving phase and grain boundaries



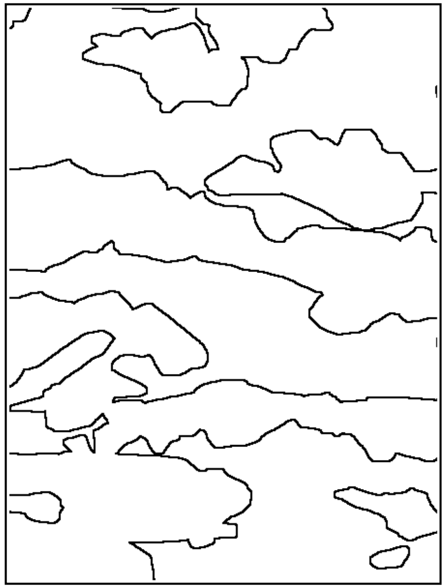
grain boundaries

A grains

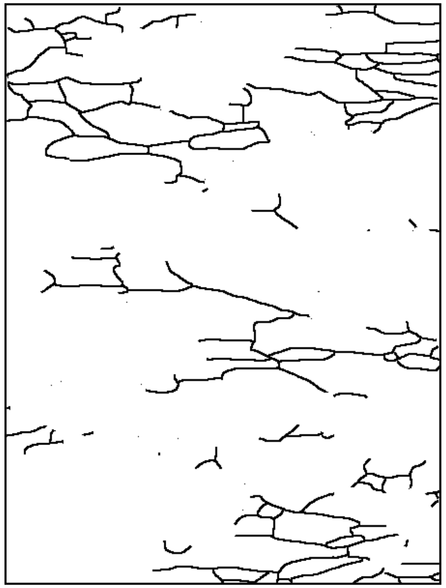
A phase



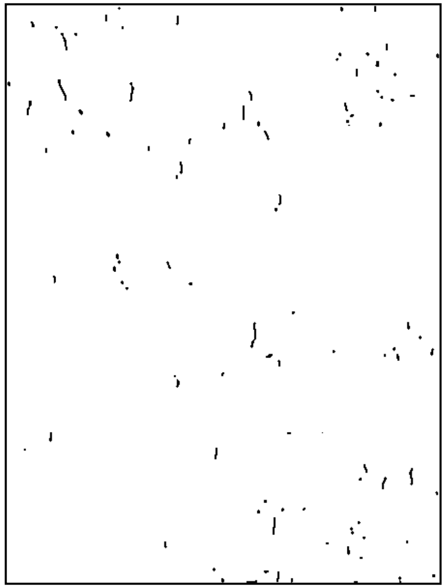
A grain outlines



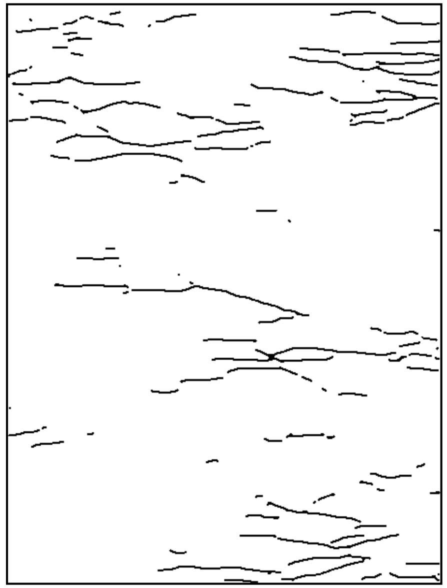
A phase outline



A grain boundaries

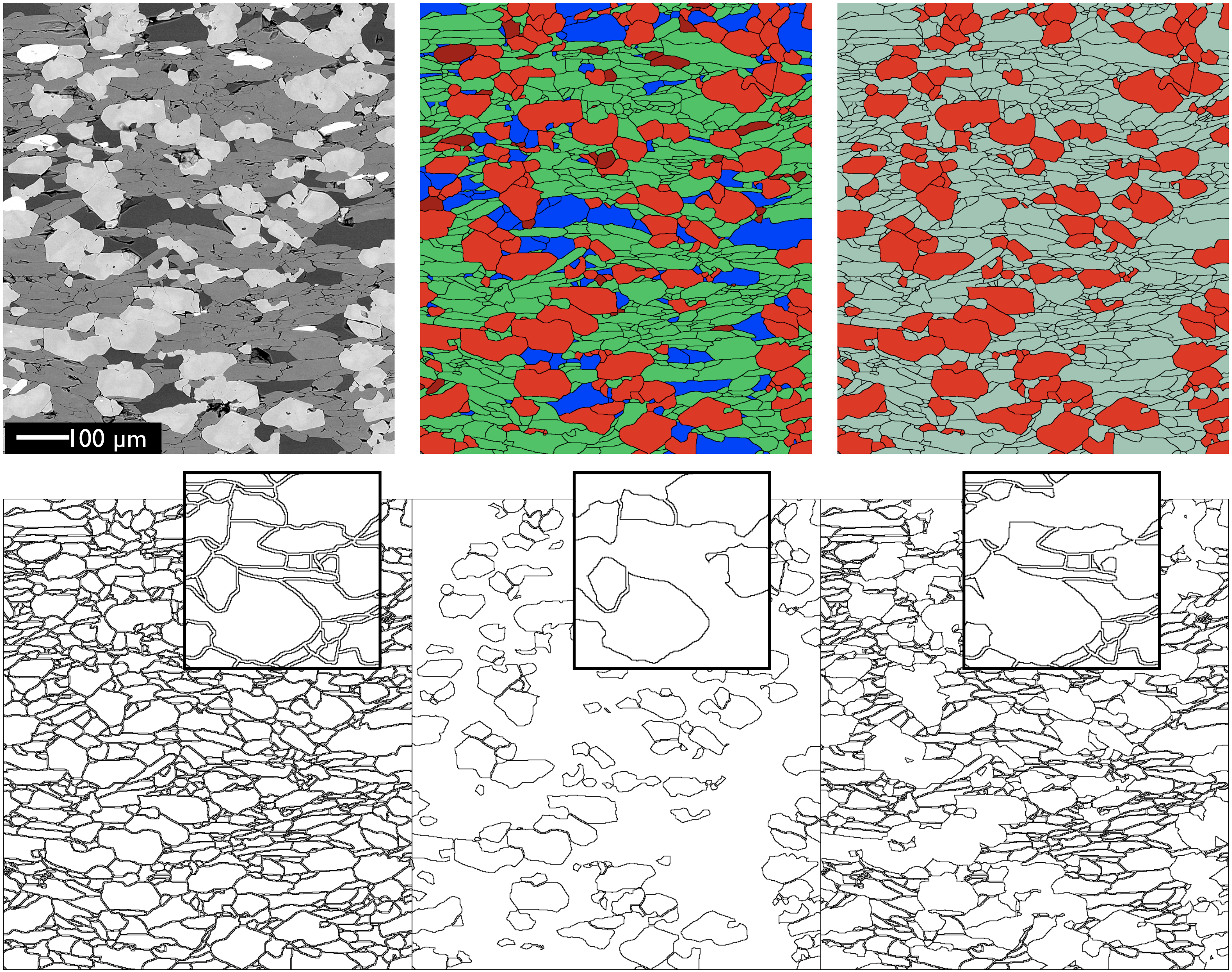


vertical A gb

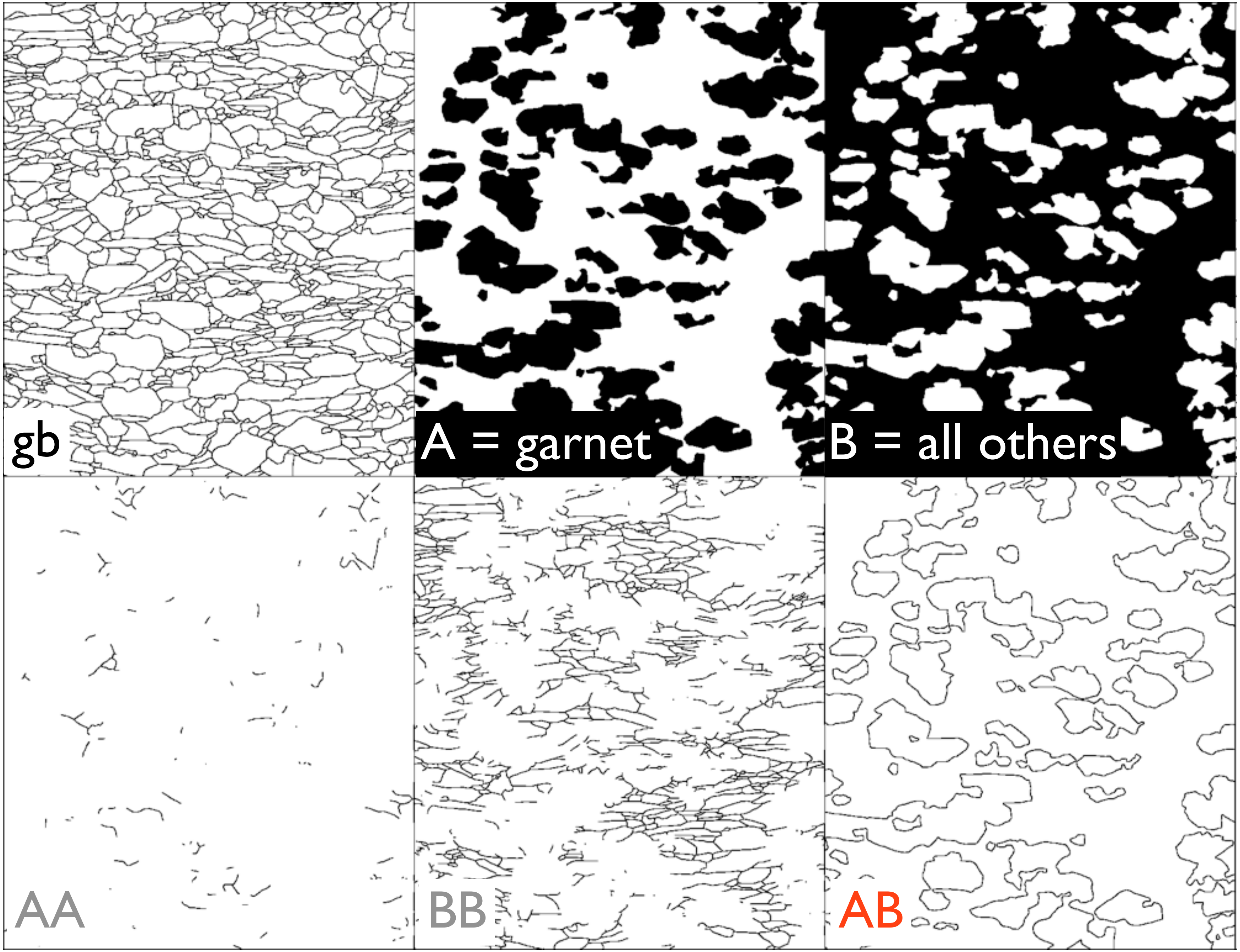


horizontal A gb

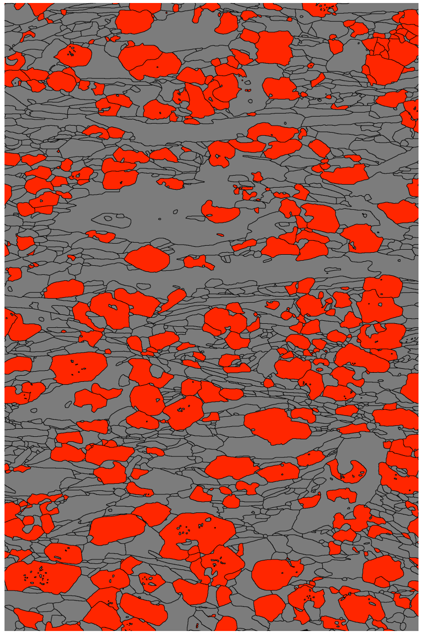
distribution of garnet in eclogite

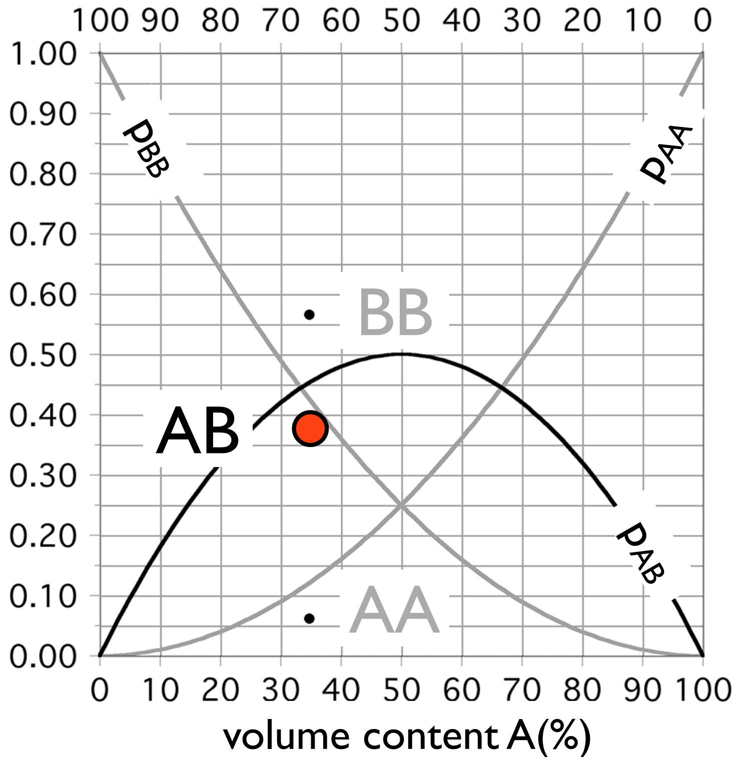


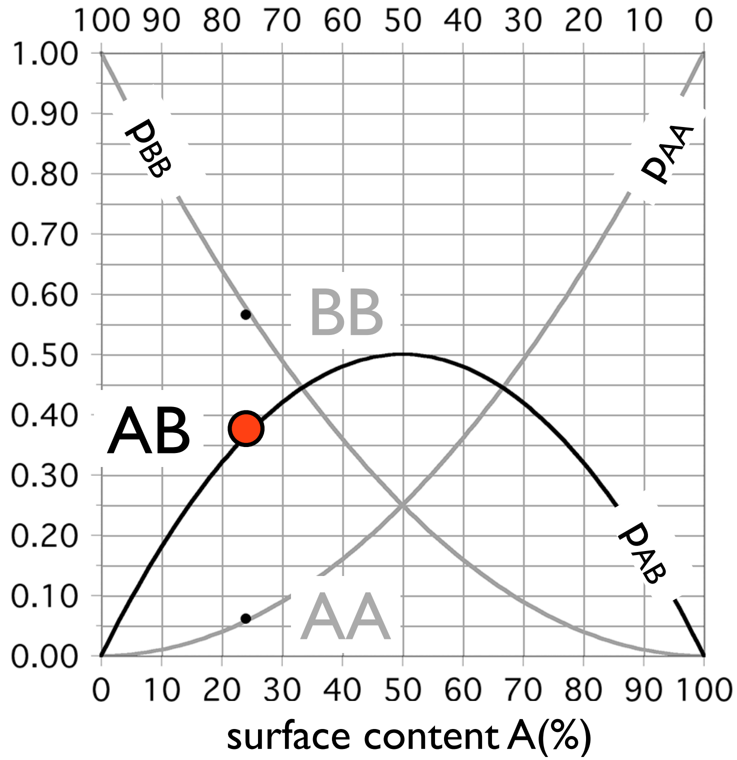
garnet in eclogite



garnet in eclogite







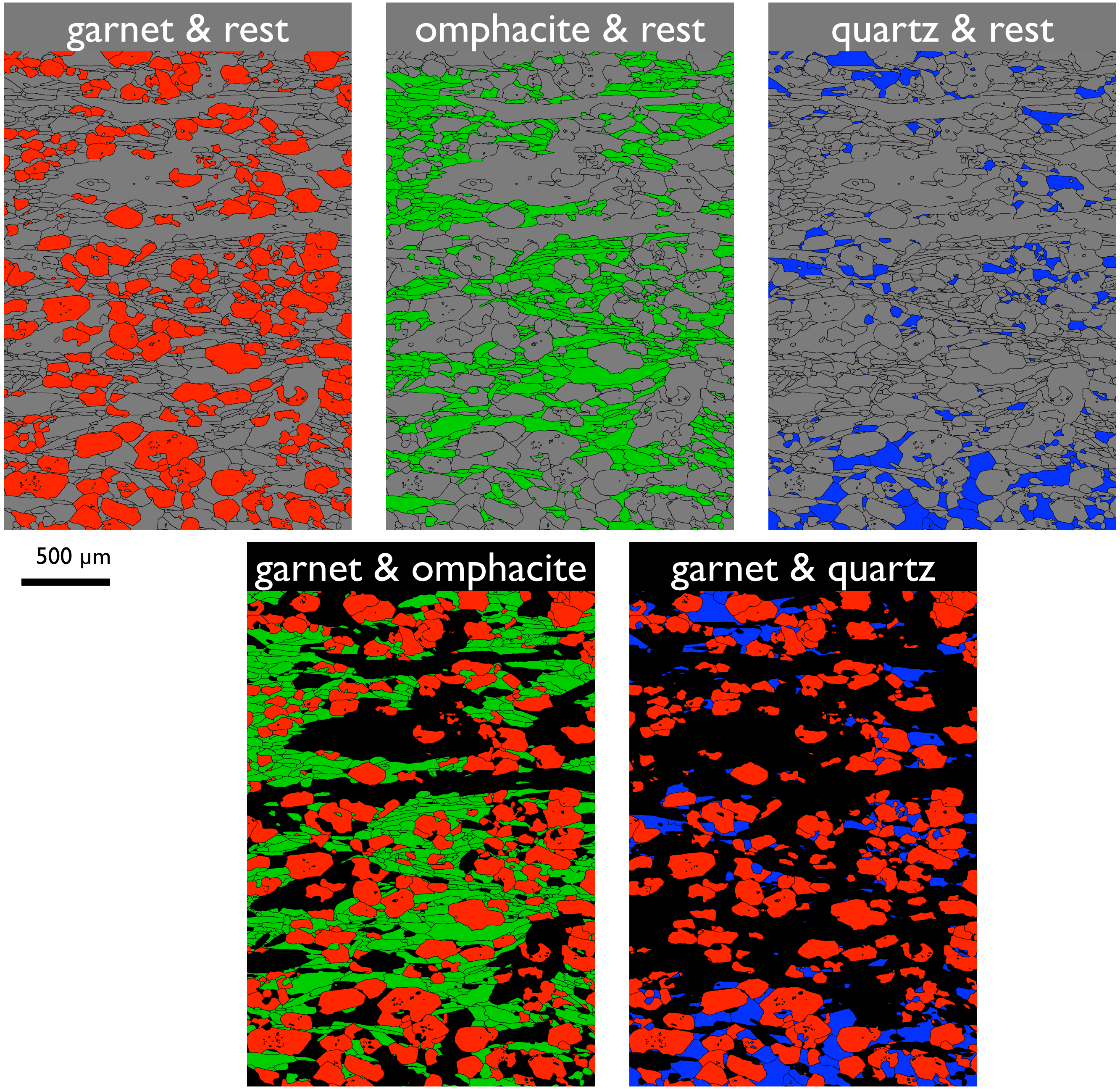
in terms of
volume proportions

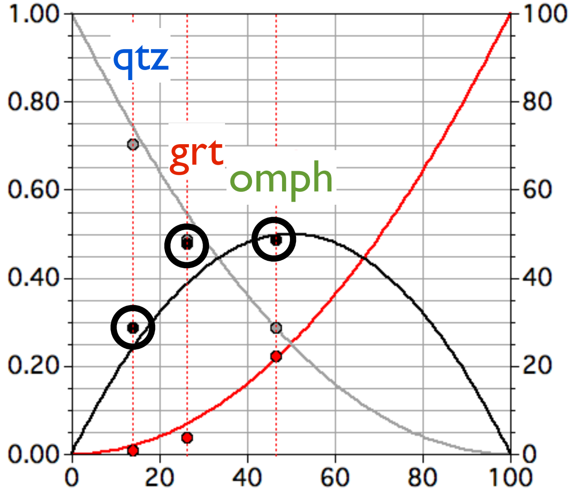
AB ~ random - clustered
AA anticlustered
BB clustered

in terms of
surface proportions

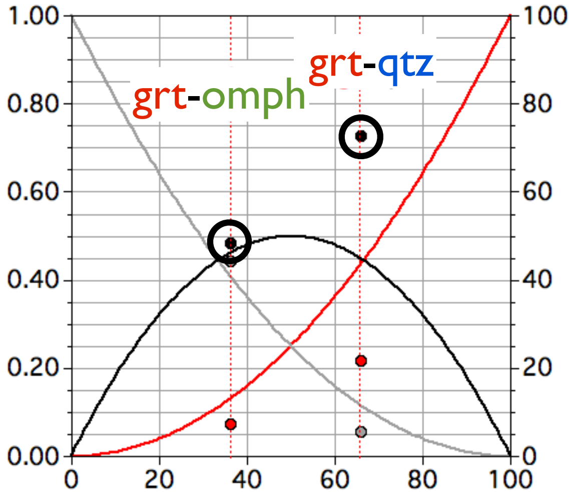
AB random
AA random
BB random

random - clustered - ordered ?





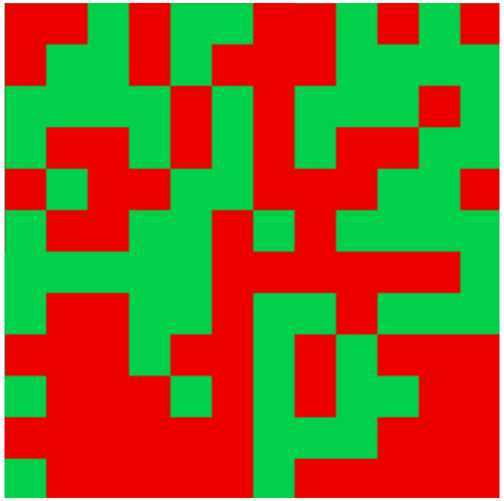
grt, omph, qtz = random
phase contacs on random curve

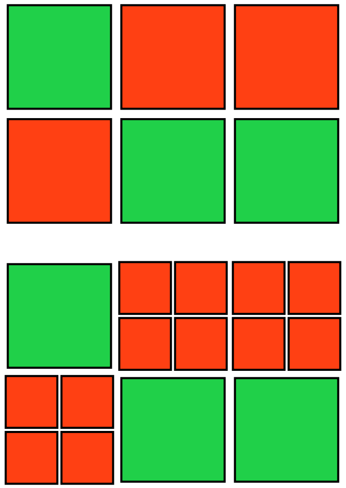


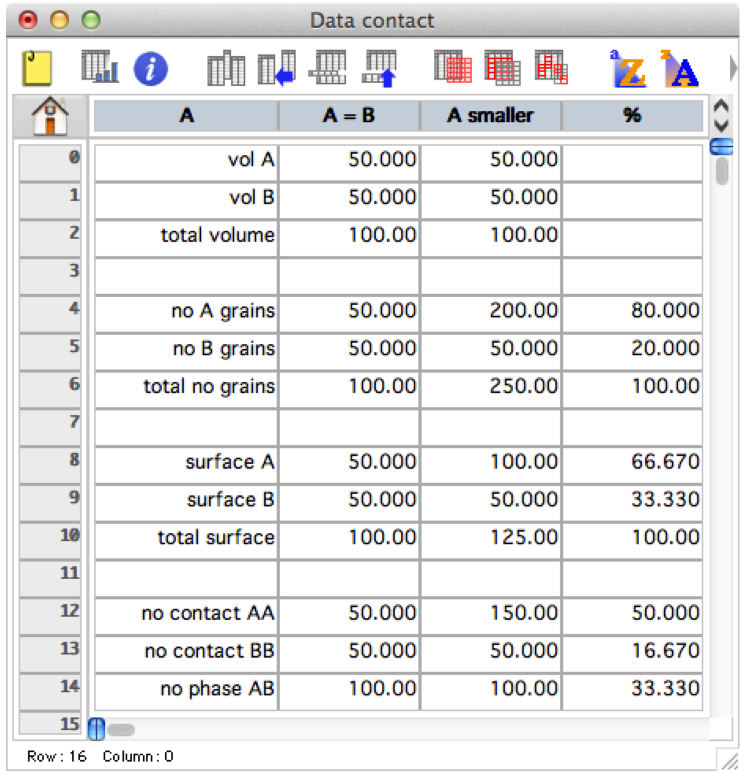
grt & omph = random
grt & qtz = ordered

2
influence of grainsize

different grain sizes

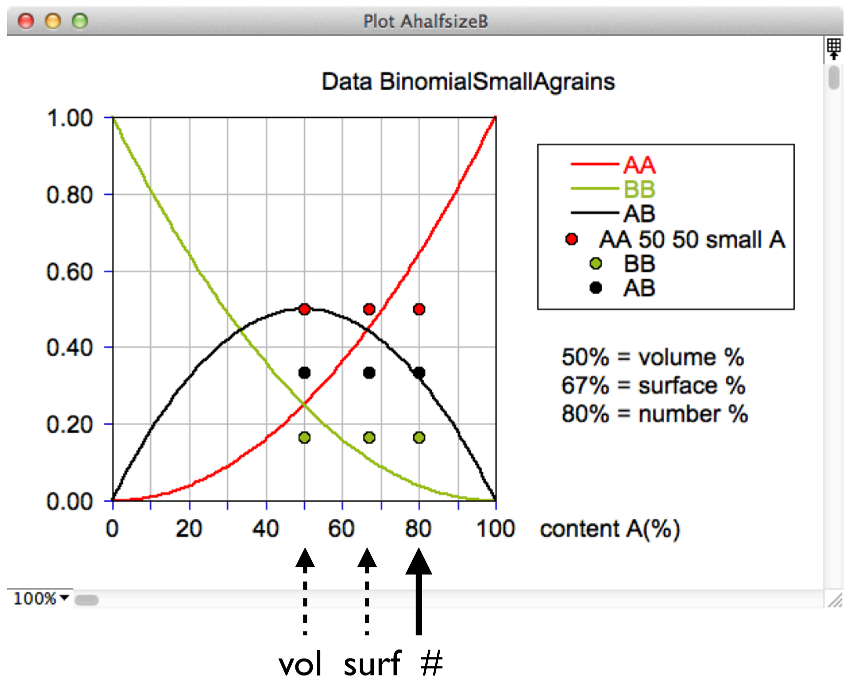






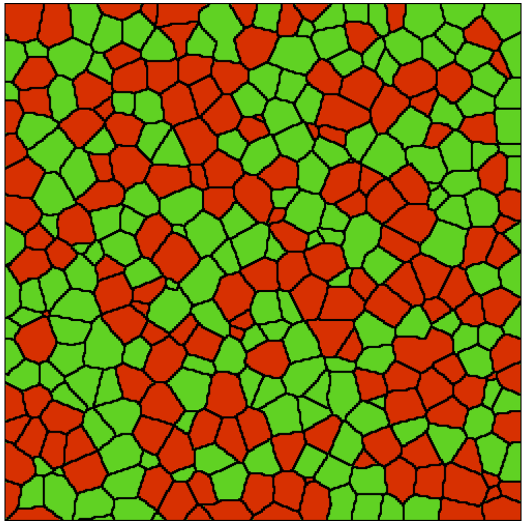
	A	A = B	A smaller	%
0	vol A	50.000	50.000	
1	vol B	50.000	50.000	
2	total volume	100.00	100.00	
3				
4	no A grains	50.000	200.00	80.000
5	no B grains	50.000	50.000	20.000
6	total no grains	100.00	250.00	100.00
7				
8	surface A	50.000	100.00	66.670
9	surface B	50.000	50.000	33.330
10	total surface	100.00	125.00	100.00
11				
12	no contact AA	50.000	150.00	50.000
13	no contact BB	50.000	50.000	16.670
14	no phase AB	100.00	100.00	33.330
15				

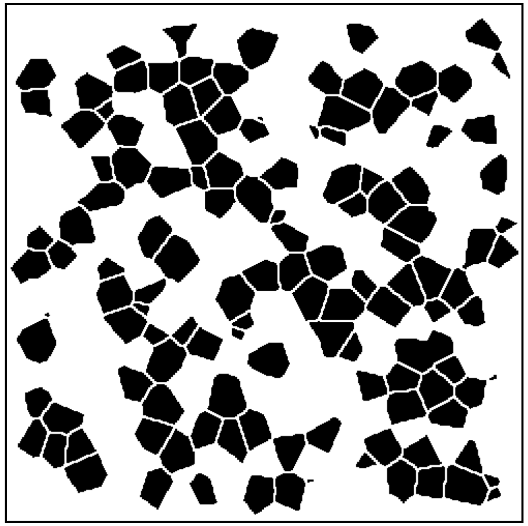
*	each grain A divided in 4	A	50 A grains		
		A*	200 A grains		
volB					
volA	= volB		#	%	%*
volA*	= volA	AB	100	50	33.3
nB	= 50	BB	50	25	16.7
nA	= nB	AA	50	25	
nA*	$= 4 \cdot nA$	AA*	150		50.0
surfB					
surfA	= surfB				
surfA*	$= 2 \cdot surfA$				



note: for A = 1/2 size of B
number% best fit:
phase = random
BB = ordered
AA* = clustered

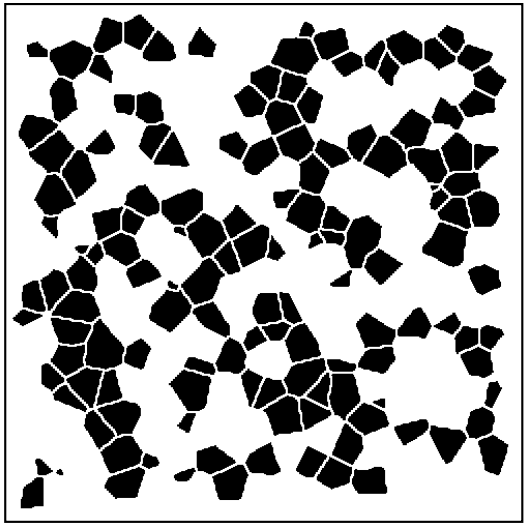
2D grain size of Voronois





A (129 grains)

mean=30.3, RMS=31.4



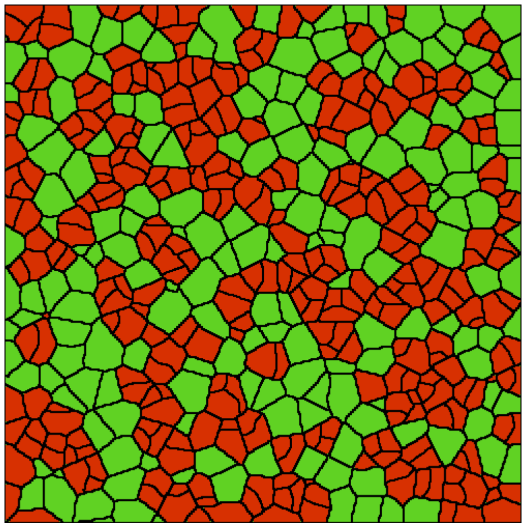
B (140 grains)

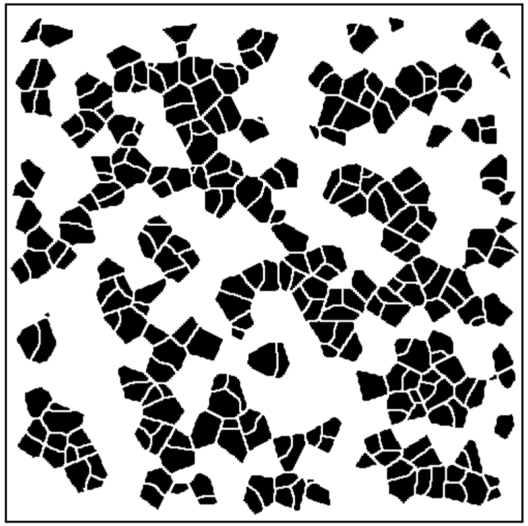
mean=28.9, RMS=29.9

size A ≈ B

no. A ≈ B

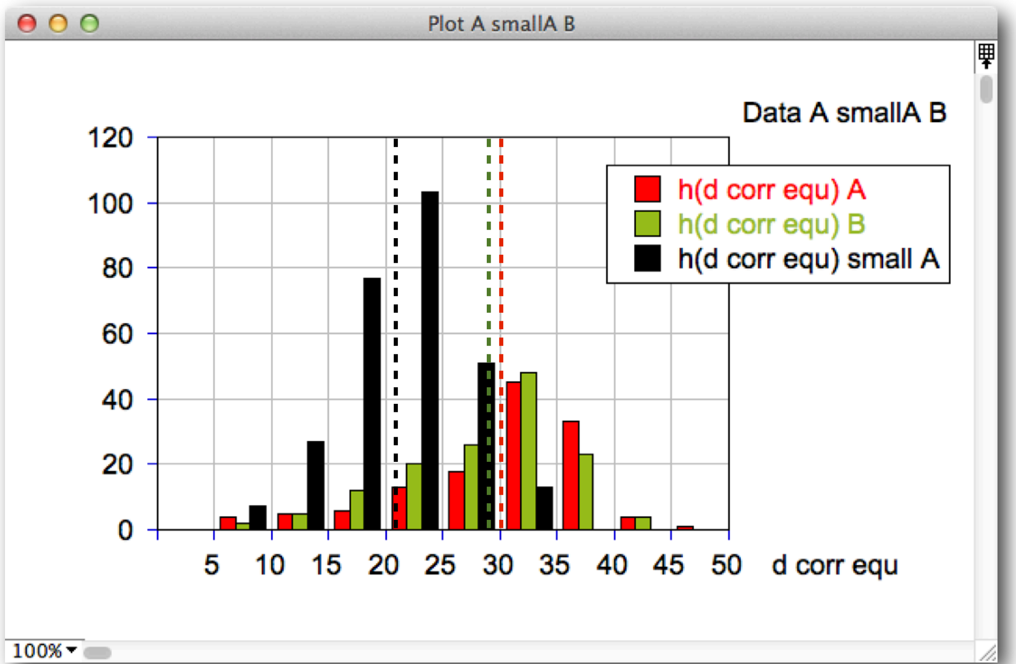
no. Asmall ≈ 2x



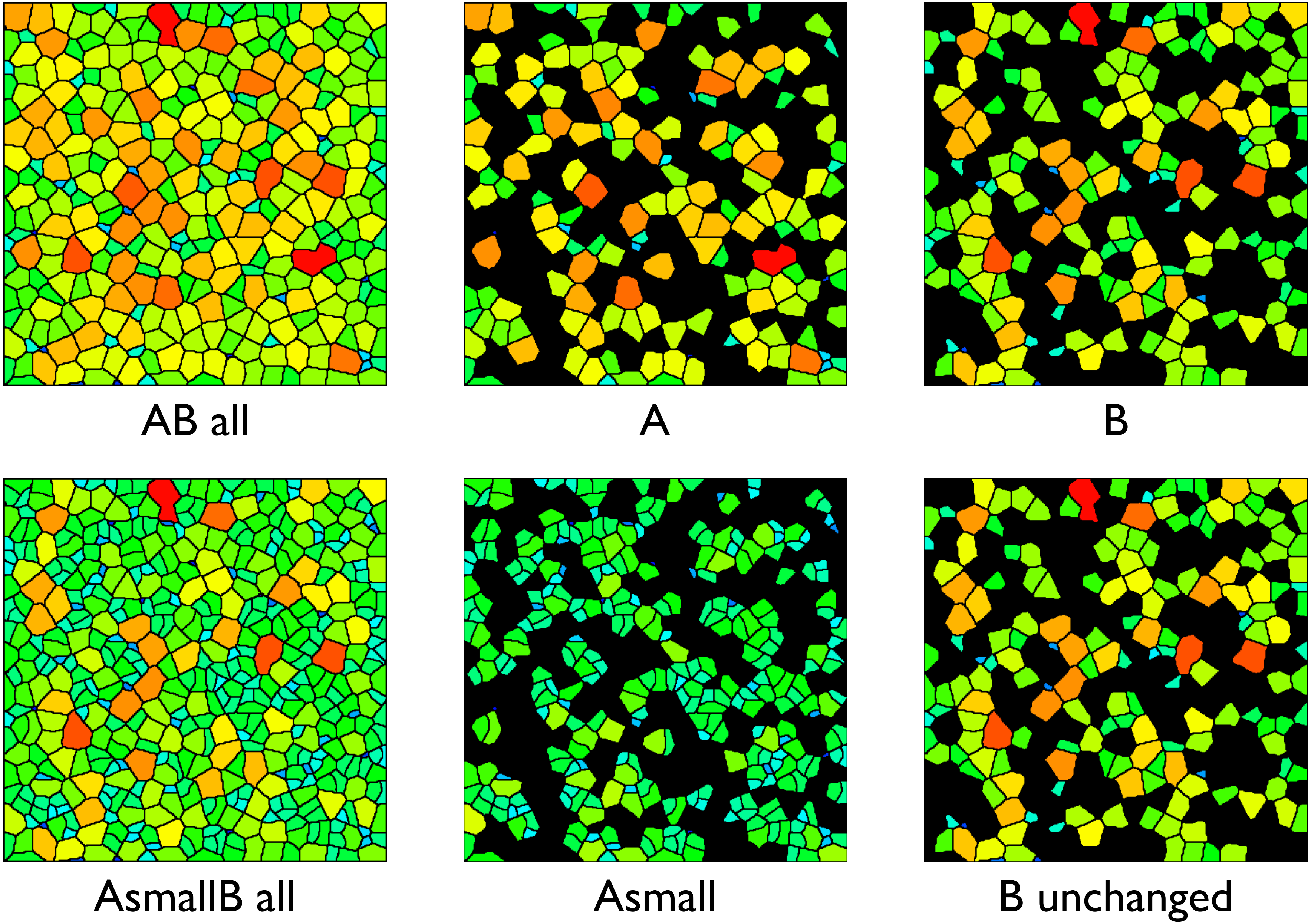


Asmall (278 grains)

mean=21.0, RMS=21.7

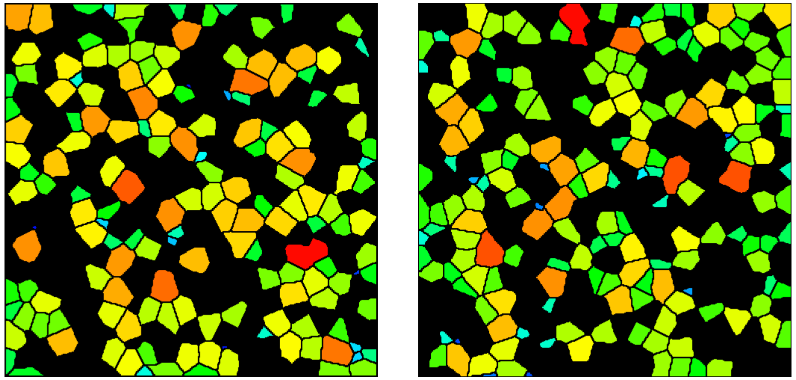


grain size A < grain size B

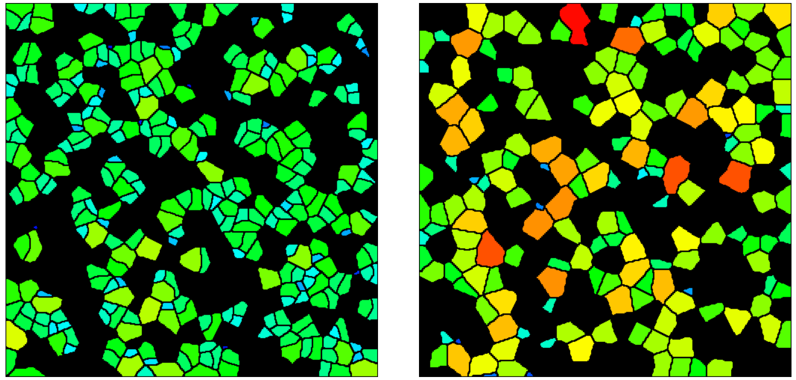


small phase A obtained by subdividing grains, B phase remains unchanged

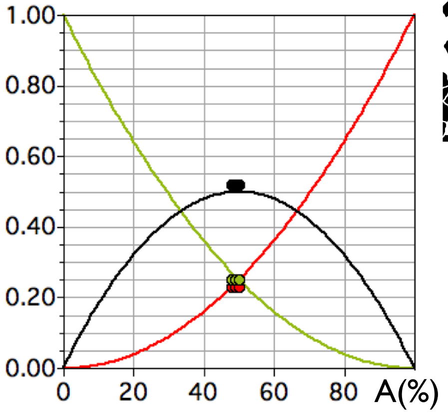
volume & - surface % - number %

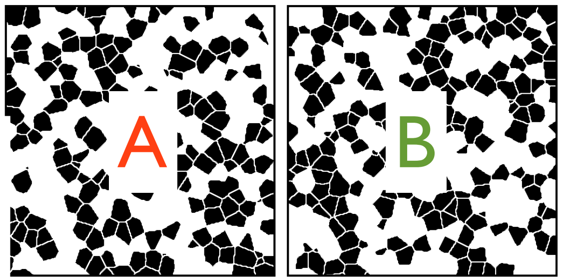


grainsize A = grainsize B

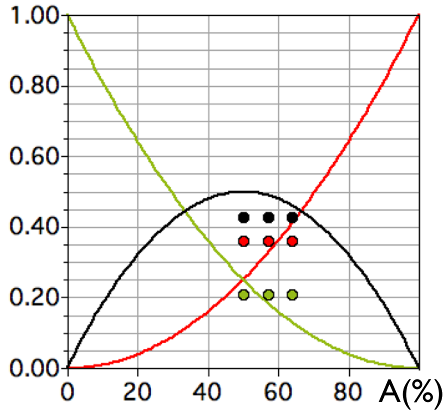


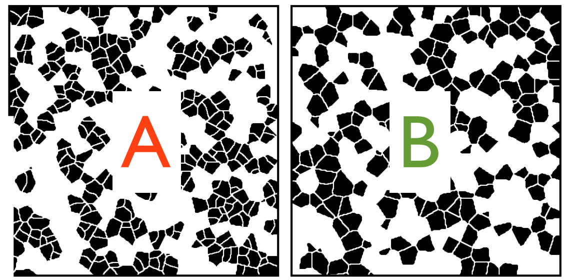
grainsize A < grainsize B
phase A 'recrystallized' in situ





vol% A = 50.0
surf% A = 48.9
no.% A = 47.8
no A:B = 160:175





vol% A = 50.0
surf% A = 57.3
no.% A = 64.2
no A:B = 314:175

3

variations

Menegon et al. 2013

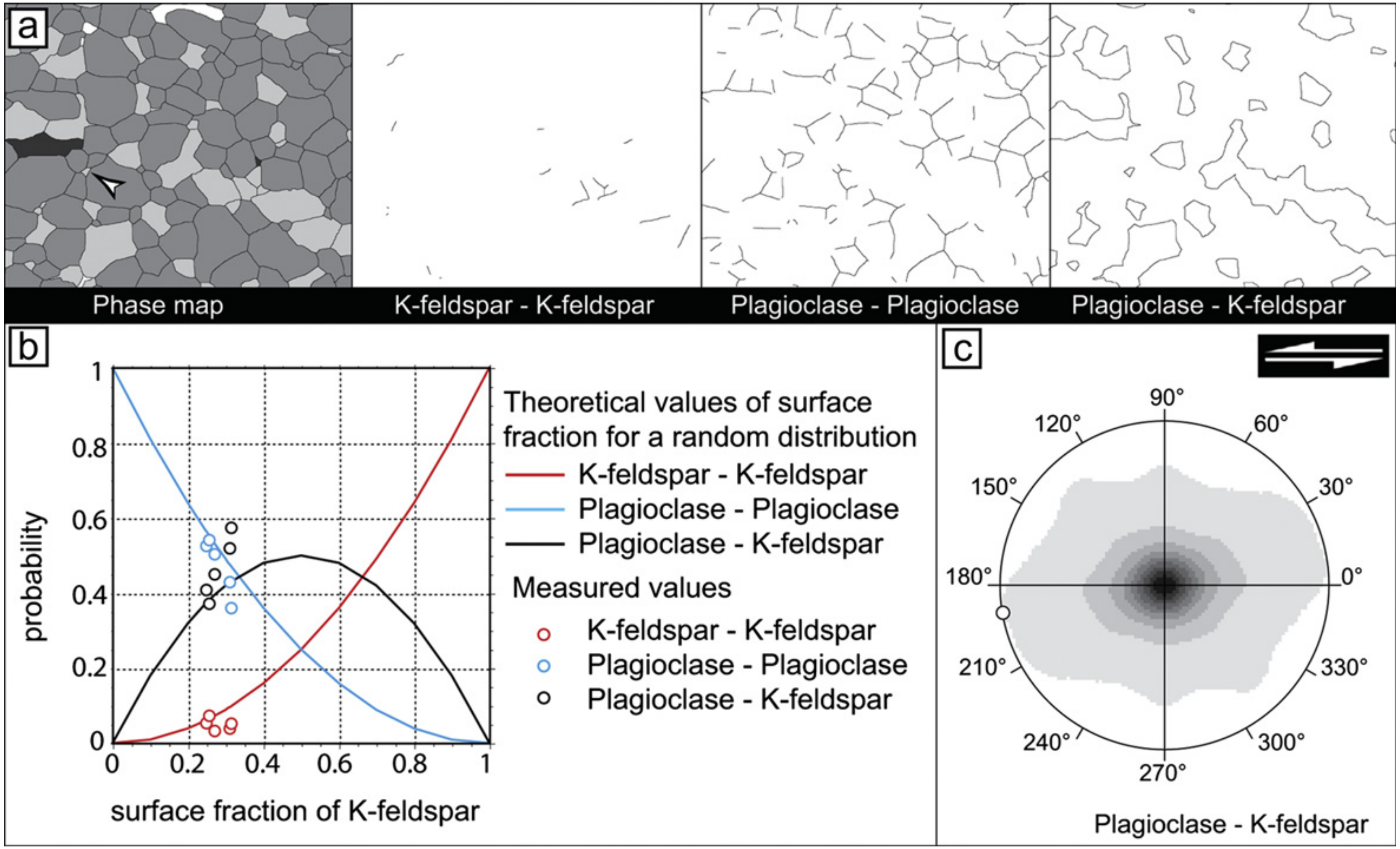


Fig. 7. (a) Example of phase map used in the analysis of spatial distribution of feldspars in the recrystallized matrix, and bitmaps of the grain- and phase boundaries derived from the map. The arrowhead indicates a K-feldspar grain at a quadruple junction between plagioclase grains. (b) The fraction of grain- and phase boundaries measured in five different phase maps are plotted as circles to evaluate the deviations from randomness. Curves show the theoretical fractions of grain- and phase boundaries as a function of the surface fraction of K-feldspar expected for a random distribution in a two-phase mixture (c) Autocorrelation function (ACF) calculated for the plagioclase – K-feldspar phase boundaries. The ACF is shaded at 10% multiples of the ACF max (located in the centre). For the sake of clarity, the ACF is scaled such that the 10% contour touches the superposed reference circle. The black circle indicates the highest correlation length at 12° (measured anticlockwise) from the trace of the mylonitic foliation (E–W).

The microstructure of recrystallized feldspars is characterized by the predominance of phase boundaries over grain boundaries

Kilian et al. 2011

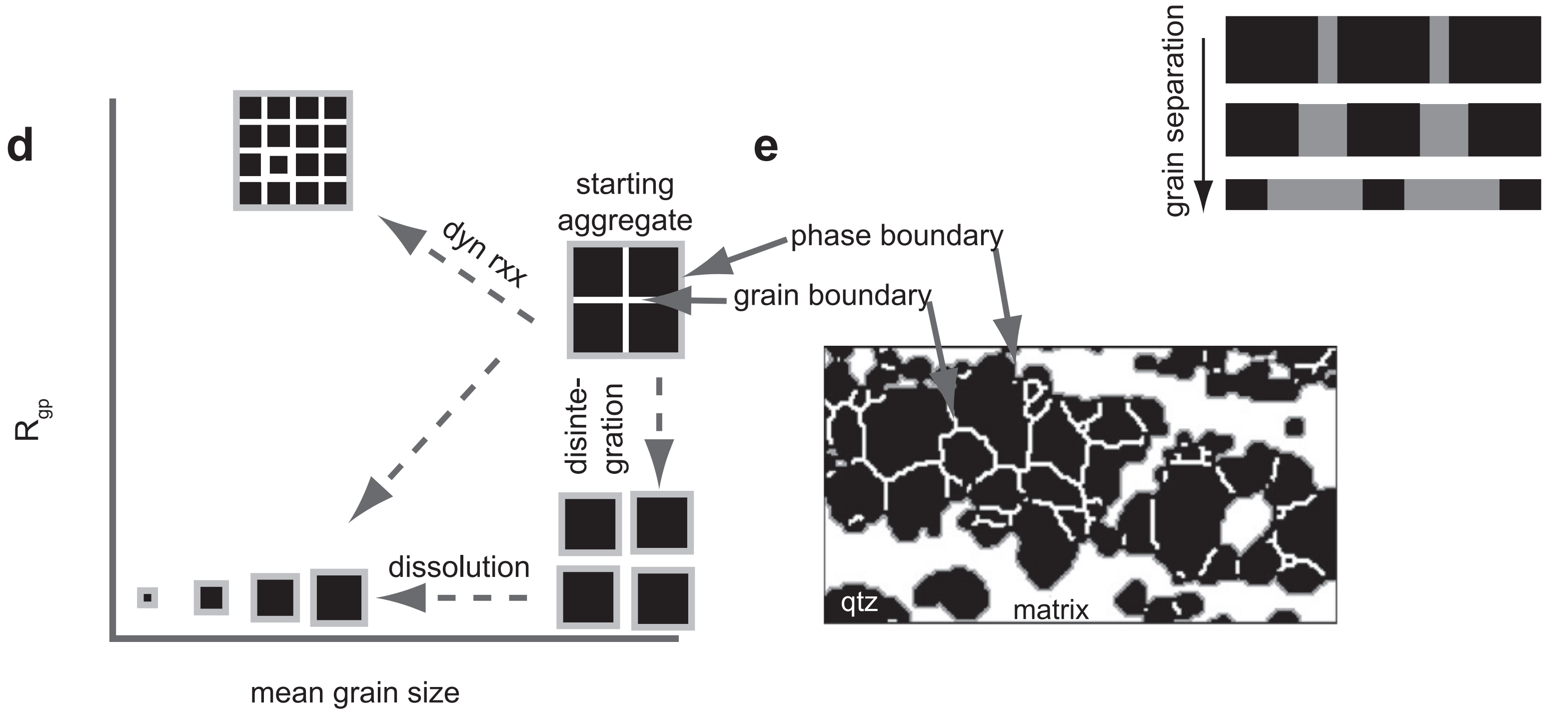


Fig. 15. Phase distribution and grain size evolution. (a) Phase map of quartz (black), plagioclase (dark gray), K-feldspar (light grey) and mica (white). The map shows a quartz aggregate in the transition between the mylonite and the ultramylonite with different stages of disintegration. (b) Rpg (ratio of grain boundary/phase boundary area) versus the mean grain size in 6 different, laterally disintegrating aggregates. Symbols correspond to individual, homogenous aggregates. (c) Relationship between the mean quartz grain size in a layer and the relative quartz volume fraction. The relative quartz volume fraction in a layer decreases with increasing disintegration, as grains are separated by K-feldspar. In layers with a higher grain separation the mean grain size is smaller. (d) Schematic model of Rpg – grain size evolution. Black squares are separated from another by grain boundaries (white) and from the matrix by phase boundaries (dark grey) (e) Example of an analyzed area. The evaluation of Rpg and the grain size would correspond to a single point in the diagram b).

practical application

dislocation creep vs. diffusion creep

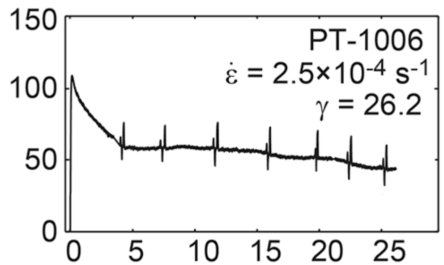
Gas medium High pressure Torsion apparatus (UMN)

Miki Tasaka

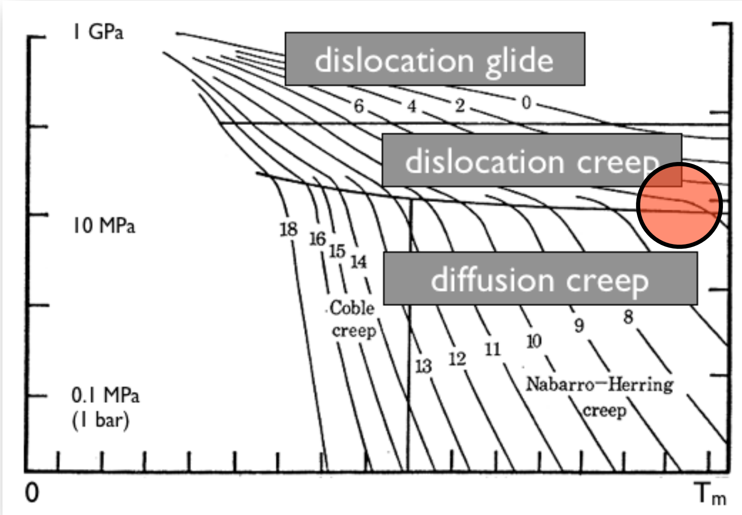
Mark Zimmerman

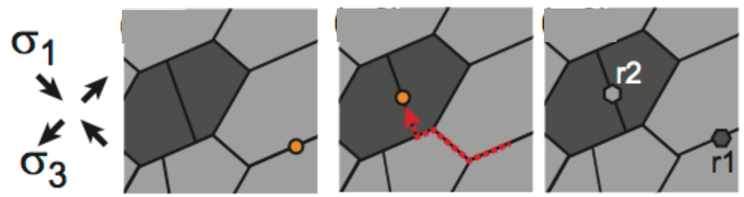
David Kohlstedt

70% iron-rich olivine
30% orthopyroxene
hotpressed @1200°C
d ~15 μm



p_c = 300 MPa
T = 1200°C





in olivine:
MeO dissolves at maximum σ1.
Reaction ol → opx

in orthopyroxene:
MeO diffuses to tension σ3.
Reaction opx → ol

- olivine
- opx
- MeO
- diffusion pass

r1: Me_2SiO_4 - MeO → $MeSiO_3$
(ol) (opx)

r2: $MeSiO_3$ + MeO → Me_2SiO_4
(opx) (ol)

motivation

$$\dot{\varepsilon} = A \cdot \Delta\sigma^n \cdot exp(-Q/RT)$$

increasing strain

$$\dot{\varepsilon} = A \cdot \Delta\sigma^n \cdot d^m \cdot exp(-Q/RT)$$


JOURNAL OF GEOPHYSICAL RESEARCH
Solid Earth
AN AGU JOURNAL
Explore this journal >

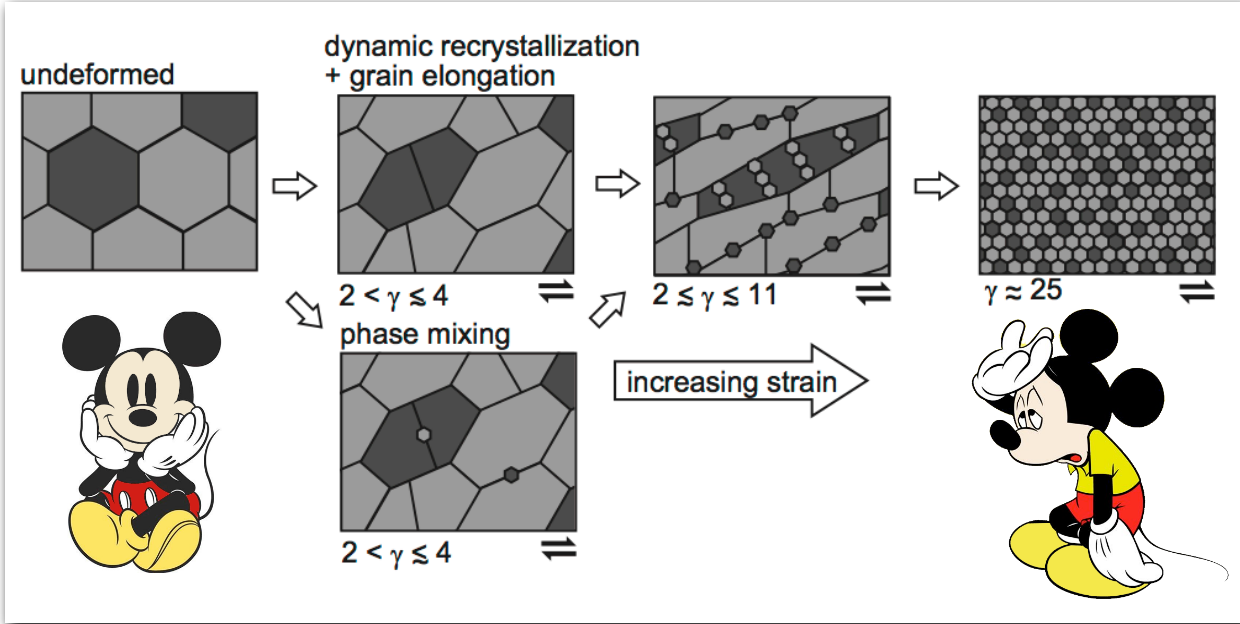
Research Article

Rheological weakening of olivine + orthopyroxene aggregates due to phase mixing, Part 1: Mechanical behavior

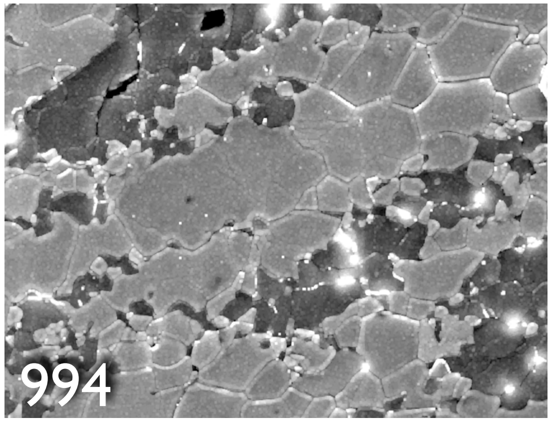
Miki Tasaka, Mark E. Zimmerman, David L. Kohlstedt

Accepted manuscript online: 8 September 2017 Full publication history
DOI: 10.1002/2017JB014333 View/save citation

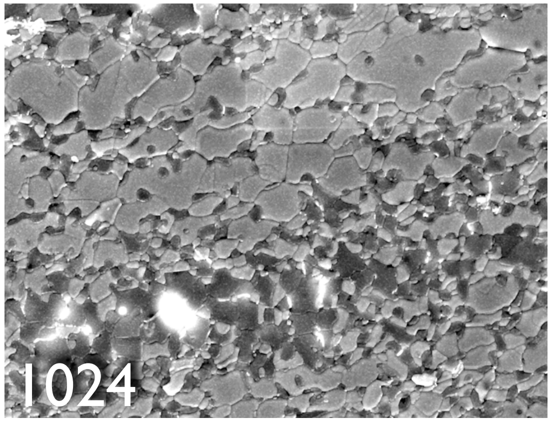
Tasaka et al. (JGR, 2017)



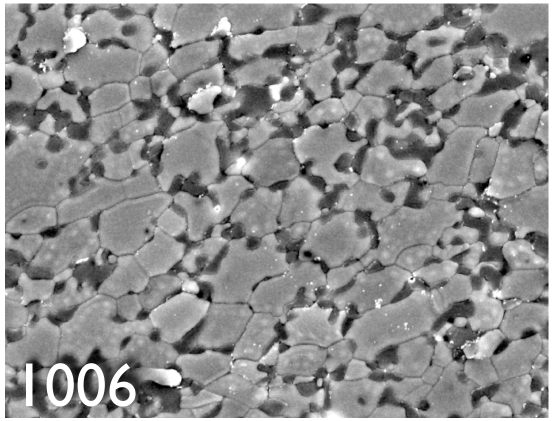
dislocation creep ?



phase mixing ?



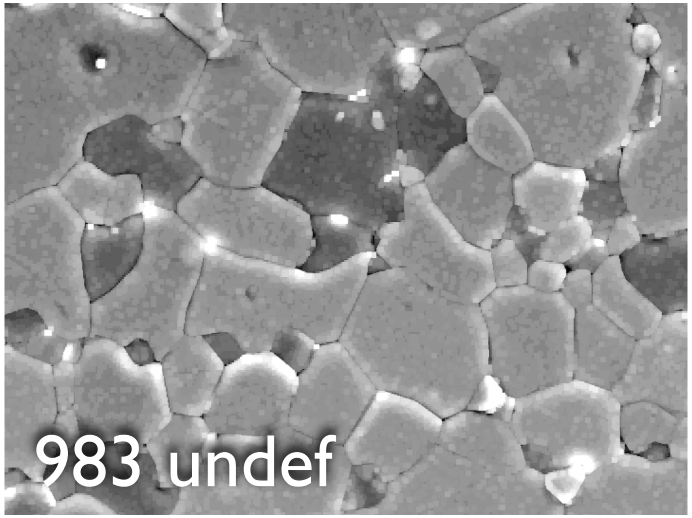
diffusion creep ?

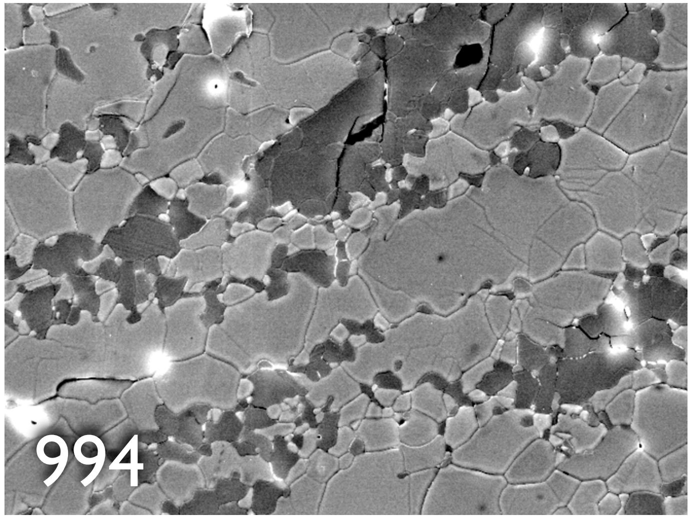


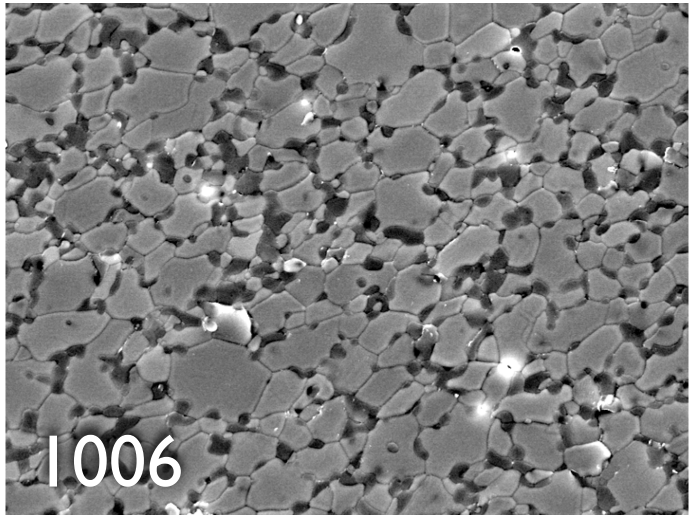
10 μm

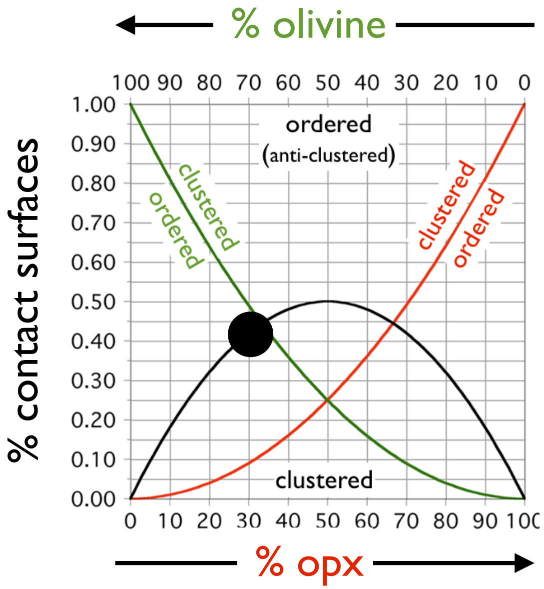
which spatial distributions do we expect ?

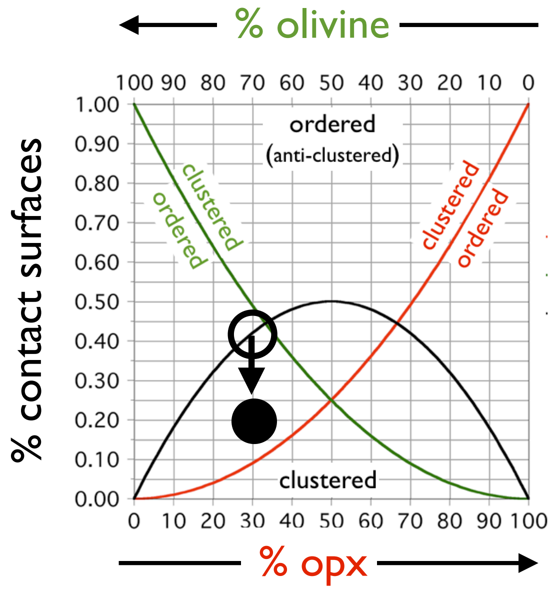
starting material | dislocation creep ⇄ diffusion creep

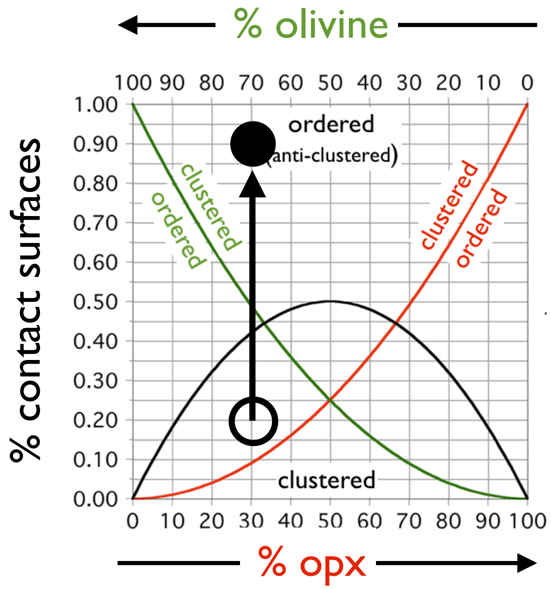








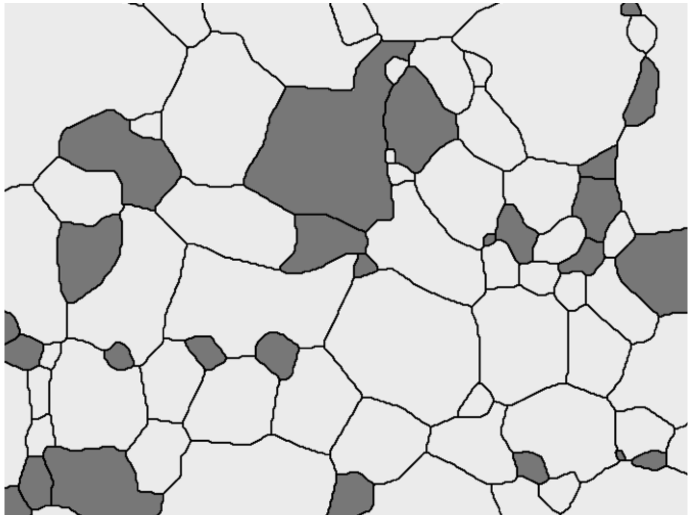




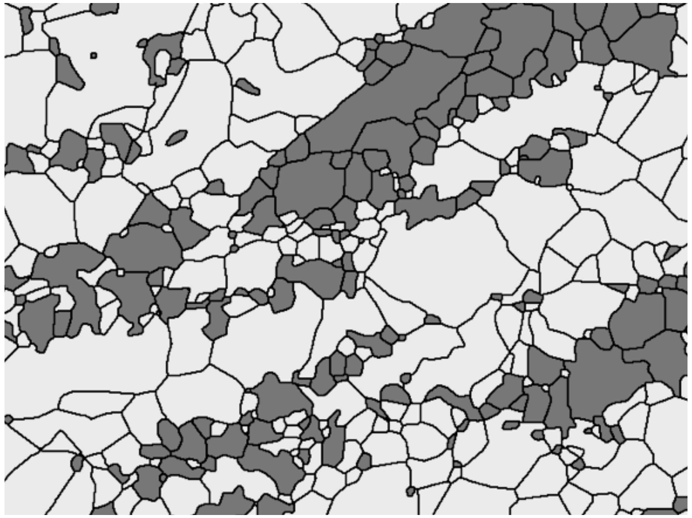
pb
ol-opx

and which spatial distributions do we get ?

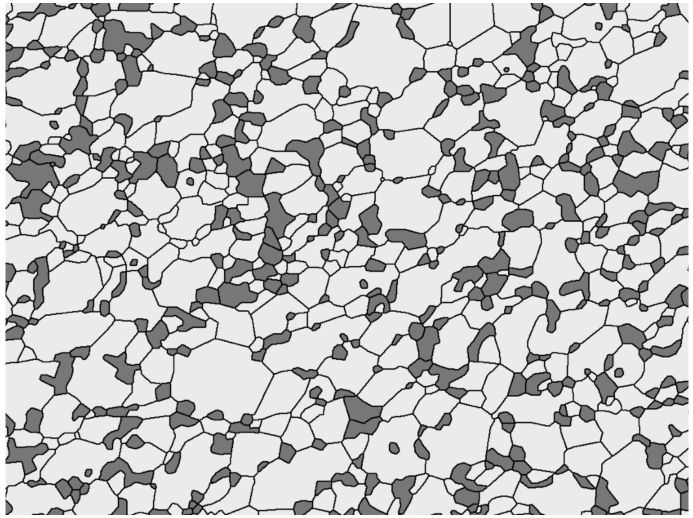
983 starting material

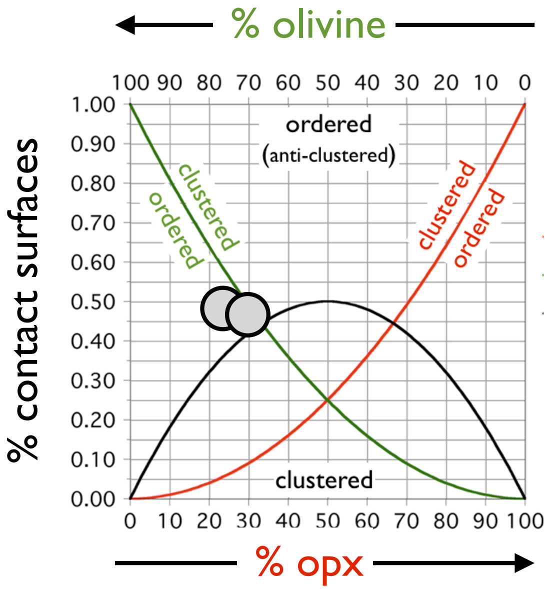


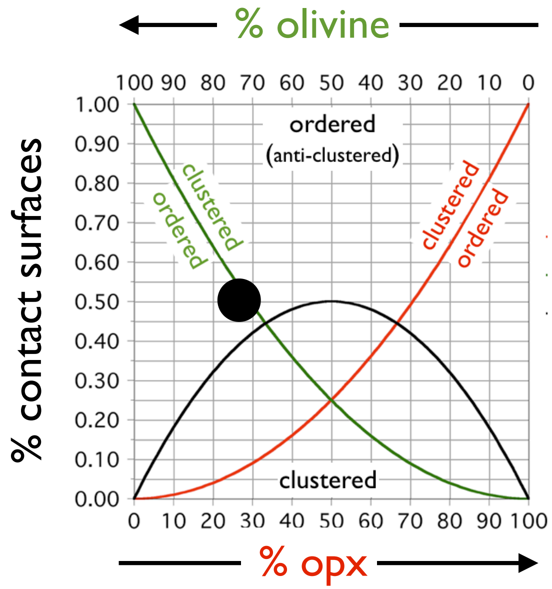
994 dislocation creep

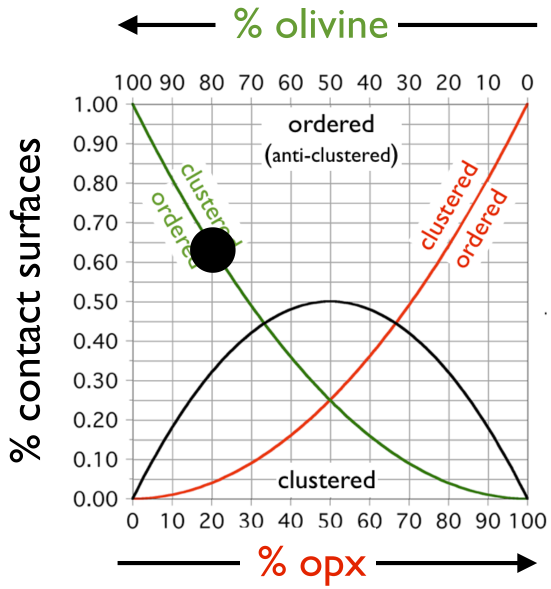


1006 diffusion creep



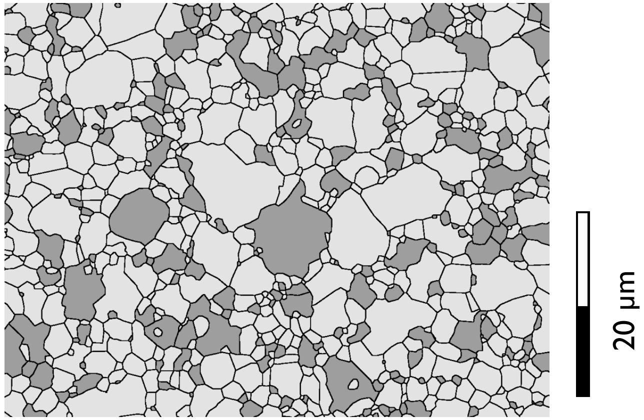


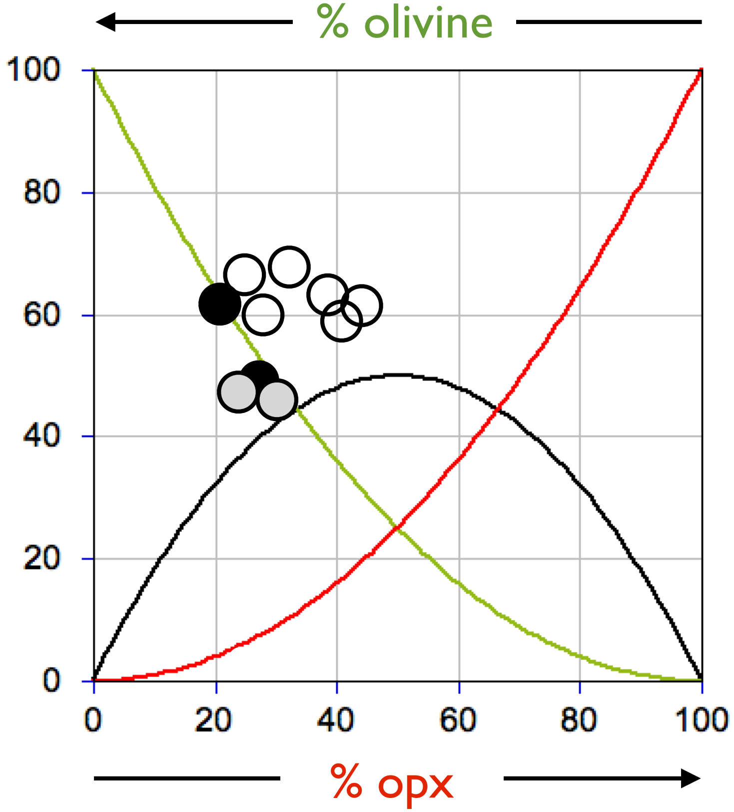




pb
ol-opx

even the starting material is ordered !!





JOURNAL OF GEOPHYSICAL RESEARCH
Solid Earth
AN AGU JOURNAL
JGR
Explore this journal >

Research Article

Rheological weakening of olivine + orthopyroxene aggregates due to phase mixing, Part2: Microstructural development

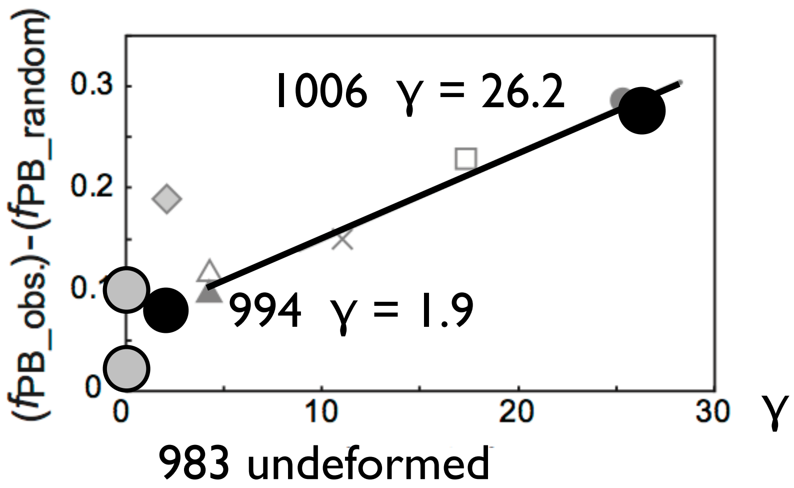
Miki Tasaka, Mark E. Zimmerman, David L. Kohlstedt, Holger Stünitz, Renée Heilbronner

Accepted manuscript online: 8 September 2017 Full publication history

DOI: 10.1002/2017JB014311 View/save citation

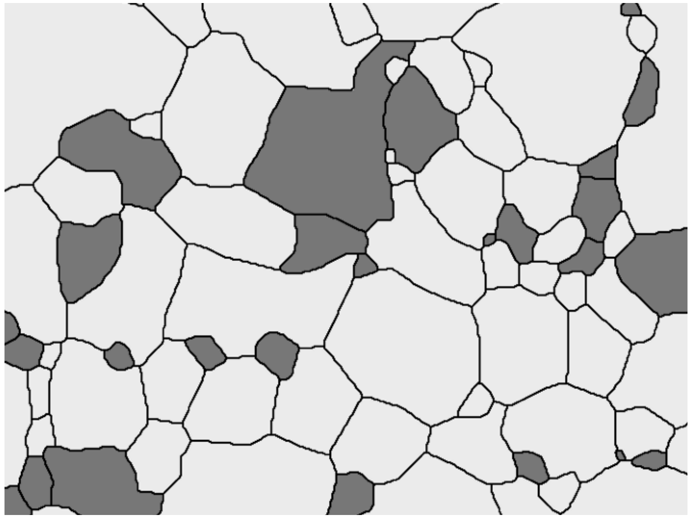
Cited by (CrossRef): 0 articles Check for updates Citation tools ▾

Tasaka et al. (JGR, 2017)

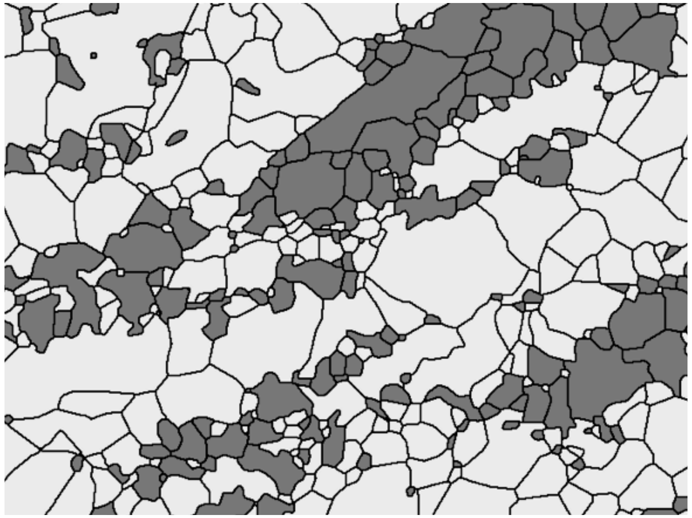


which spatial distributions do we really get ?

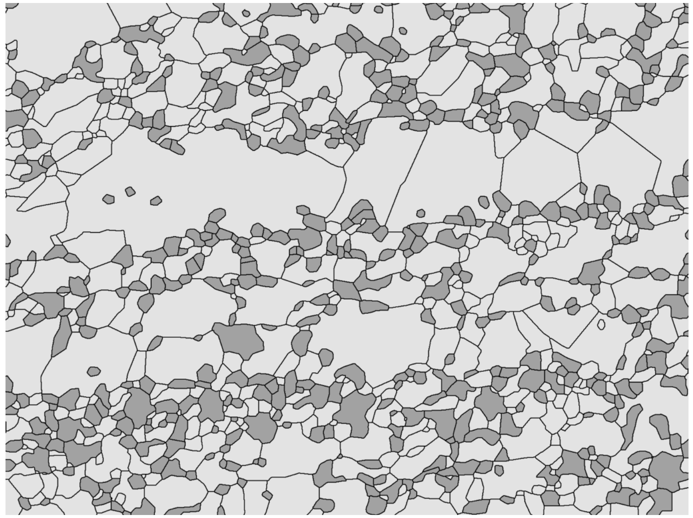
983 starting material

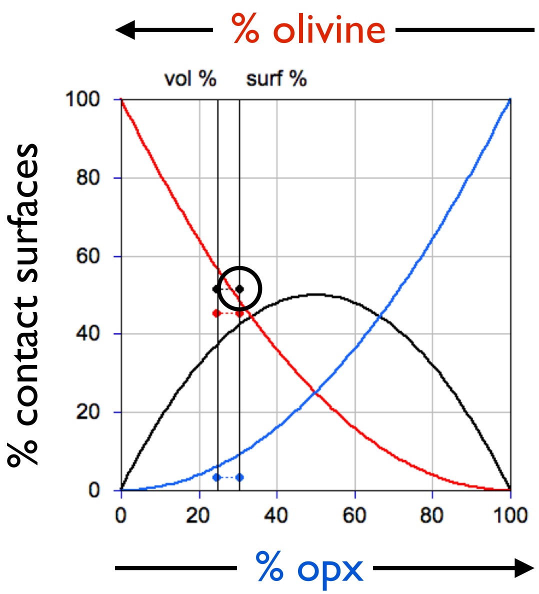


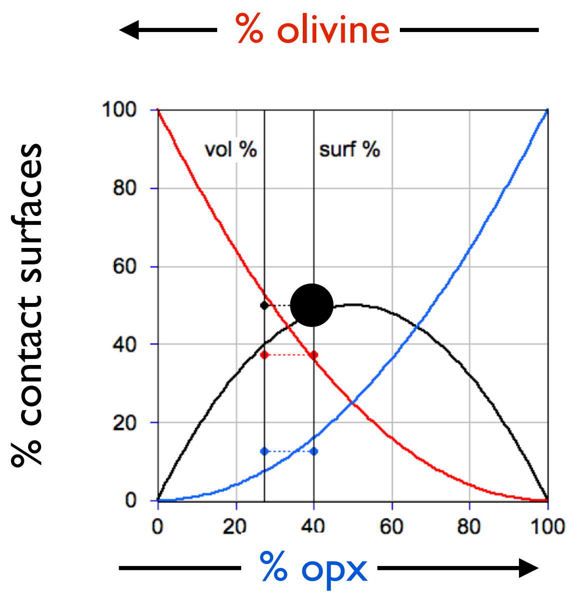
994 dislocation creep

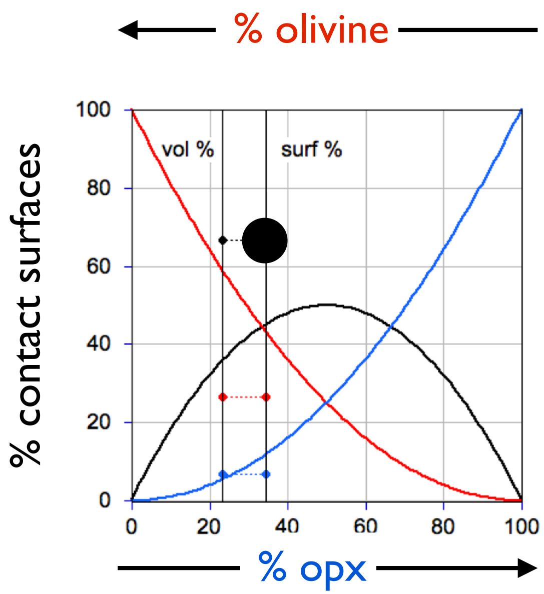


1024 diffusion creep





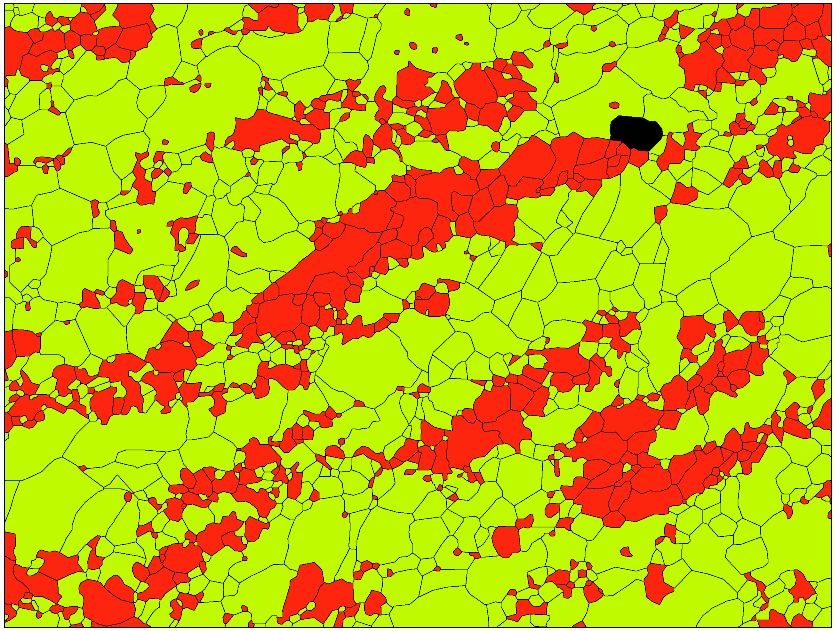


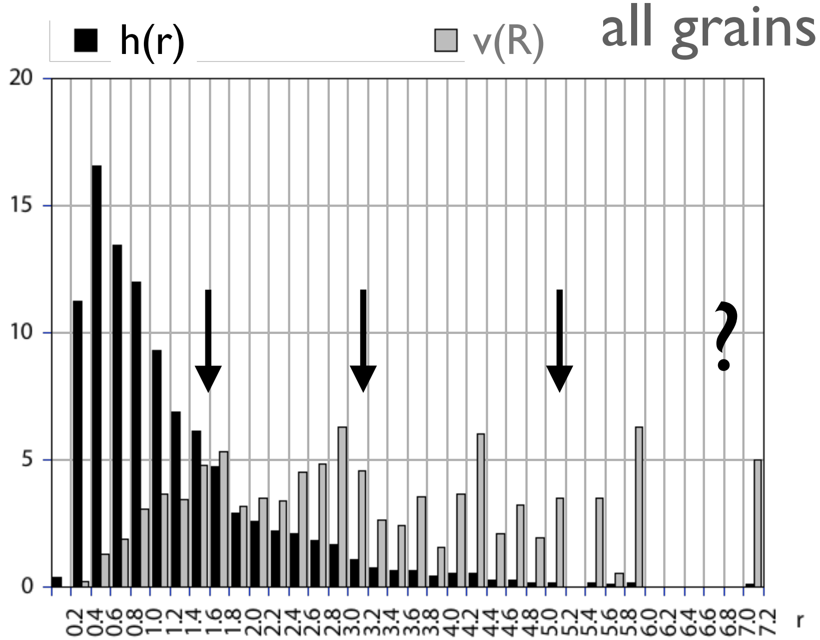


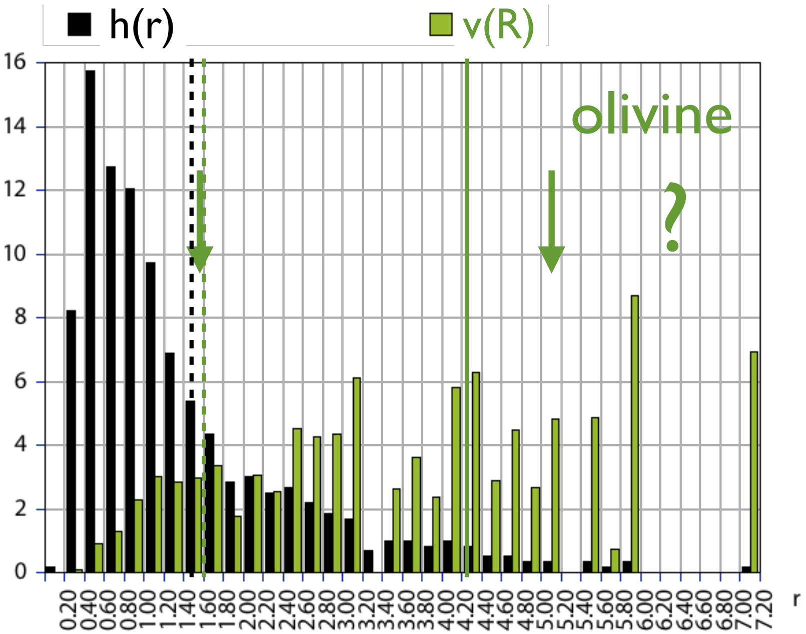
pb
ol-opx

plotted against surface fraction !

also, grain size distributions ...





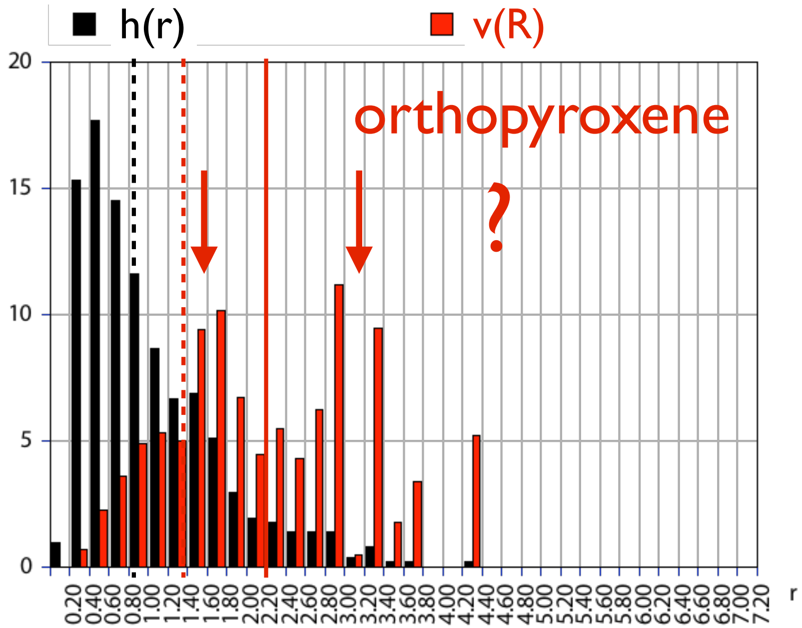


Miki's

μ(d)

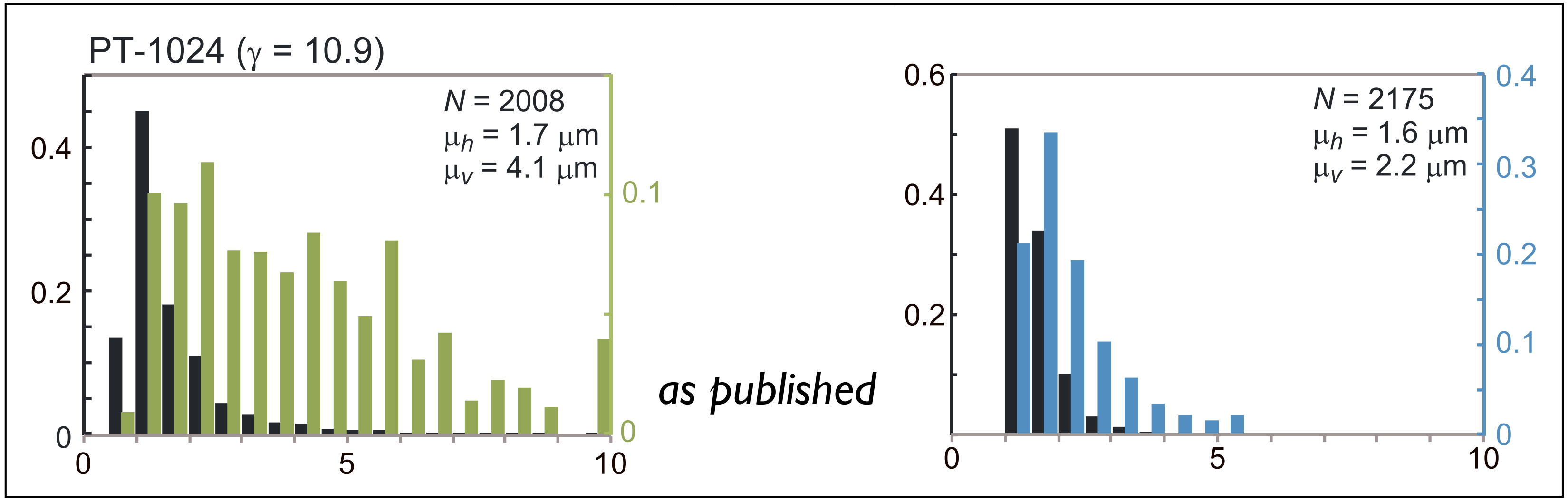
μ(D)

μ(V)



means... and modes

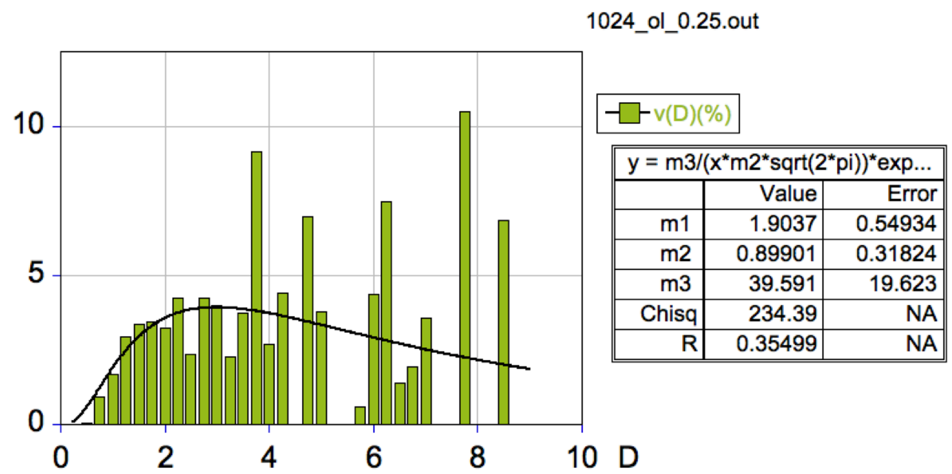
means

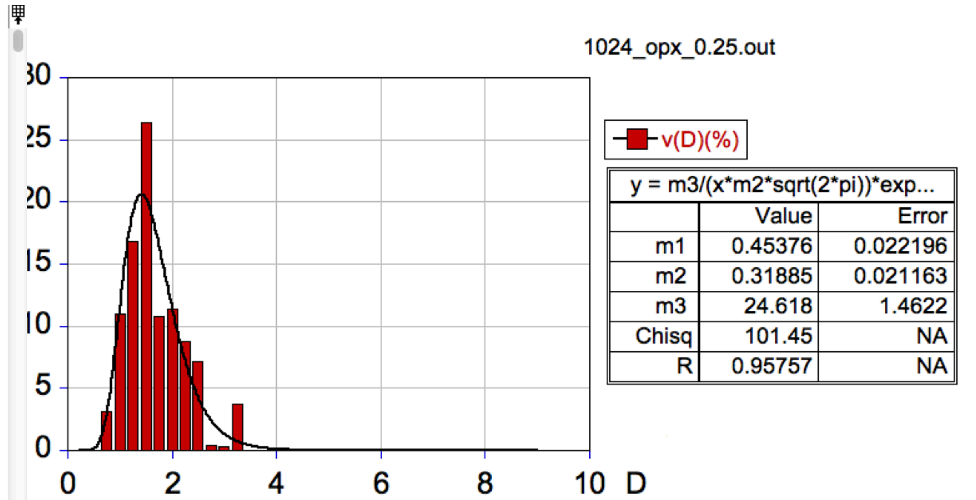


µv ol (3Dvol) 4.1 µm

µv opx (3Dvol) 2.2 µm

modes



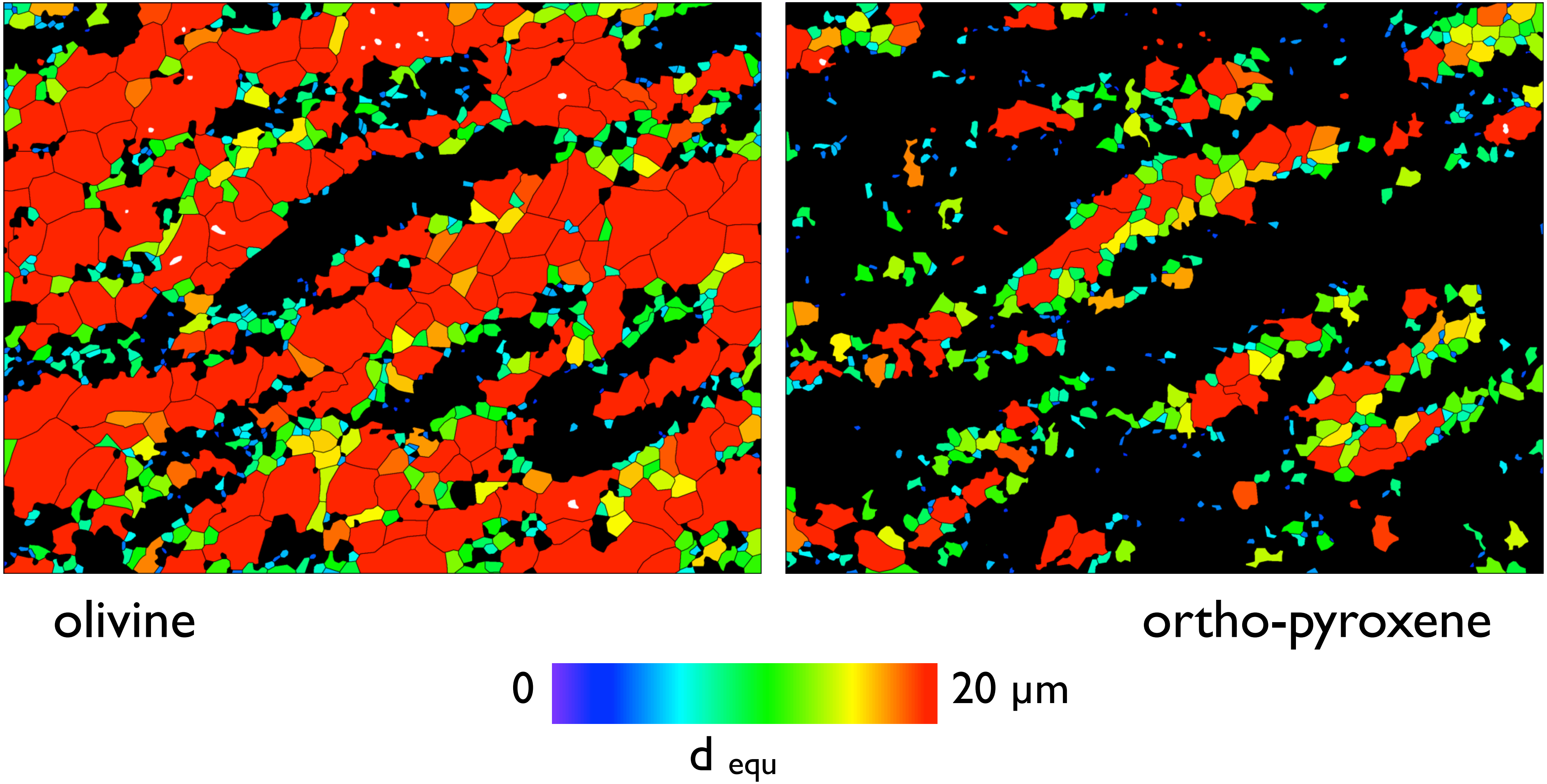


mode = 2.87 µm

re-calcuated

mode = 1.36 µm

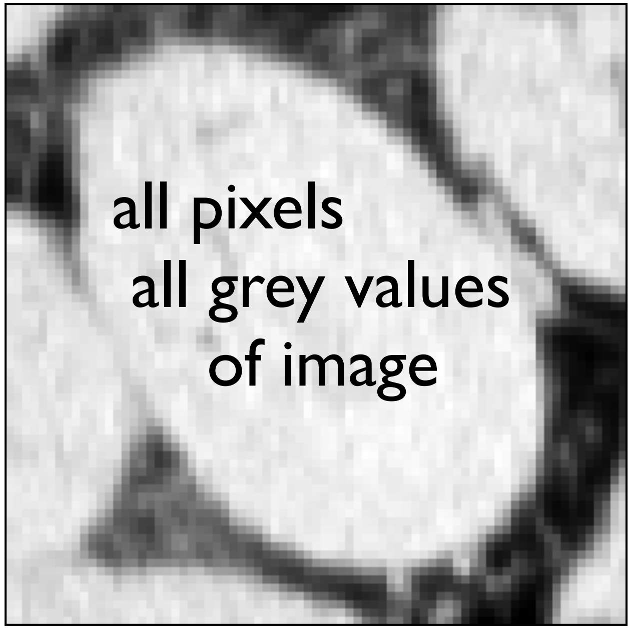
grain size of ol and opx



3
image statistics

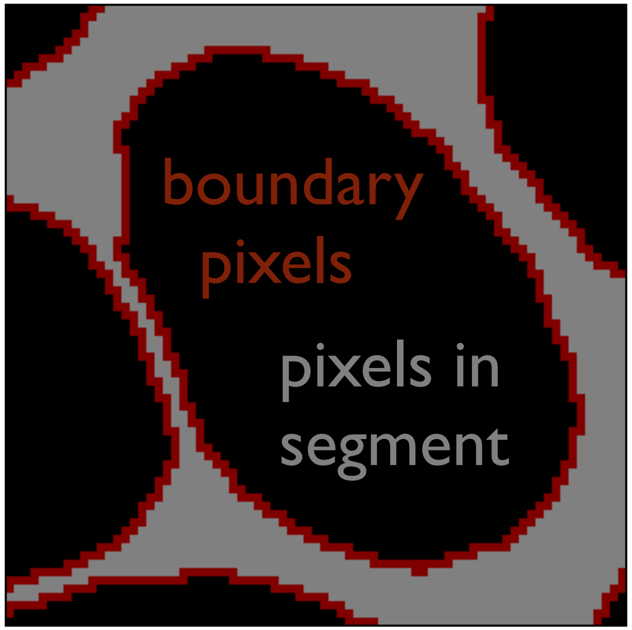
analysis of image 'as-is'

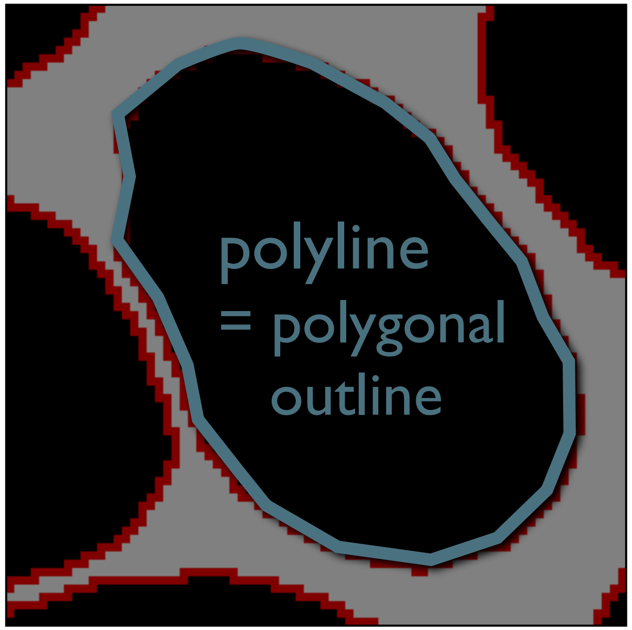
image



(no segmentation)

bitmap

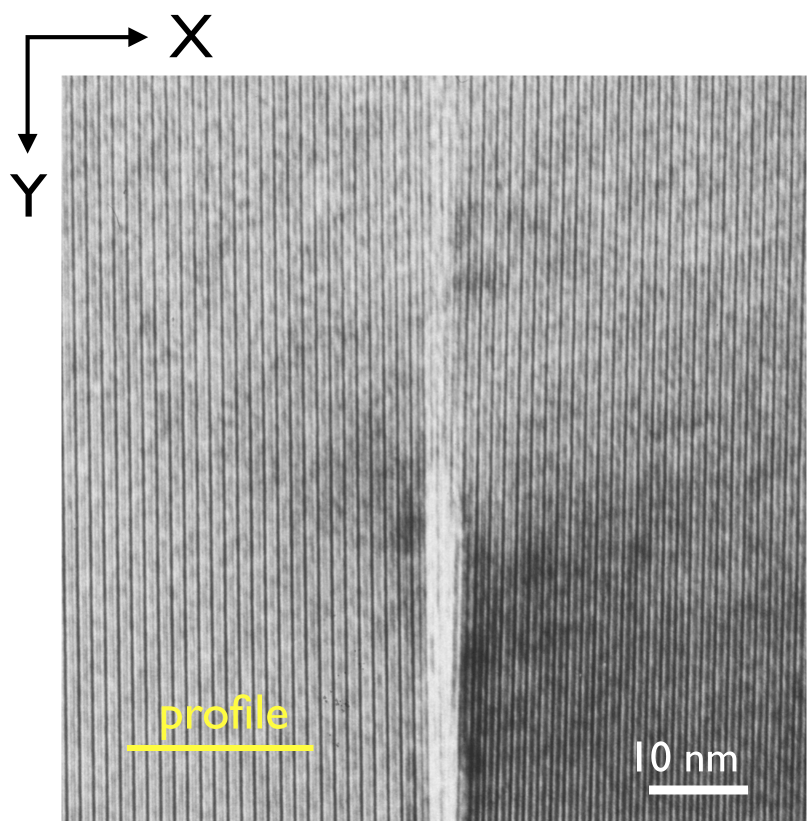


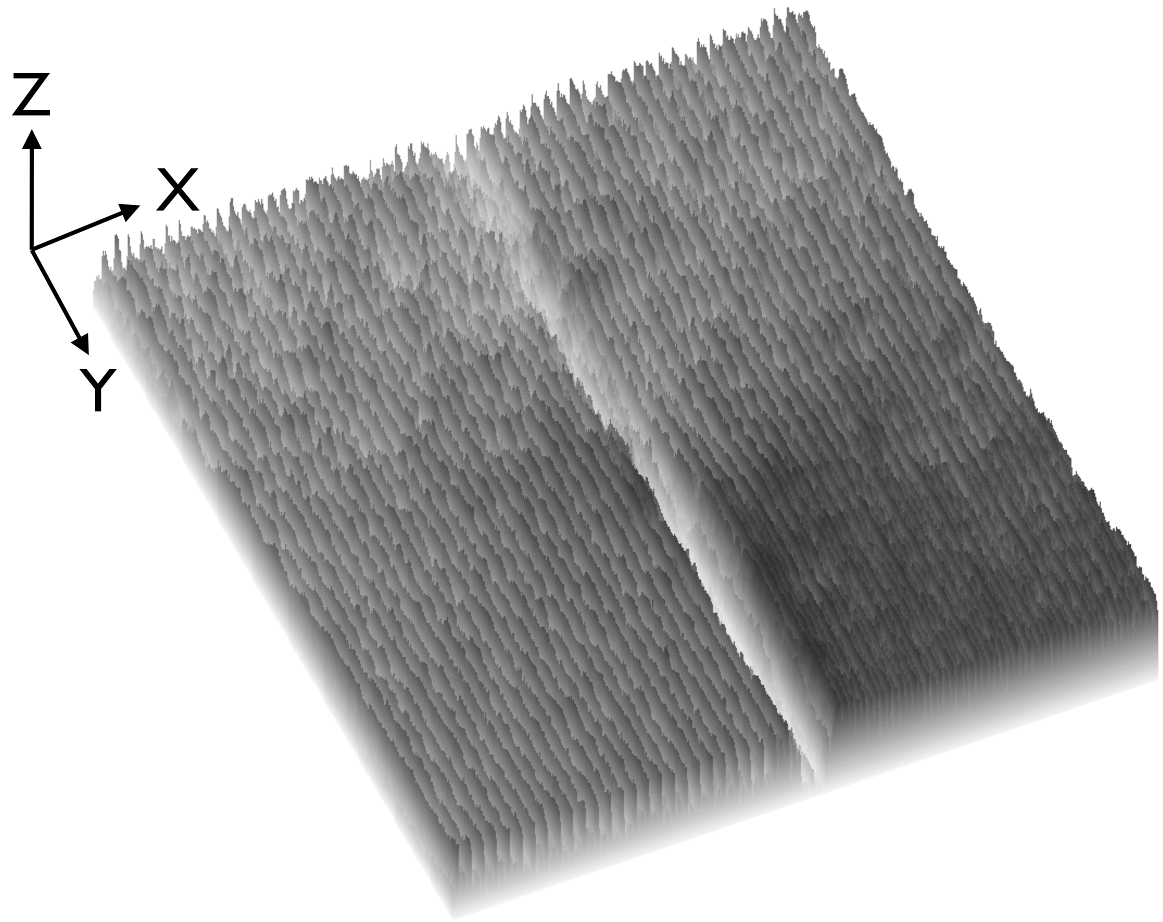


Fourier transforms

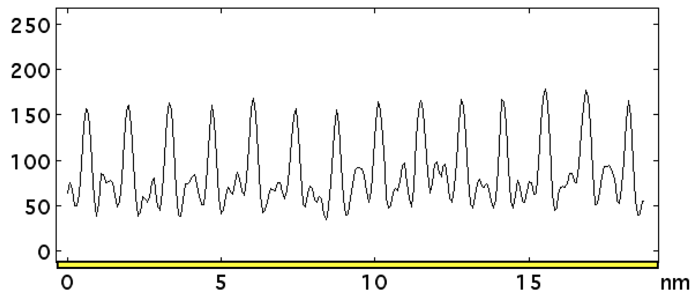
- 1D / 2D FFT
- diffraction patterns

profiles → 1D FFT → ACF

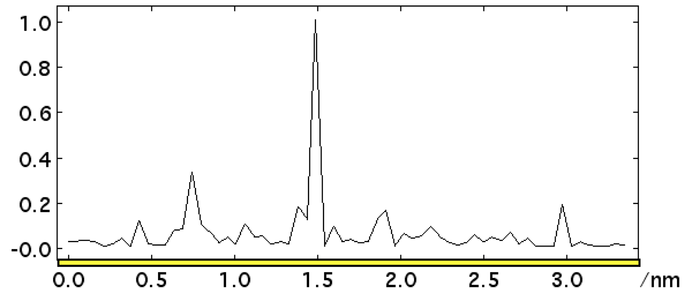




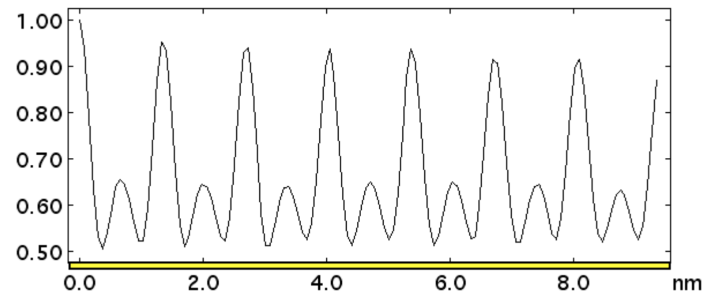
grey values (GV)



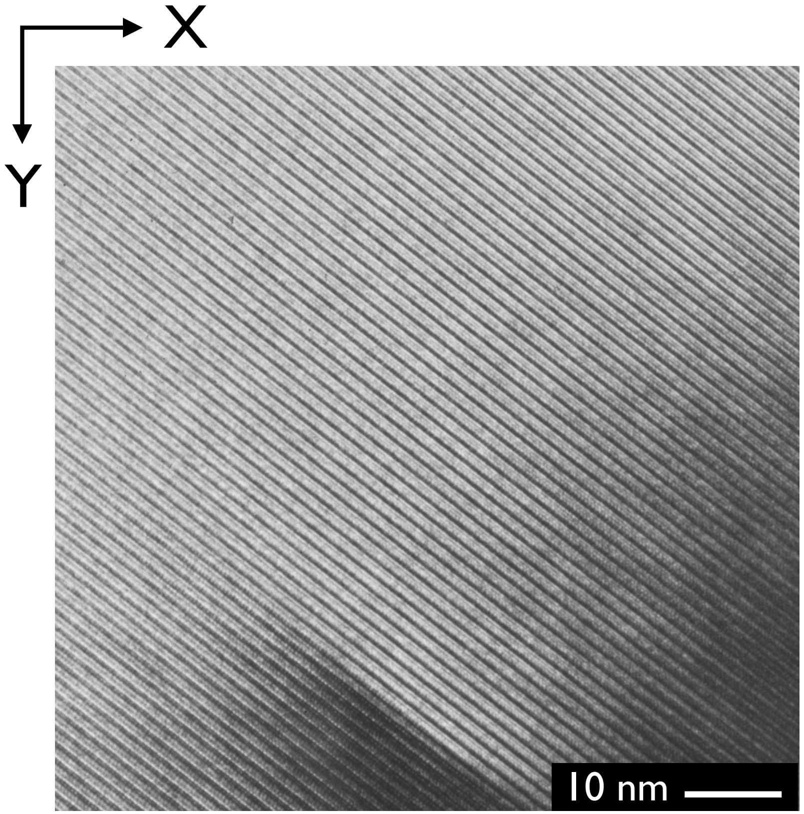
Fourier transform (FFT)



autocorrelation (ACF)

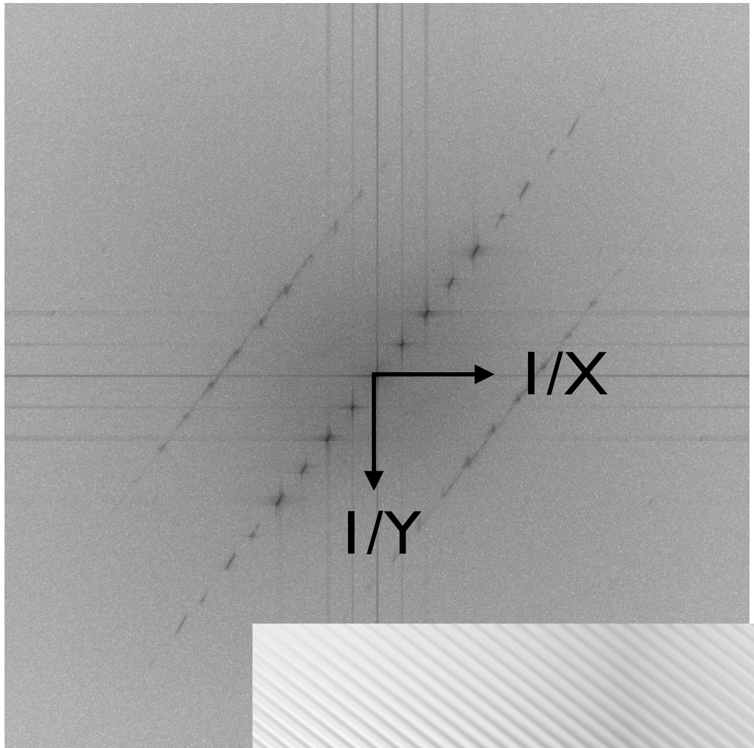


2D FFT and ACF

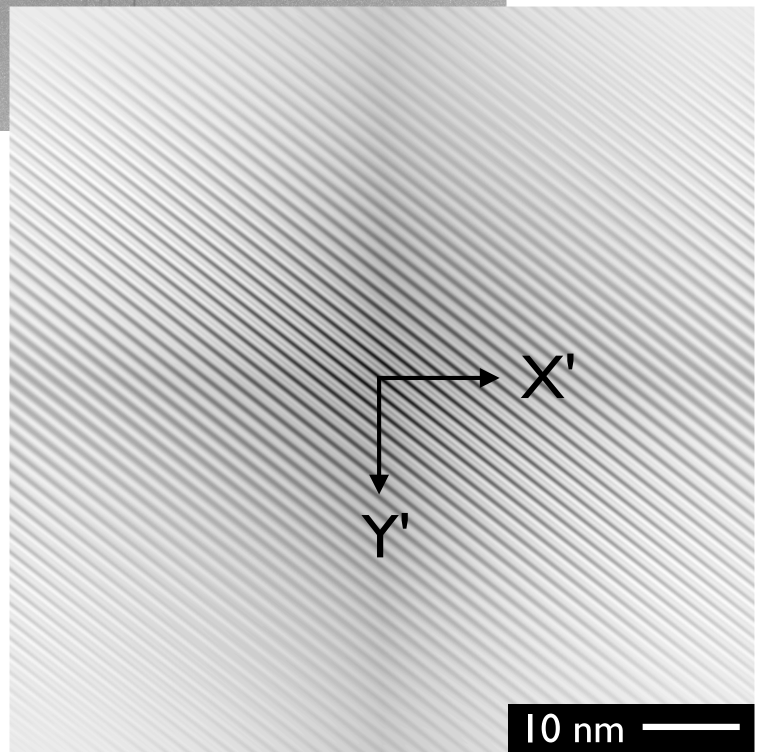


high resolution TEM image of chlorite
courtesy Andreas Kronenberg

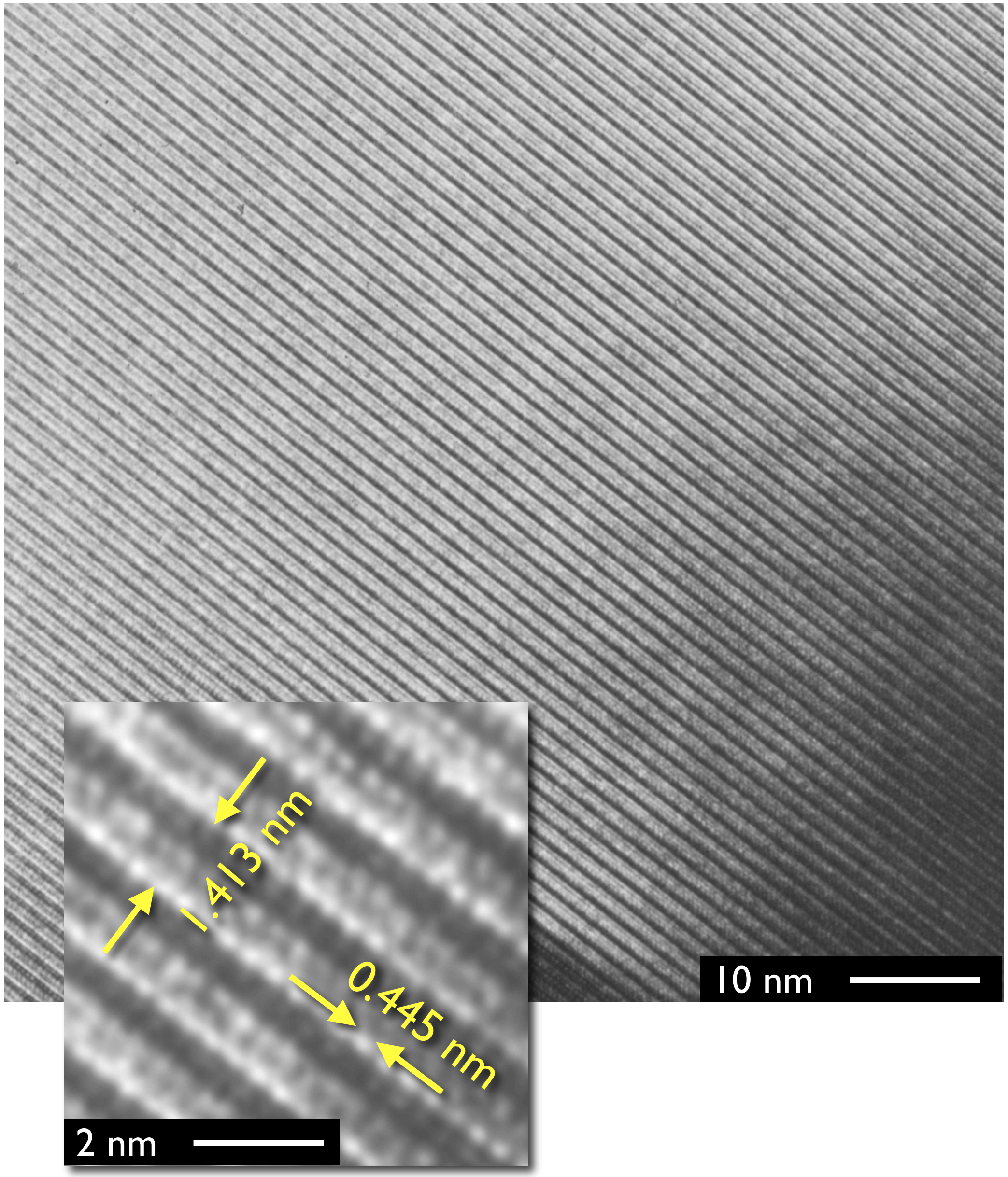
FFT

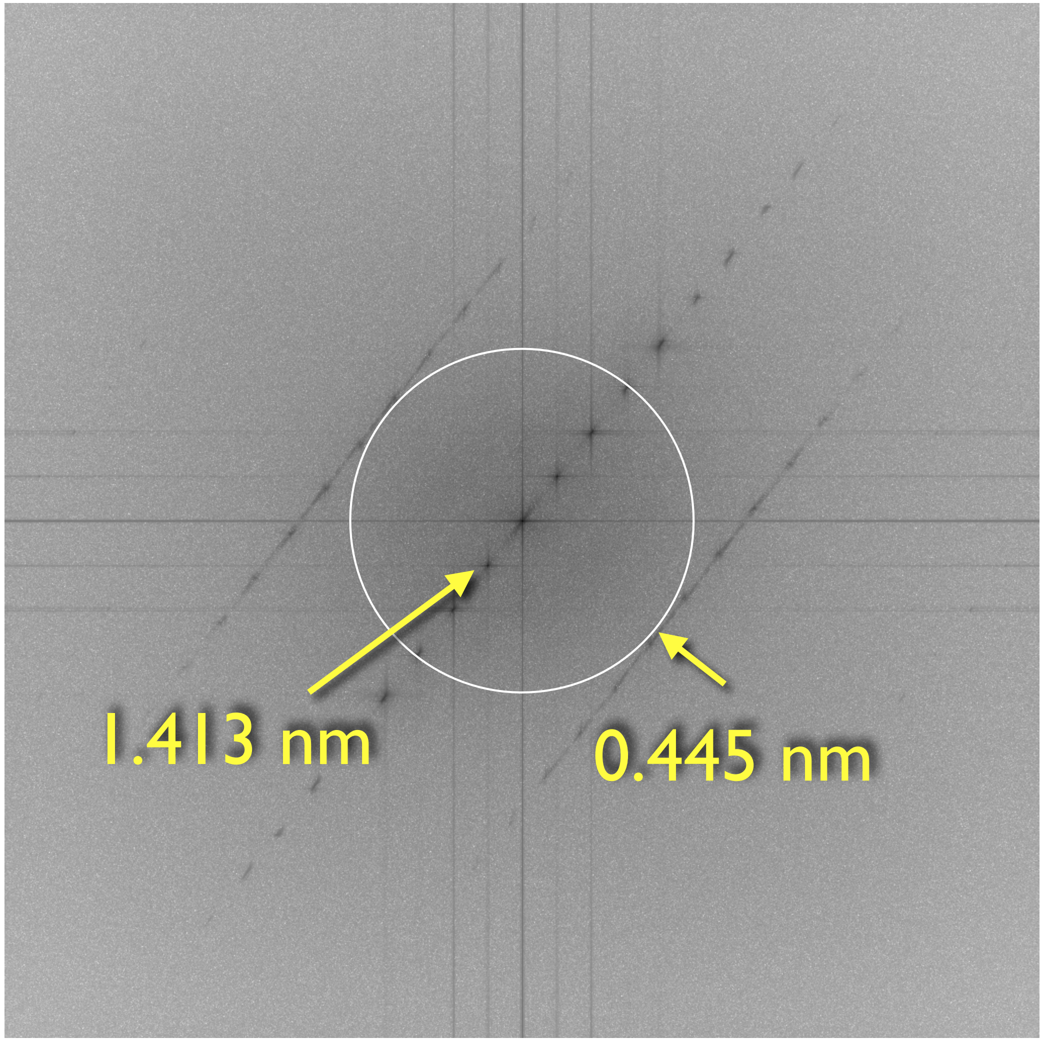


ACF



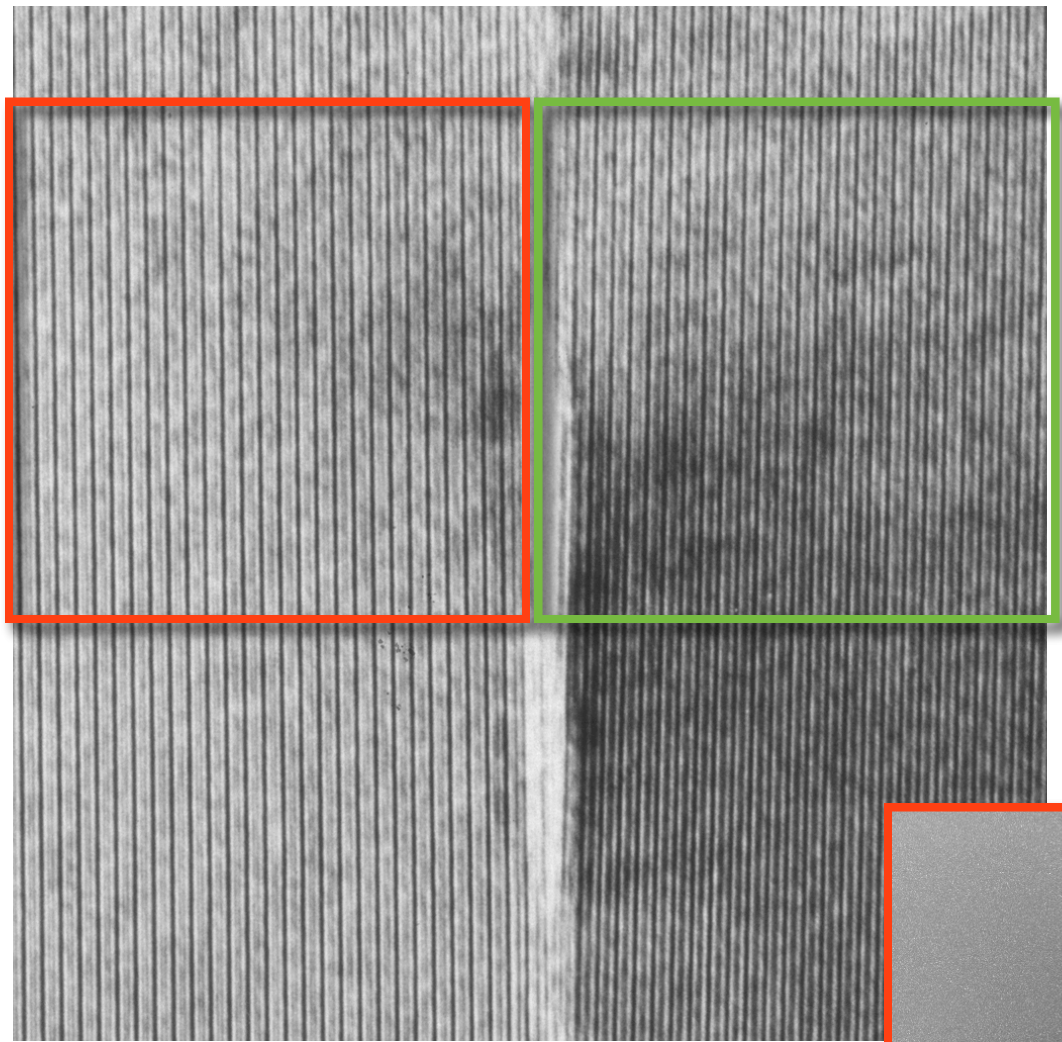
FFT - diffraction patterns

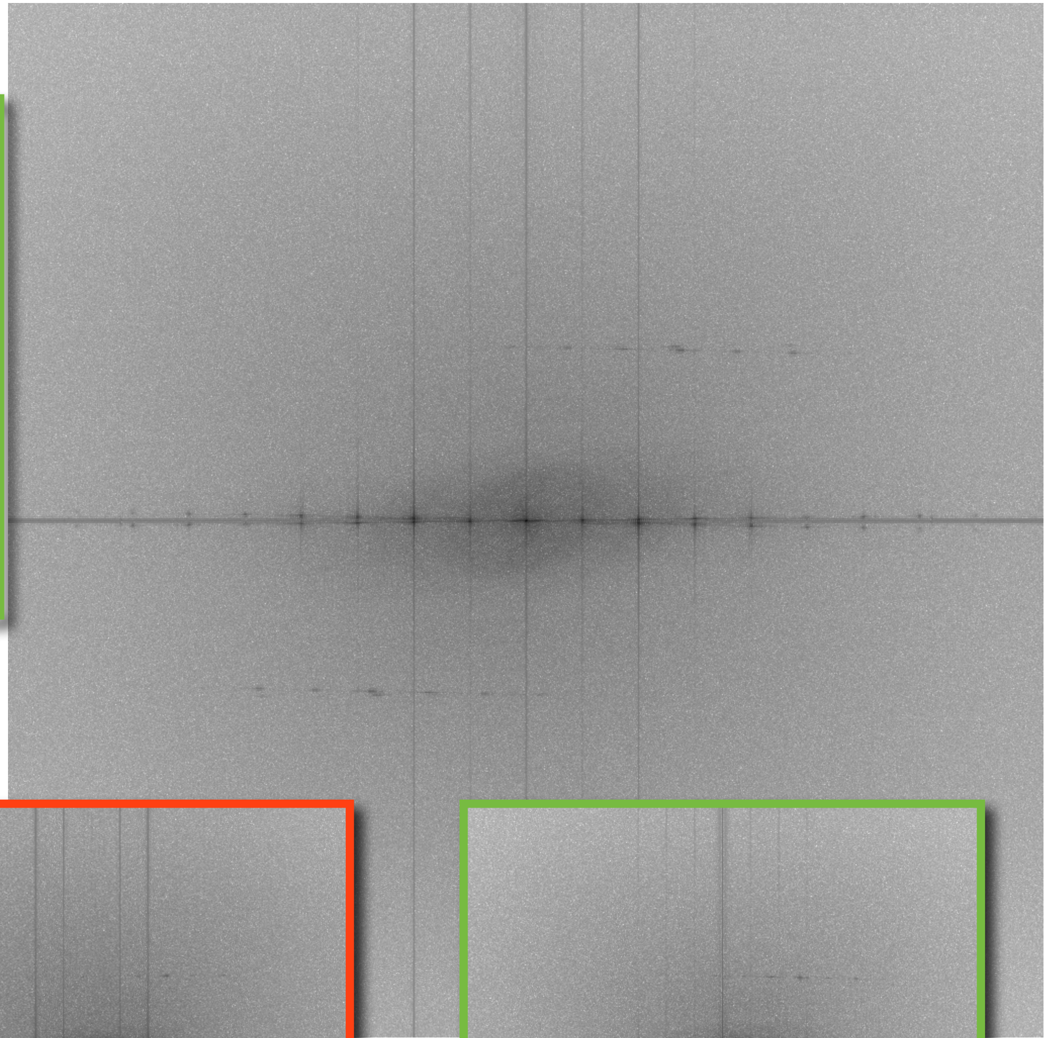


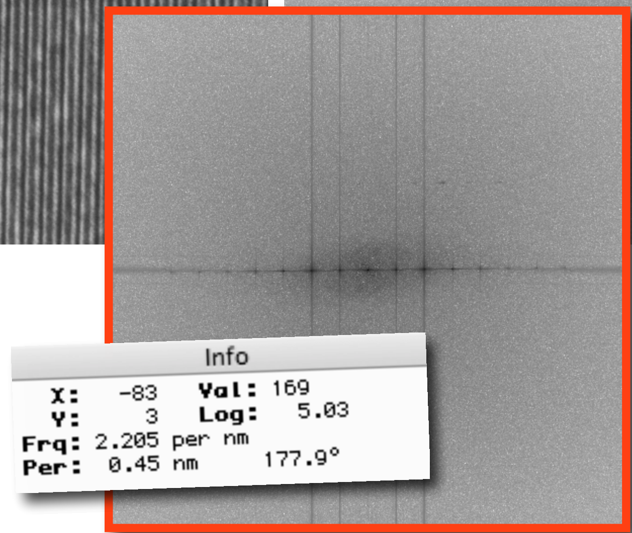


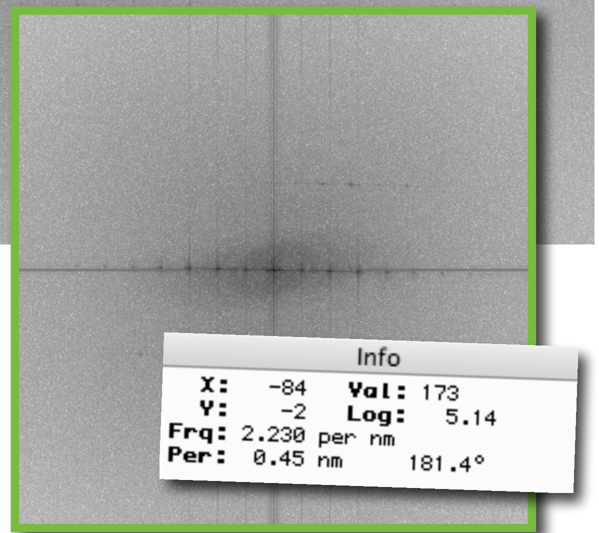
high resolution TEM image of chlorite
courtesy Andreas Kronenberg

FFT - low angle boundary









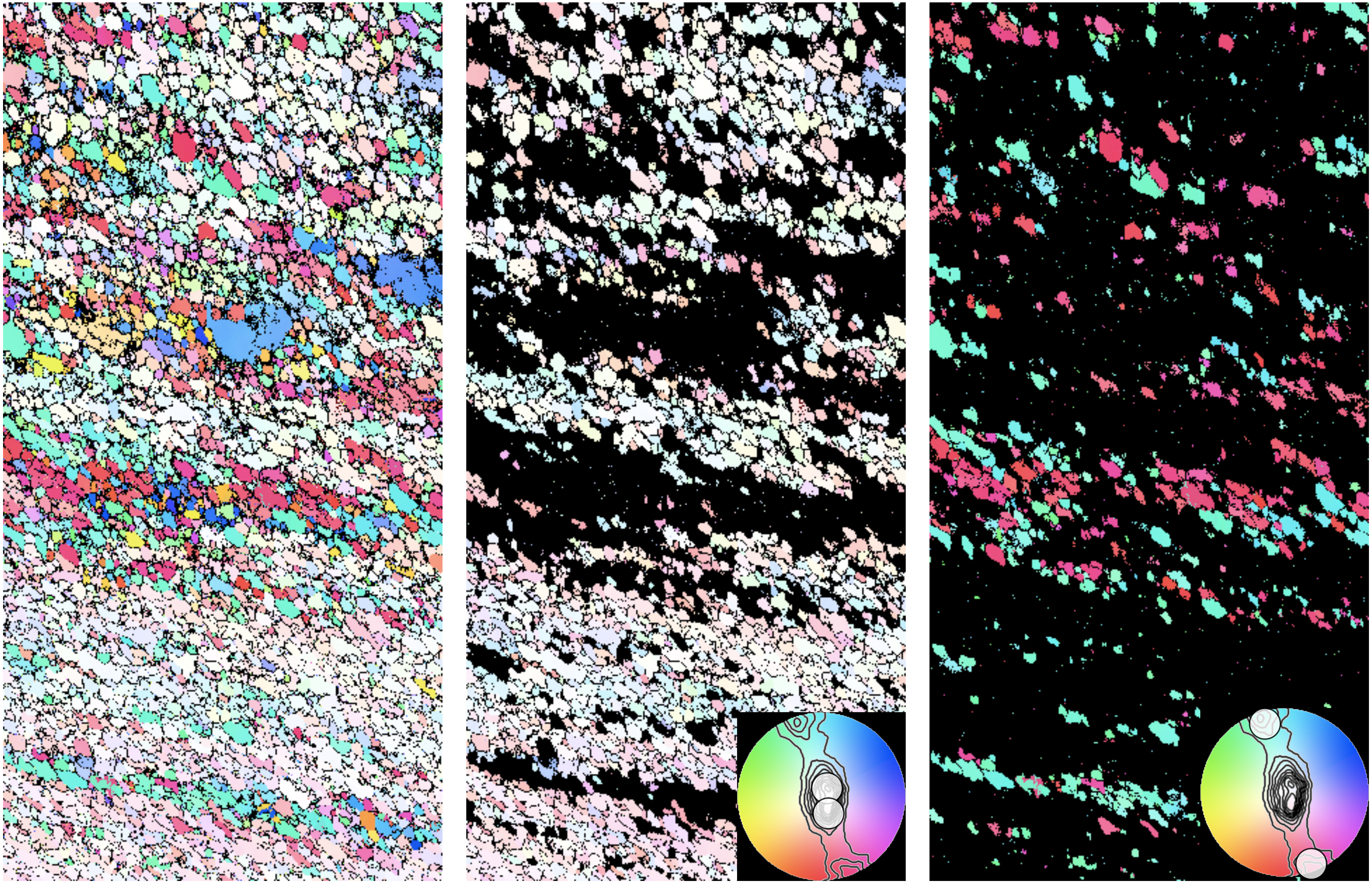
high resolution TEM image of chlorite
courtesy Andreas Kronenberg

4
autocorrelation

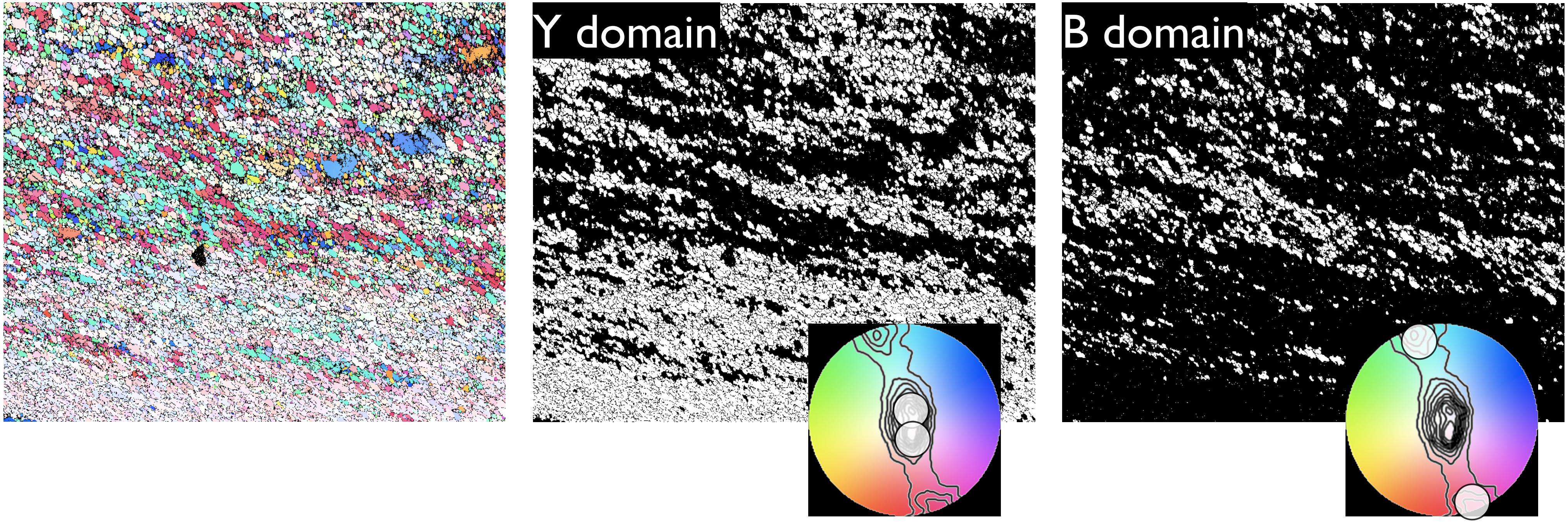
autocorrelation

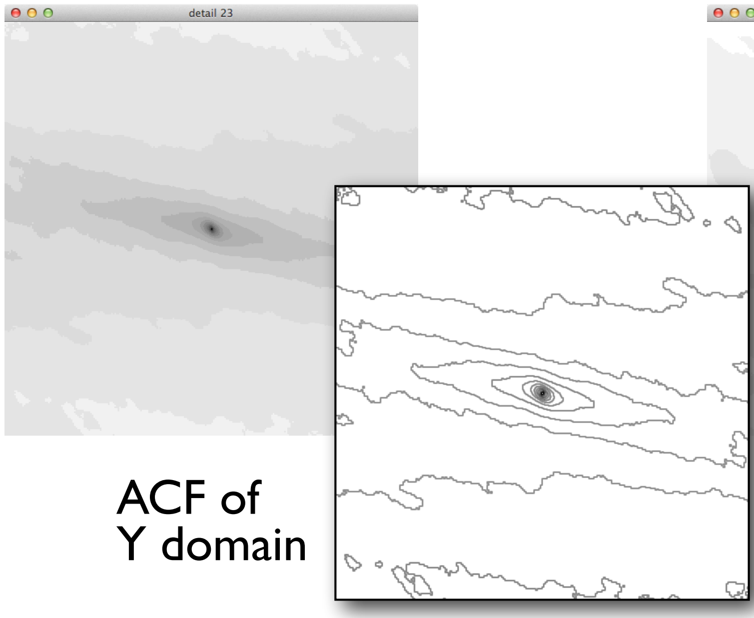
- shape
- strain
- grain size
- spatial distribution

density slicing in orientation space

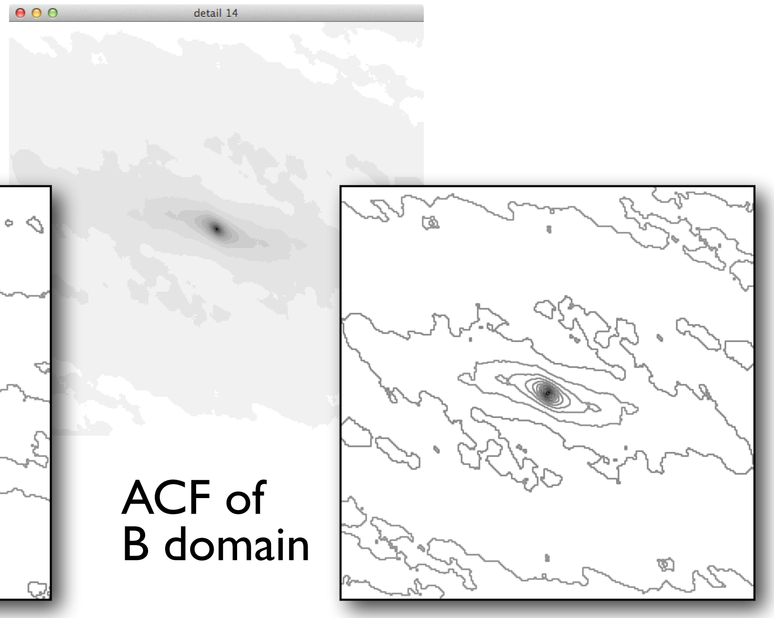


ACF - grain shape as f(CPO)



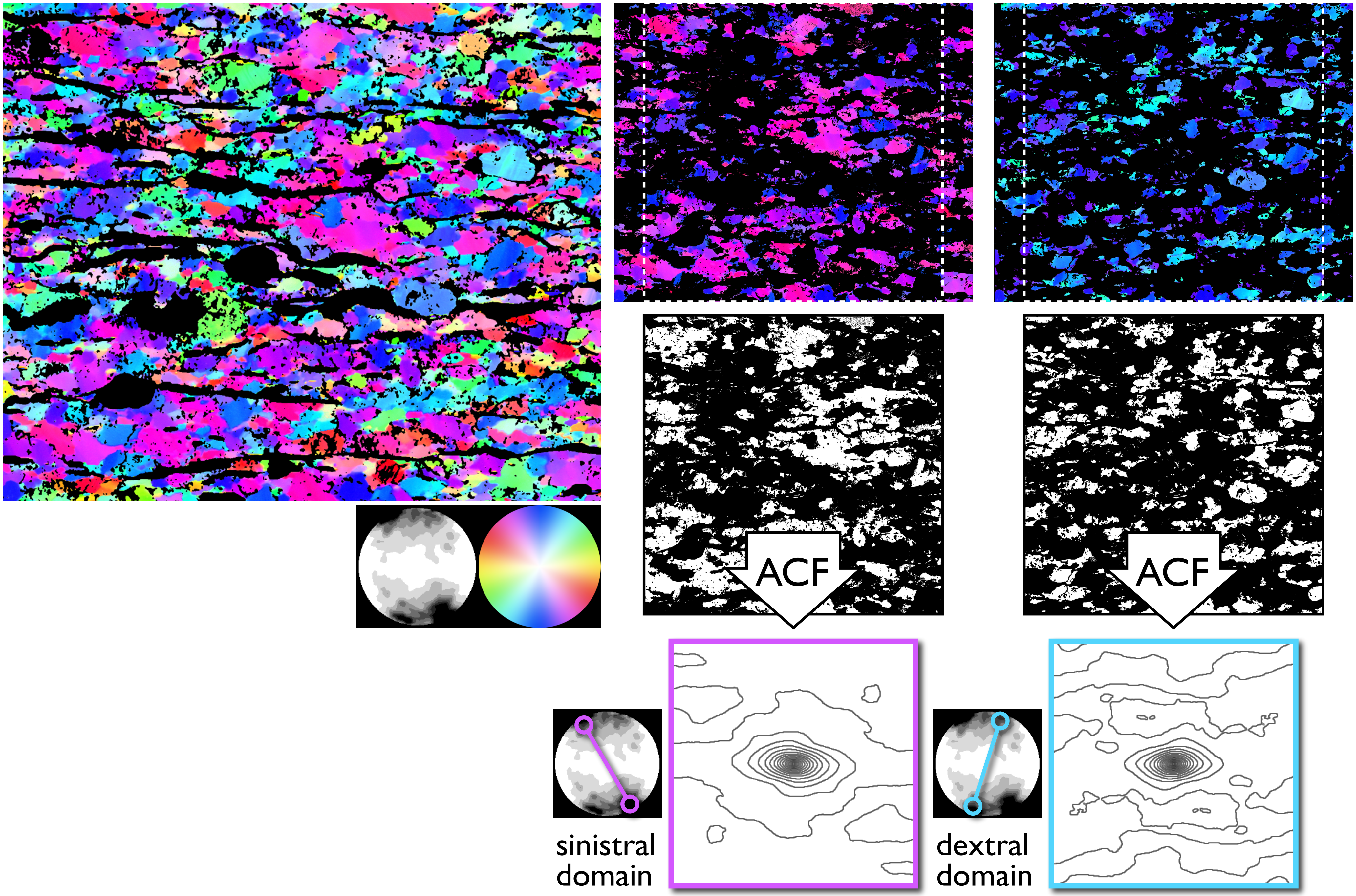


ACF of
Y domain

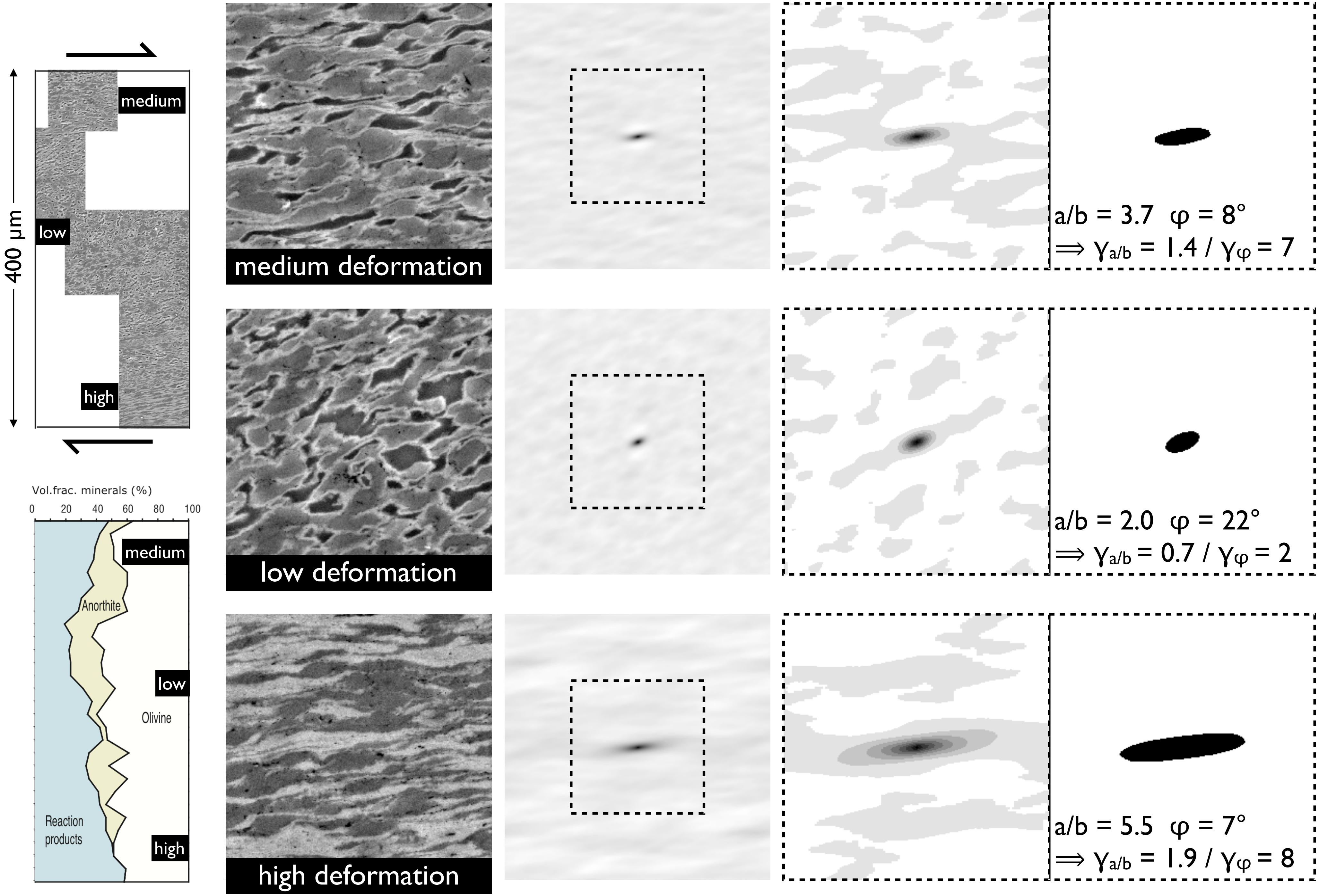


ACF of
B domain

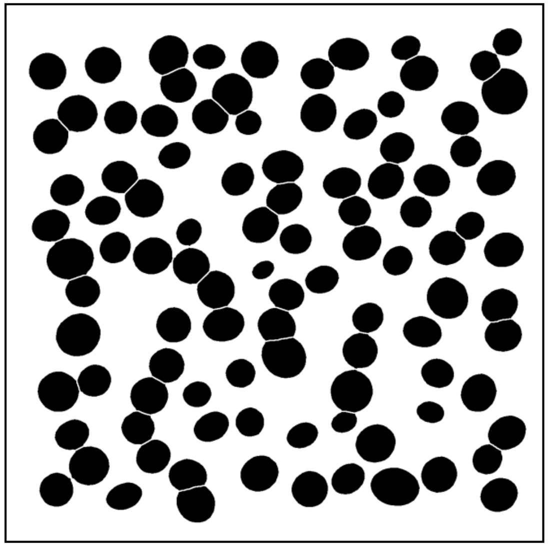
ACF - shape of texture domains



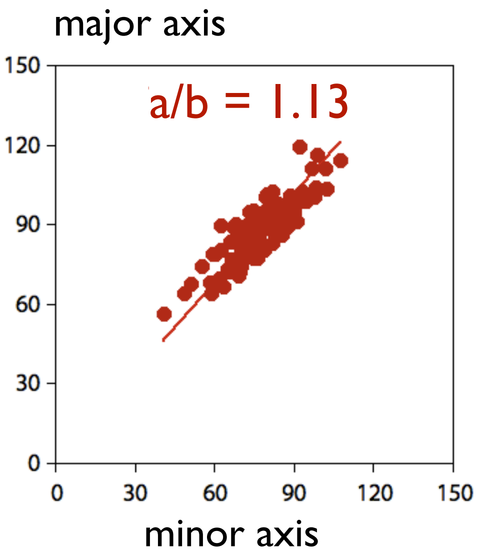
ACF→ anisotropy/orientation→ strain

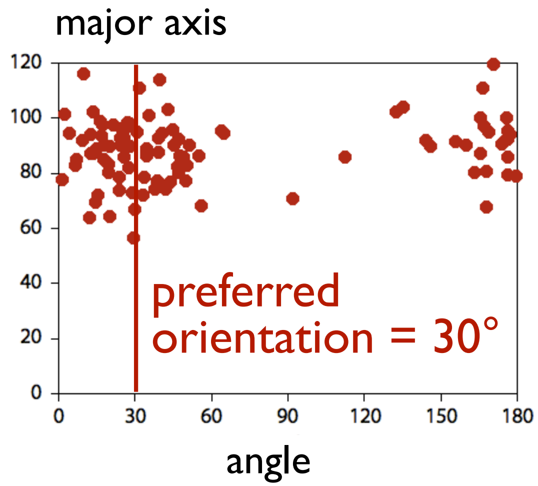


centerpoint distribution

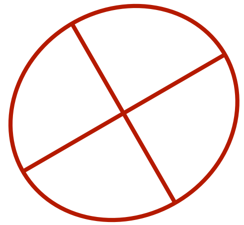


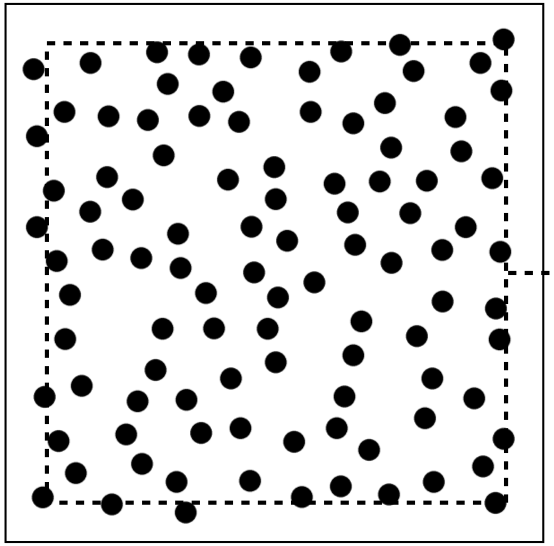
ooides bitmap





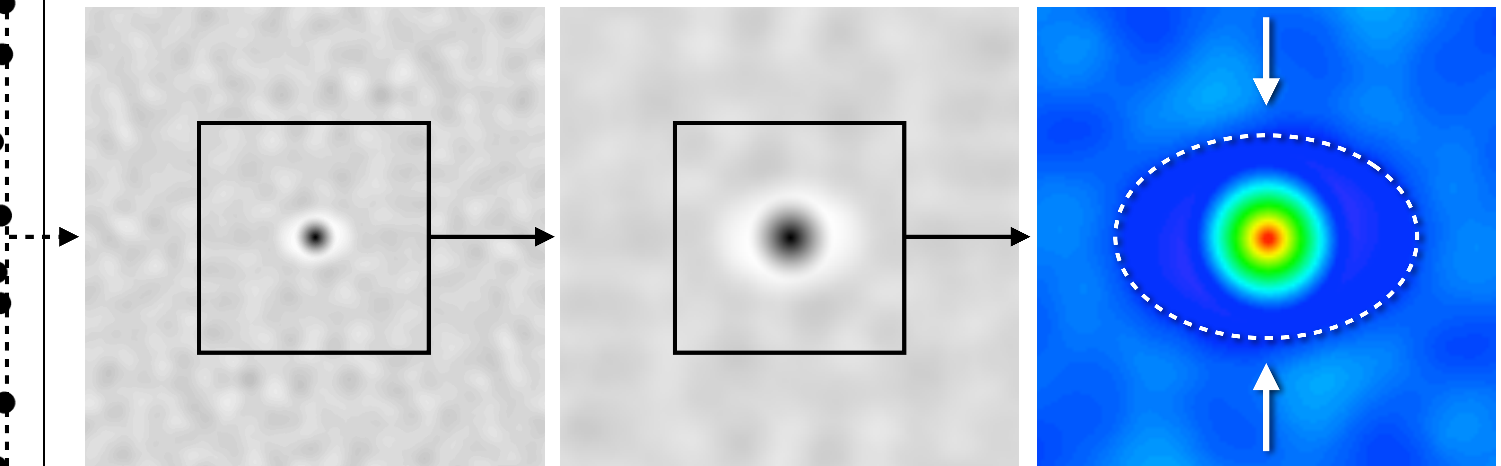
shape of particles





plot of centerpoints

matrix compaction



ACF

'halo' = anticorrelation
of centerpoints
(→ Fry plot)

end
spatial