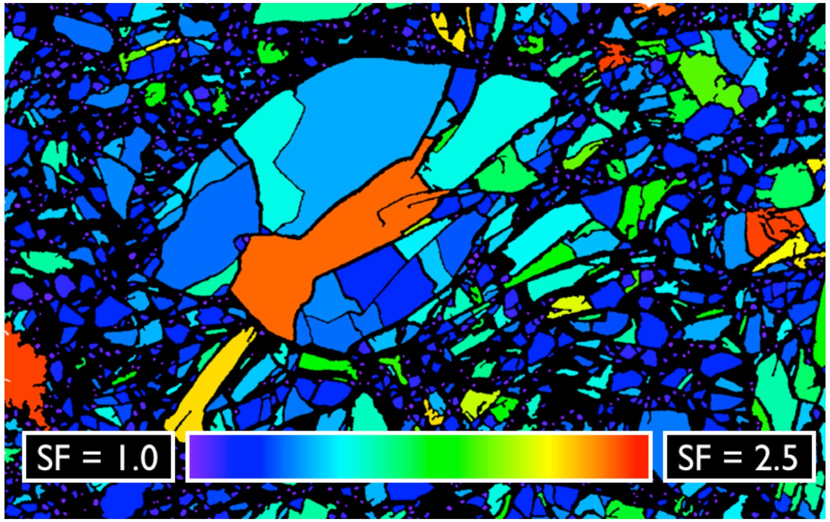
TSK19 HALLE

Workshop 2

Tuesday, March, 7, 2022



Selected topics in image analysis of deformed rocks

(I)

Shape analysis
Grain size distributions
Spatial distributions

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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)

1

basics

types of image analysis

- direct / no segmentation
- analysis of bitmaps:
  segments, objects, outlines

types of image analysis

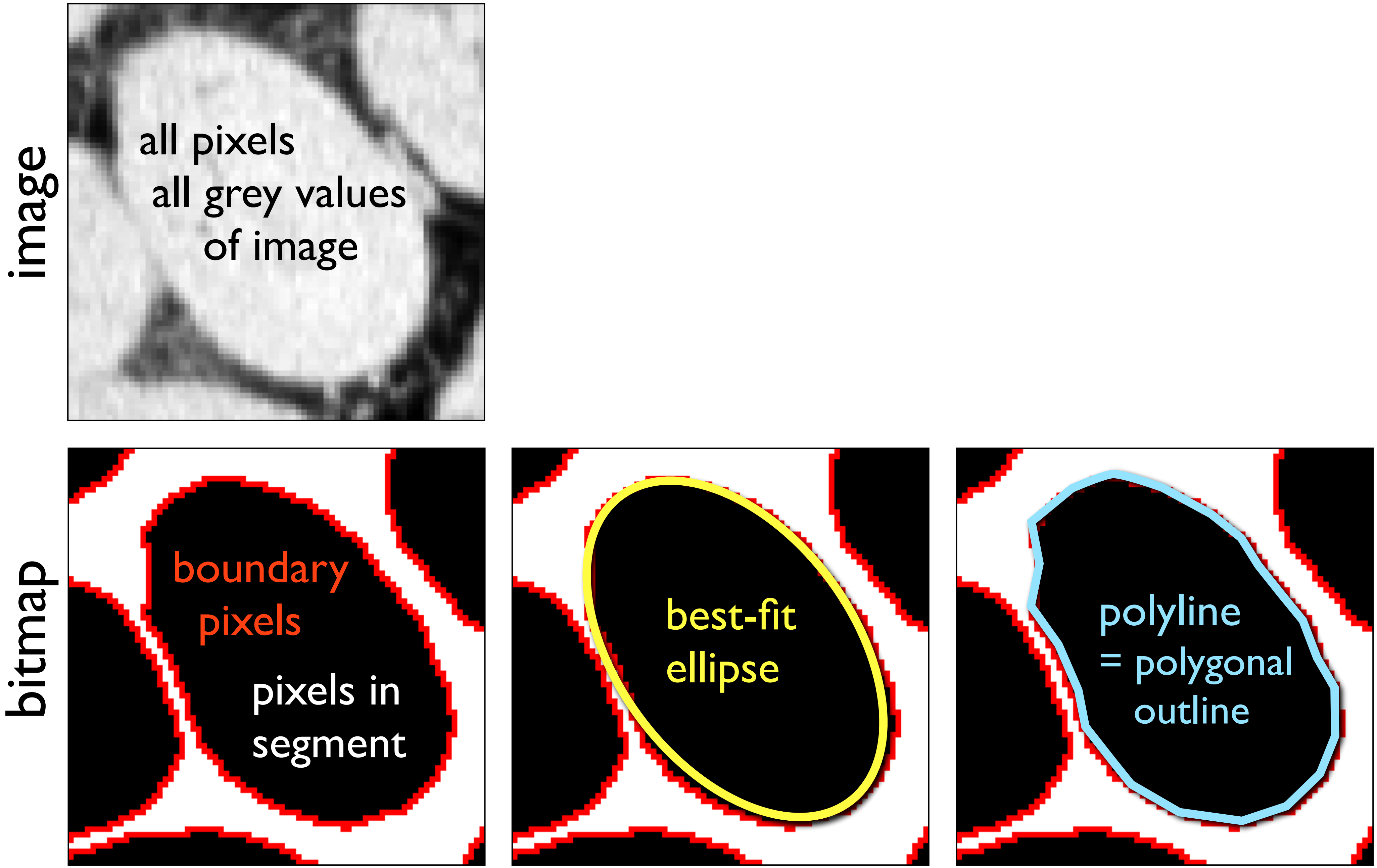


image analysis step by step

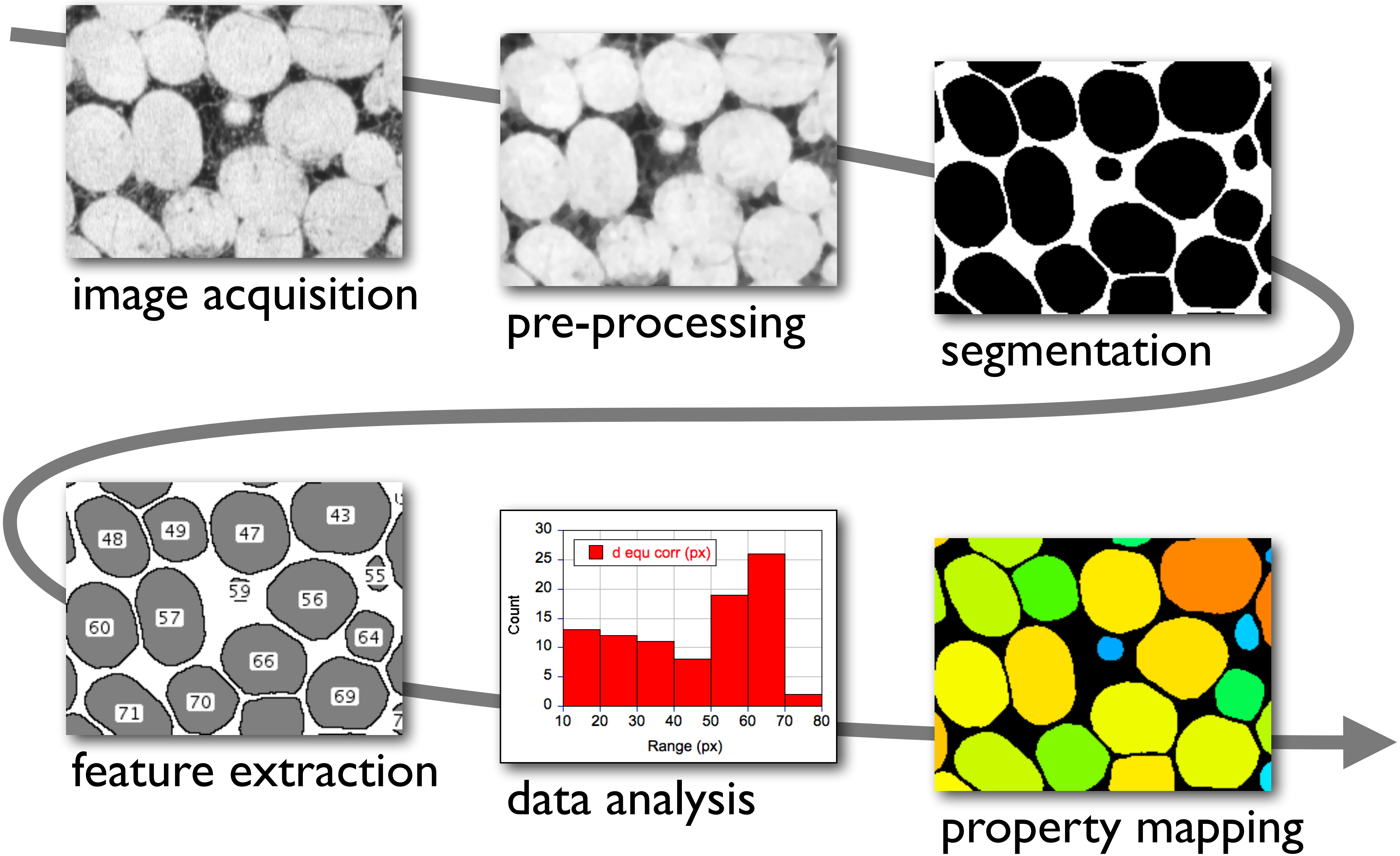
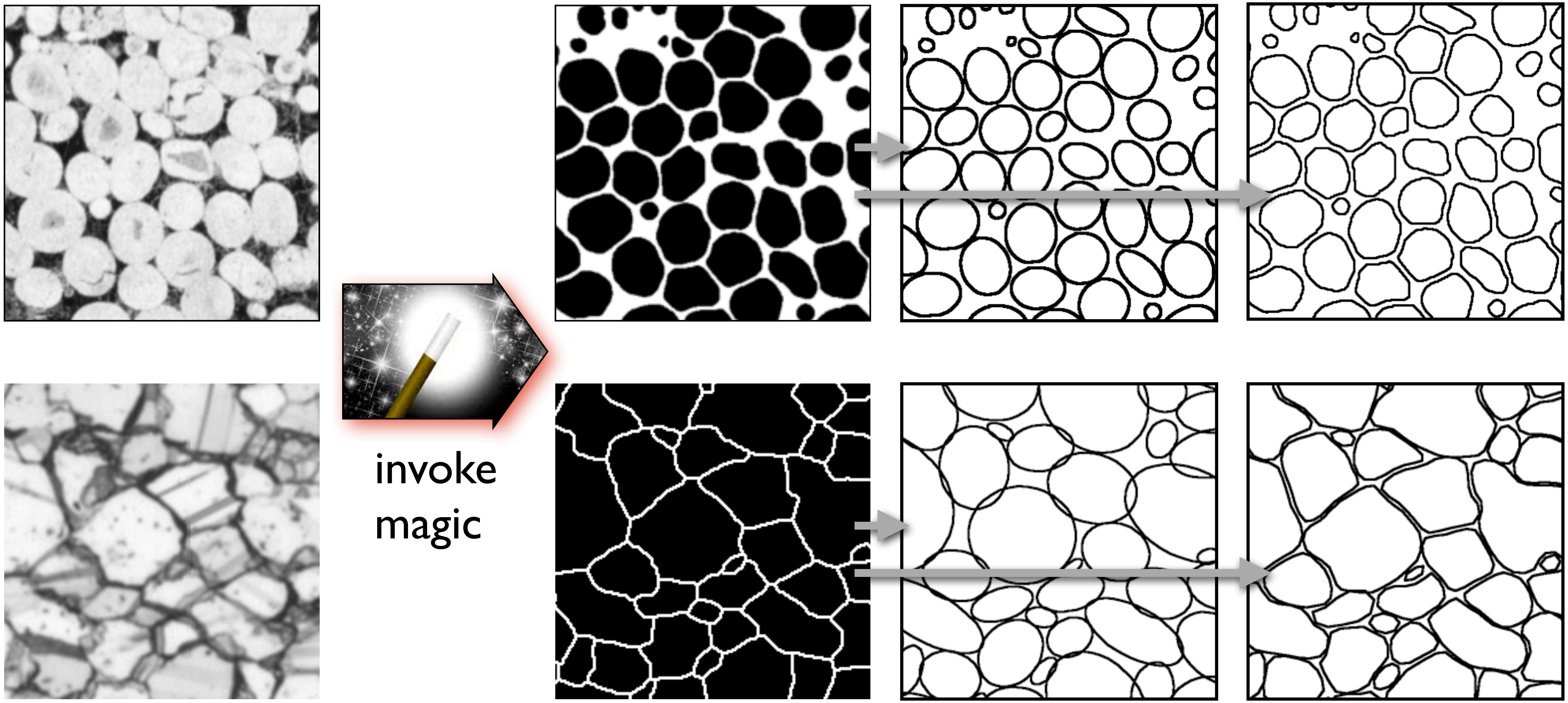


image - segments - ellipses - outlines



unsegmented image	segmented bitmap	best fit shapes (ellipses)	polygonal outlines (polylines)
gray values $Z(X,Y)$ histogram $h(Z)$	segments: connected pixels boundary pixels	center, axes, orientation $X_c Y_c$, a, b, φ	line segments connecting verteces (x_1,y_1) .... (x_n,y_n)

why image analysis ... and why not

1
use image analysis as a research tool
turn the information contained in an image into numbers
("ein Bild sagt mehr als tausend Worte")

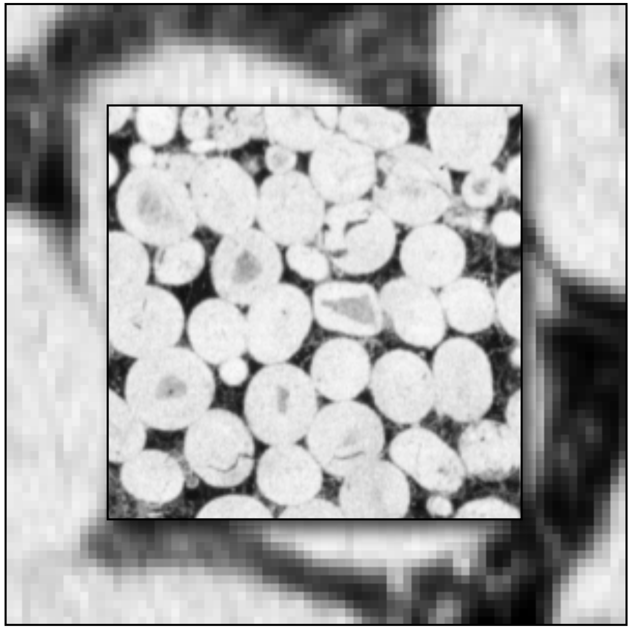
2
formulate the question for which you want the answer

3
before segmentation decide what is the aim:
shape analysis? use high resolution images - small no of segments
grain size analysis? use large number of segments

and please remember: while art is often involved in image analysis, ... image analysis is not a decorative art

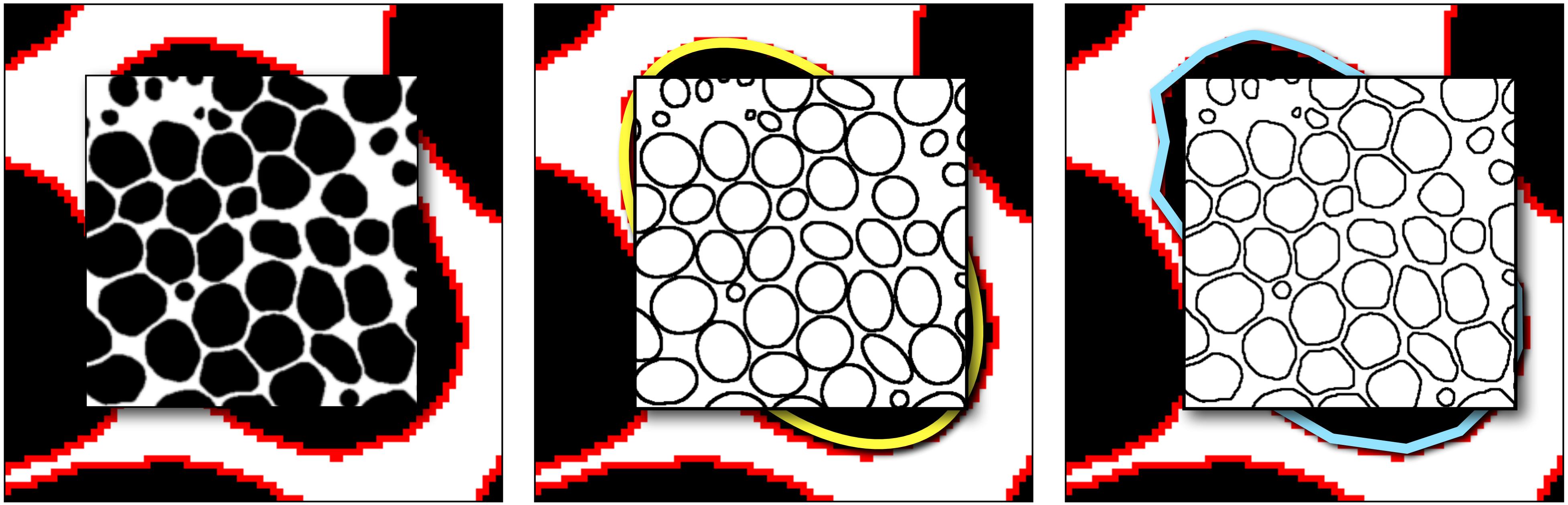
possible questions

image



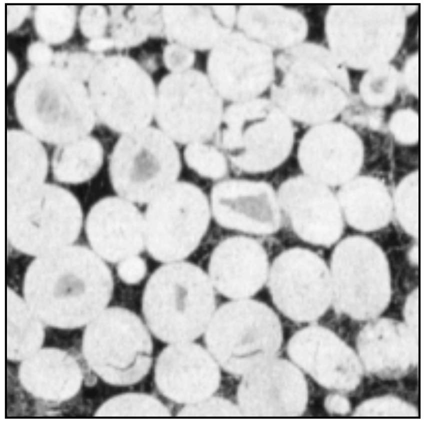
composition of ooides ? spacing ?
packing density ? grain size ?
shape preferred orientation ?
detailed shape of ooides (indentations) ?

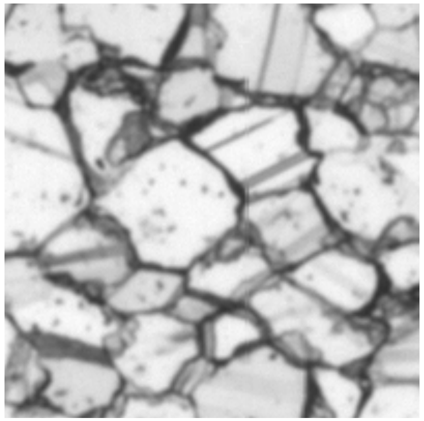
bitmap



2
nothing on segmentation

the art of segmentation

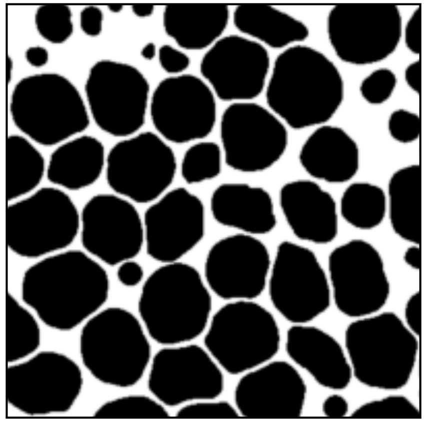


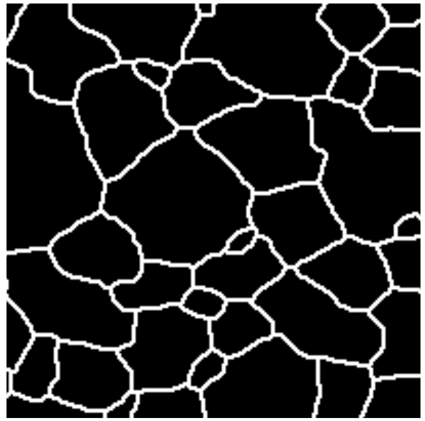


unsegmented image

gray values Z(X,Y)
histogram h(Z)

how to segment an image...
... in five easy steps





segmented bitmap

segments:
connected pixels

segments (or regions)

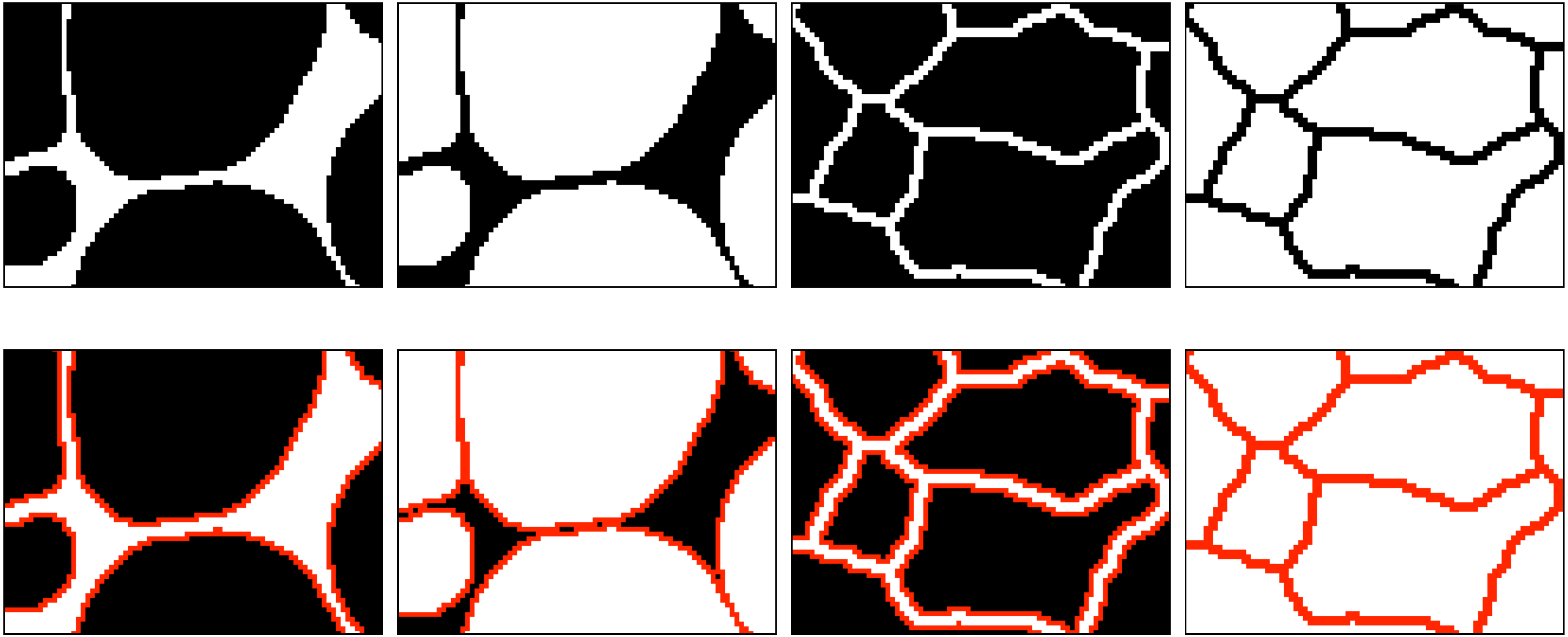
- neighbouring segments should have signicantly different values with respect to the characteristic on which they are uniform

segment = black = particle

segment = black = matrix

segment = black = grain

segment = black = grain boundary



segment boundary

segment boundary

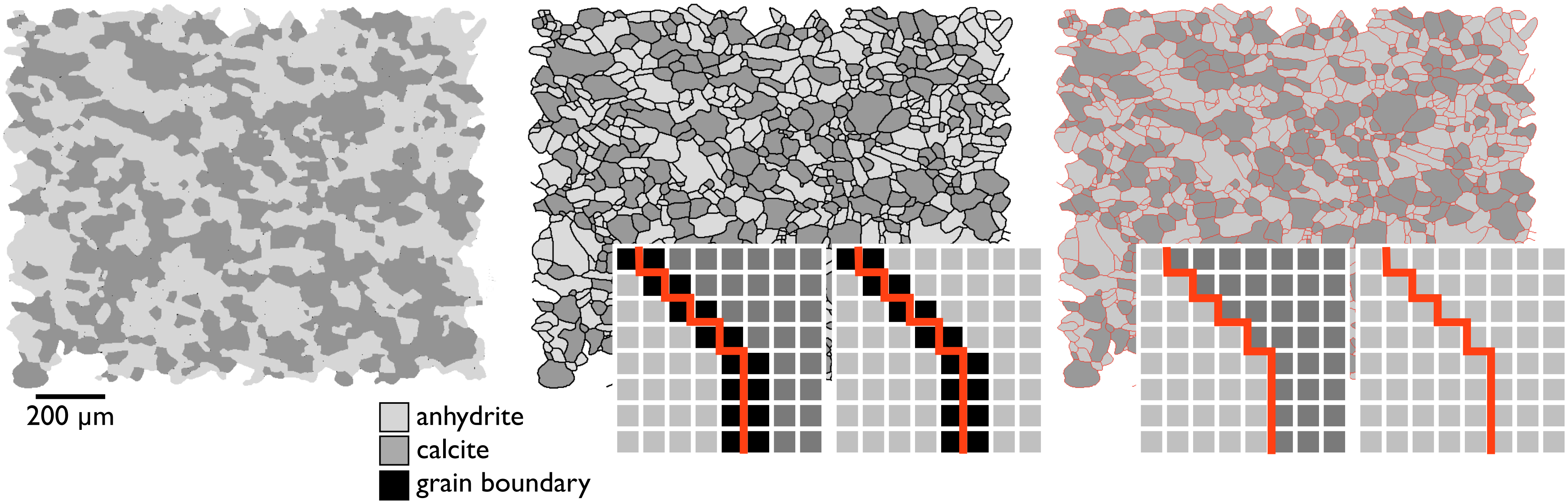
segment boundary

segment boundary

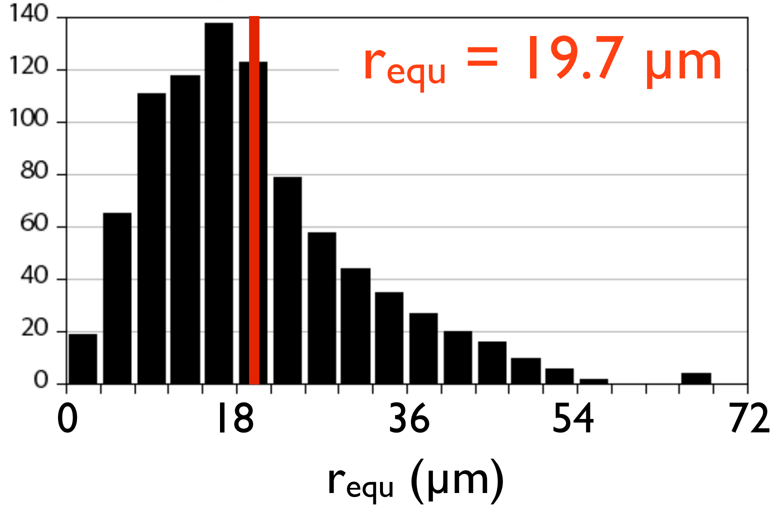
segment vs. grain boundaries

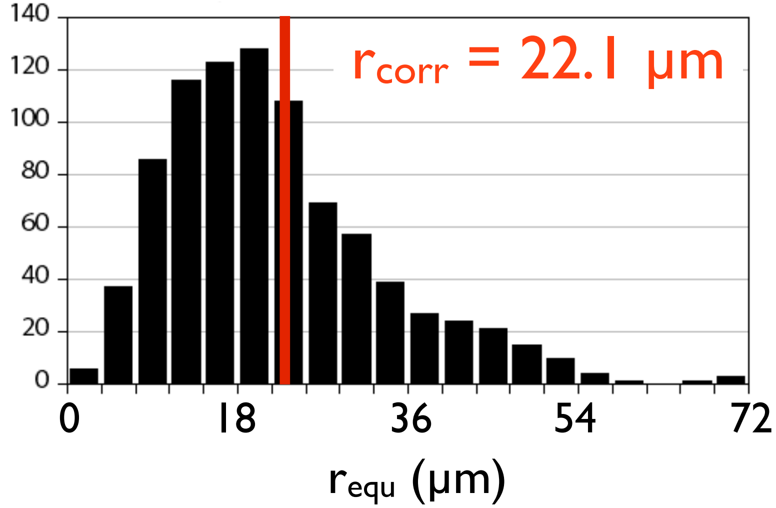
phase map

grain map



calcite + anhydrite

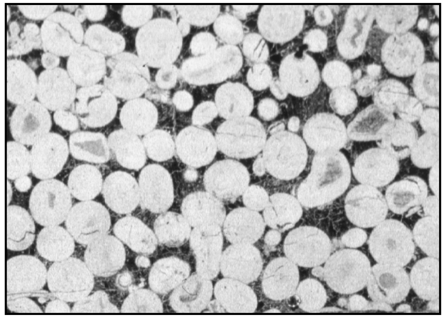


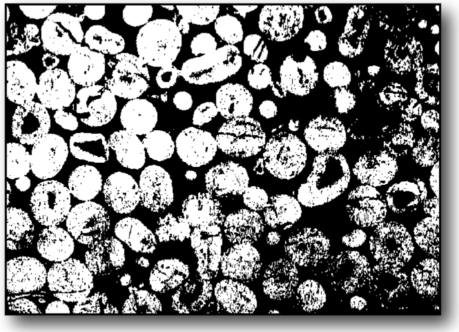


segmentation techniques

pixel based (grey value based)

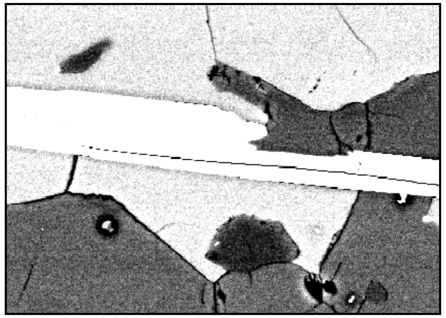
- thresholding, grey level slicing, histogram based

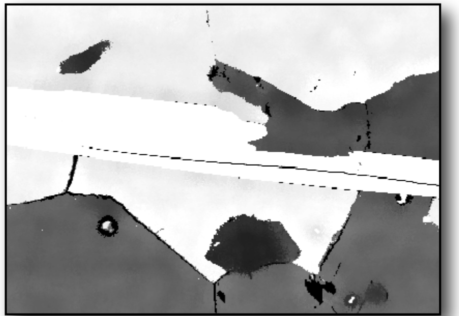




region based

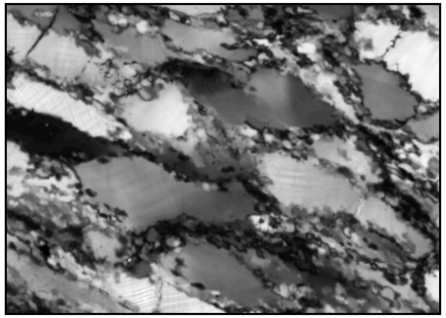
- statistical region growing, seeded, unseeded

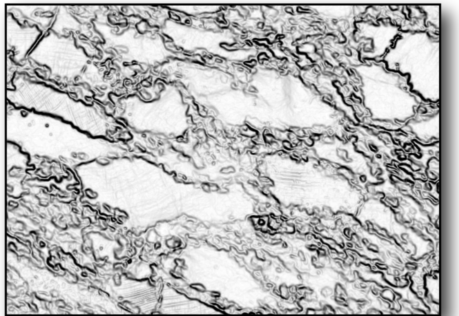




edge based

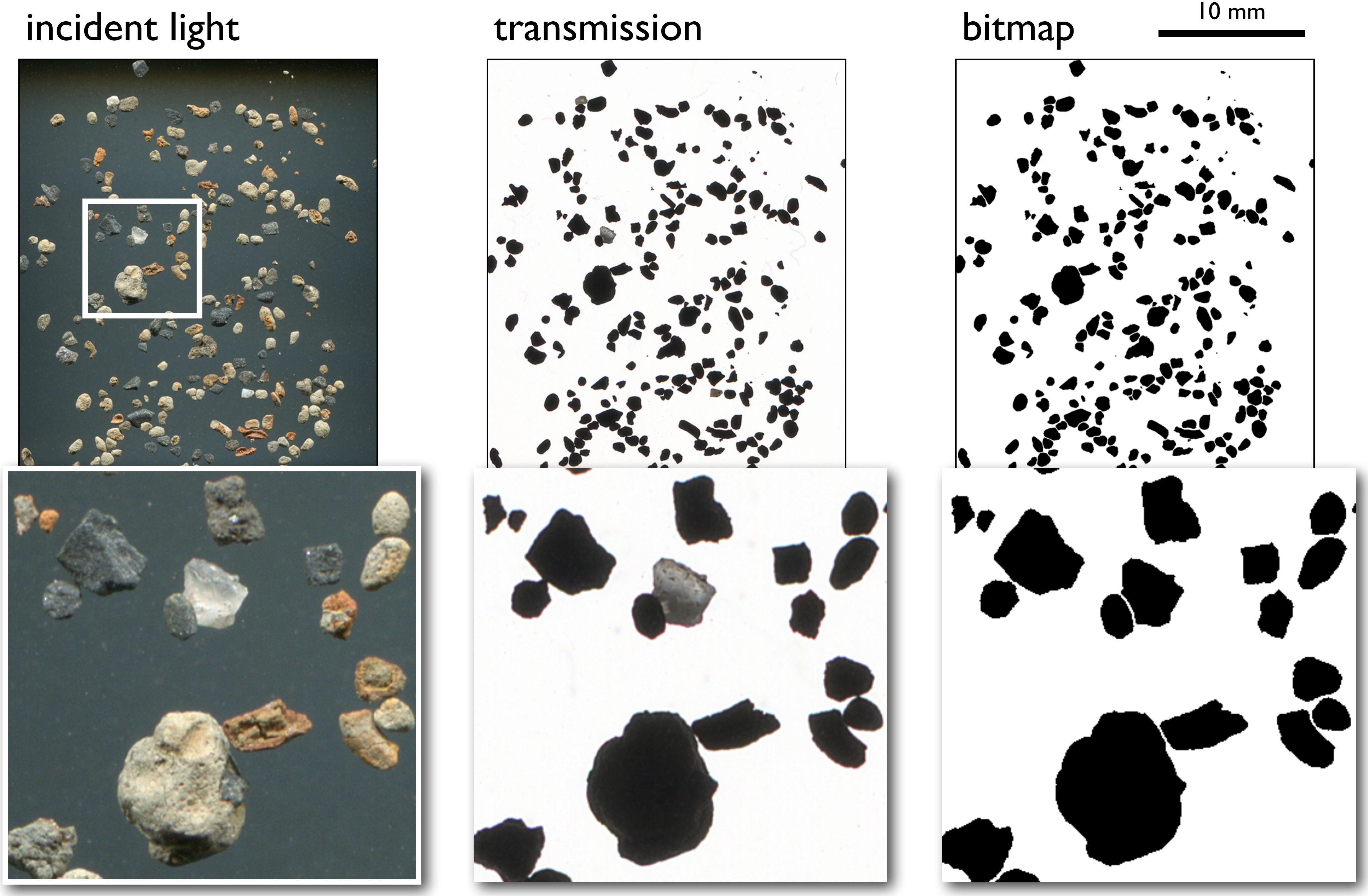
- Sobel filter, Laplace filter





... and many others ...

easy segmentation on scanner

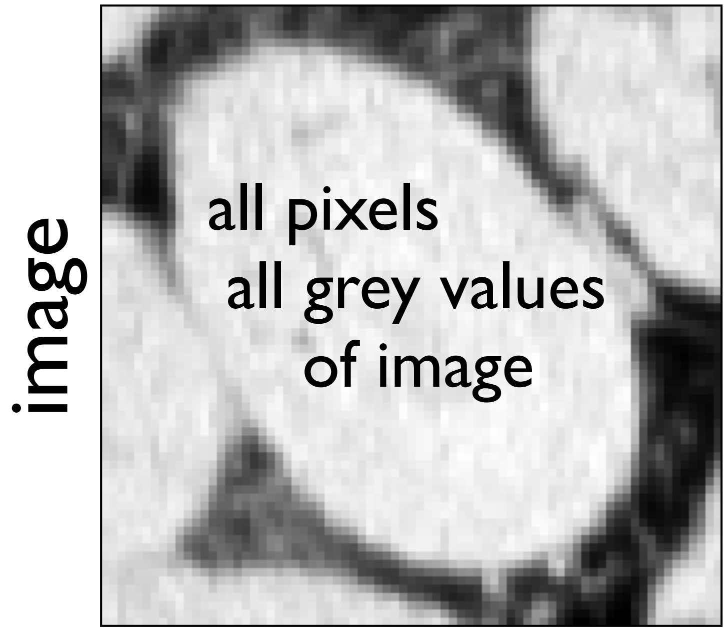


3

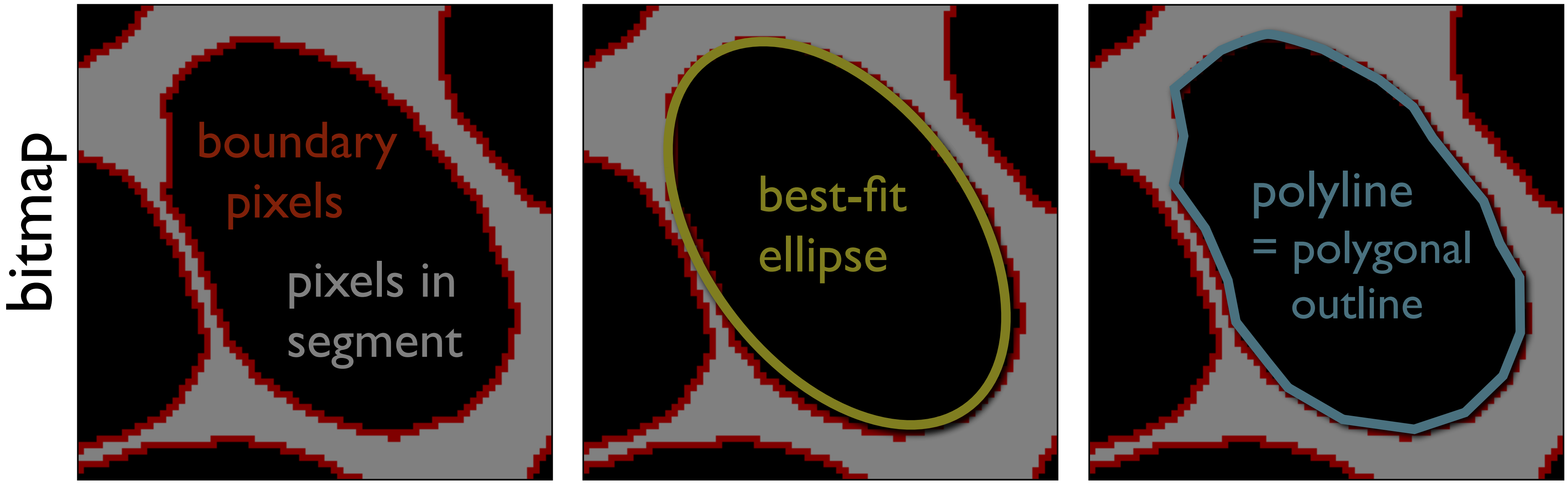
'direct' shape...

...later

analysis of image 'as-is'

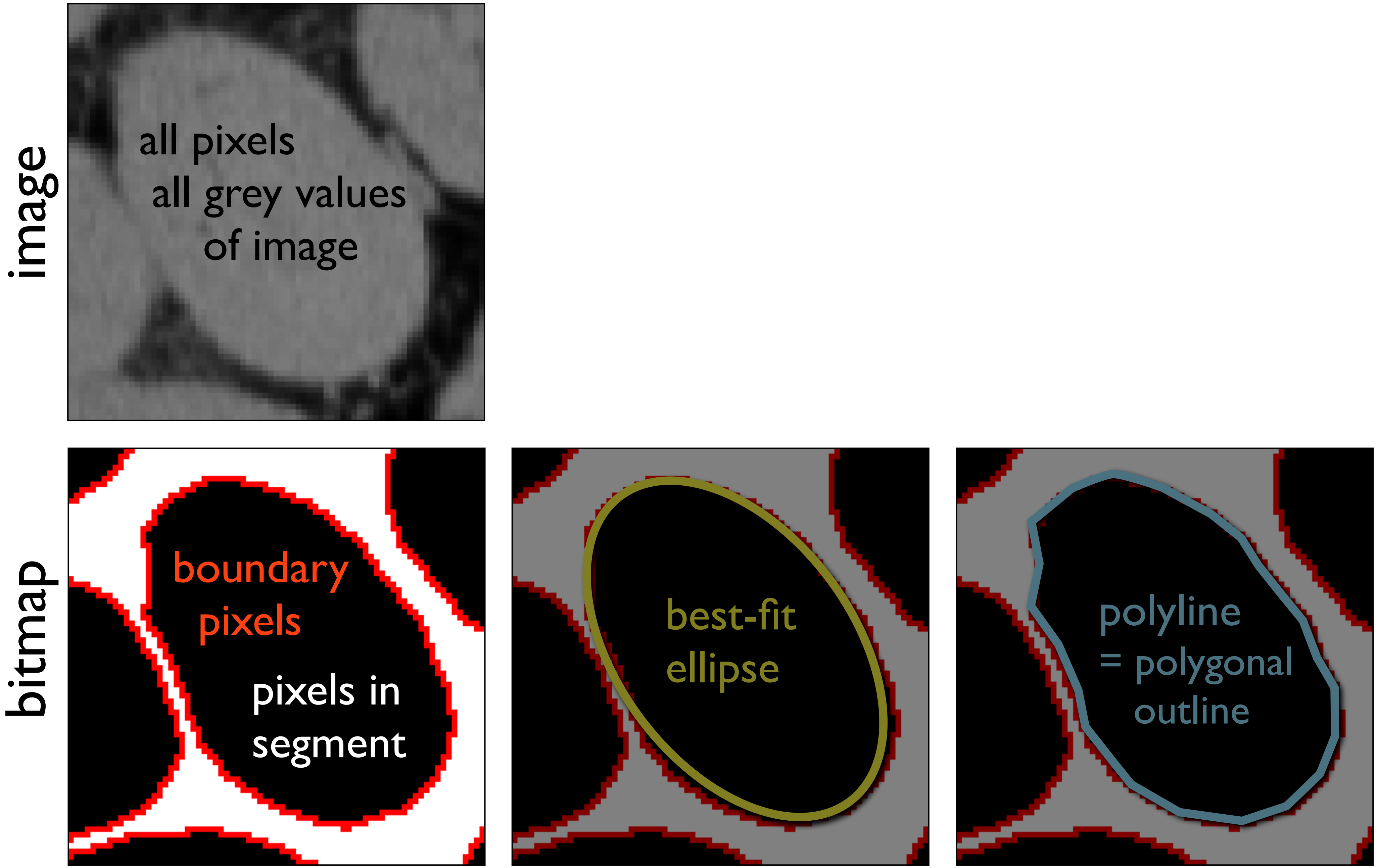


see (3) phase distributions



4
shape of segments

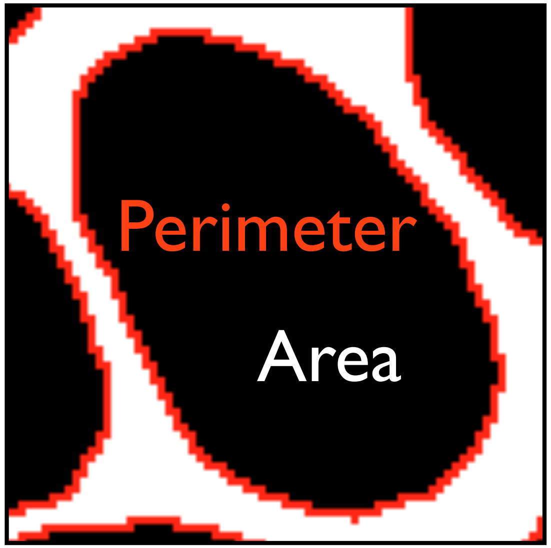
analysis of segments



using segments:

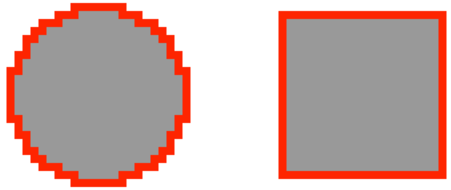
- size
- re-directed sampling
- shape factor

segment - region of connected pixels

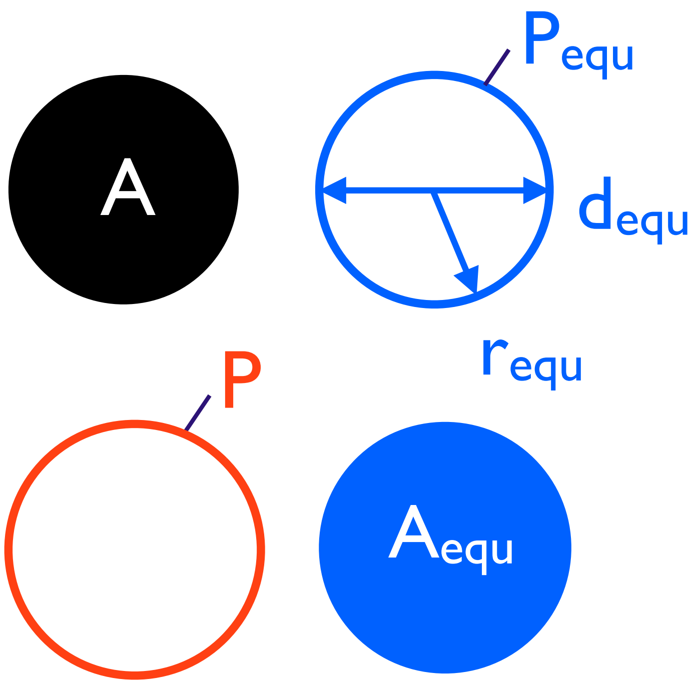


Area = number of pixels

Perimeter
from boundary pixels



number of boundary pixels:	88 px	88 px
length of perimeter:	69.11 px	88 px



area equivalent circle

r_{equ} (area equivalent radius) $= \sqrt{(A / \pi)}$

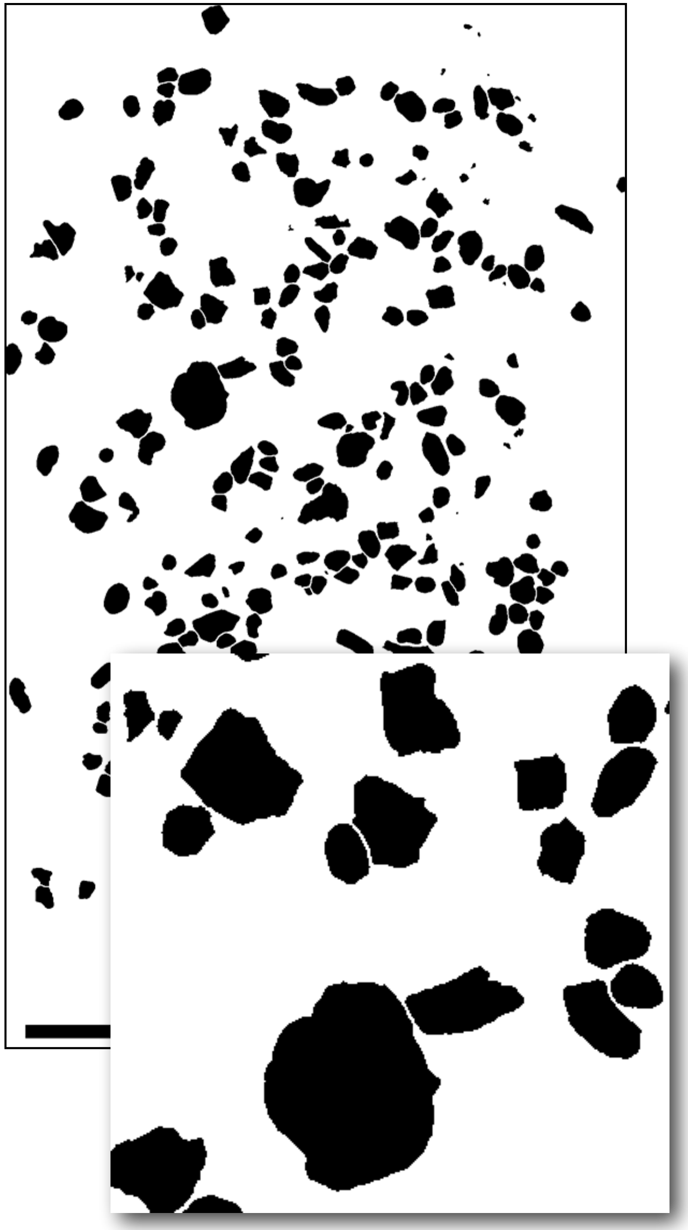
d_{equ} (area equivalent diameter) $= 2 \cdot \sqrt{(A / \pi)}$

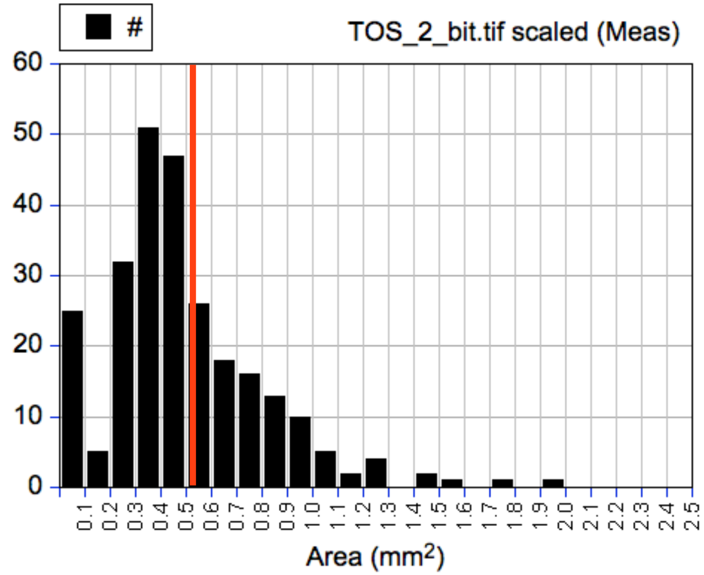
P_{equ} (area equivalent perimeter) $= 2 \cdot \sqrt{(\pi \cdot A)}$

perimeter equivalent circle

A_{equ} (perimeter equivalent area) $= P^2 / 4\pi$

size of segments

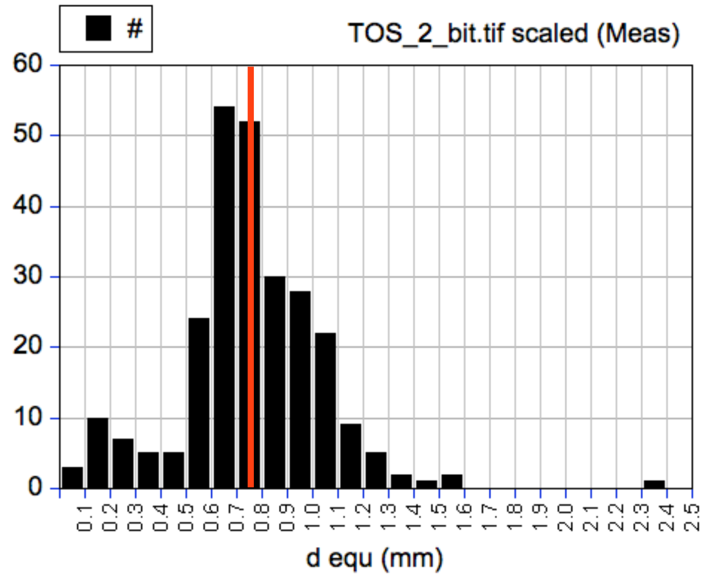




size distribution
by area

mean A = 0.525 mm^2

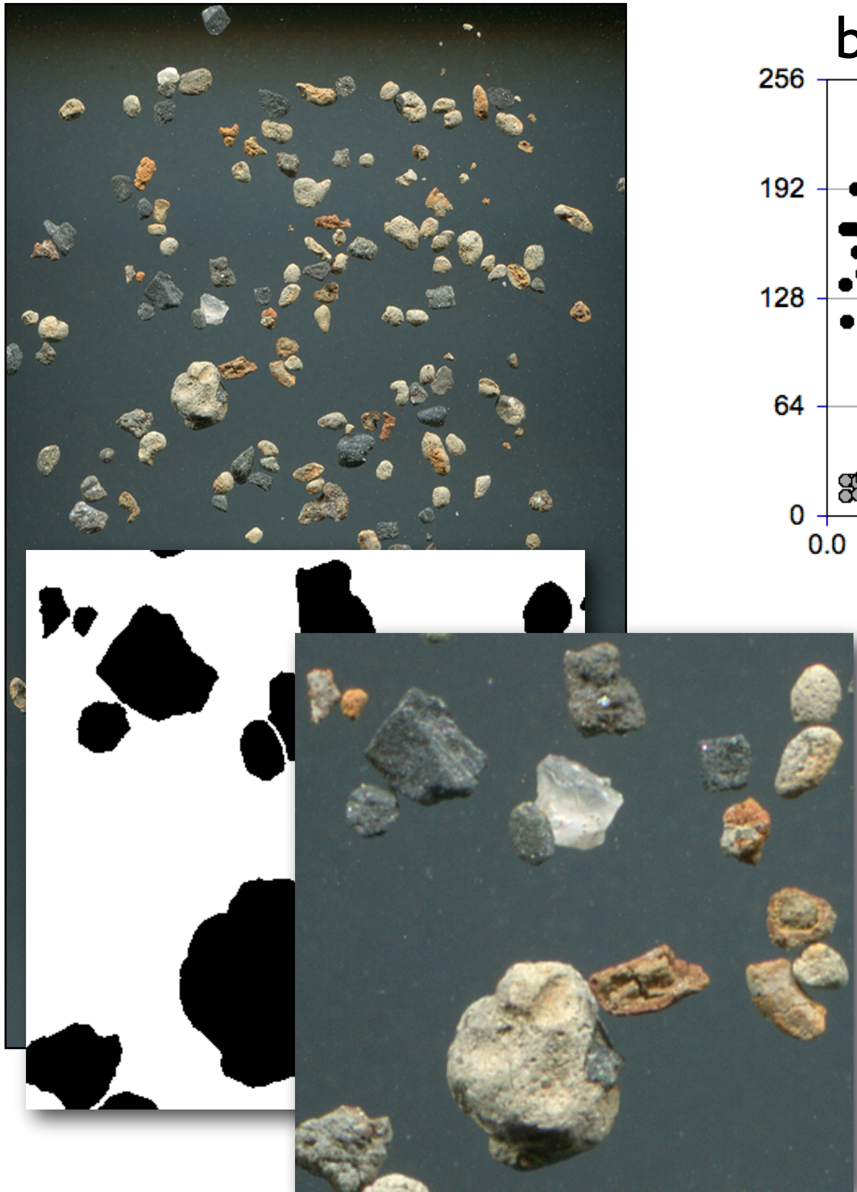
⇒ mean d_{equ} = 0.41 mm



size distribution
by diameter of area
equivalent circle

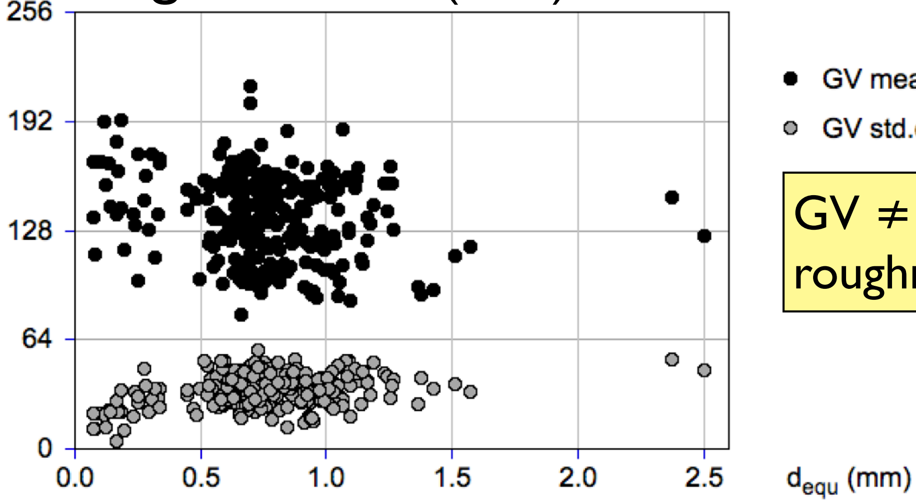
mean d_{equ} = 0.76 mm

brightness - roughness



re-direct analysis from bitmap to original

brightness as f(size)

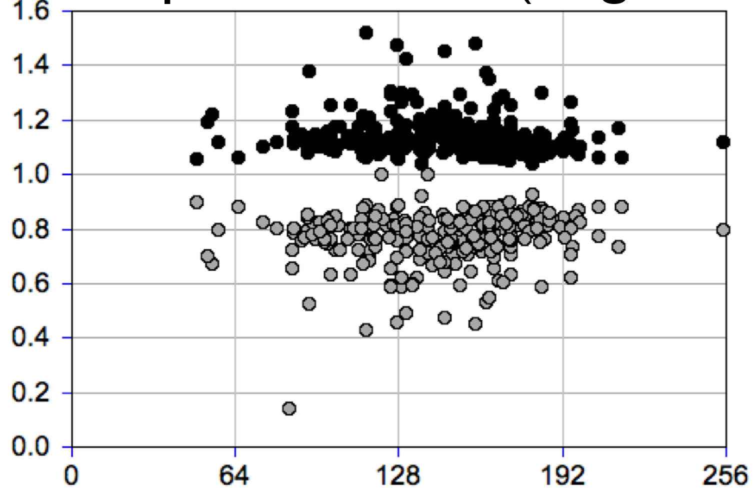


● GV mean

○ GV std.dev

GV $\neq$ f(d_{equ})
roughness $\neq$ f(d_{equ})

shape factors as f(brightness)



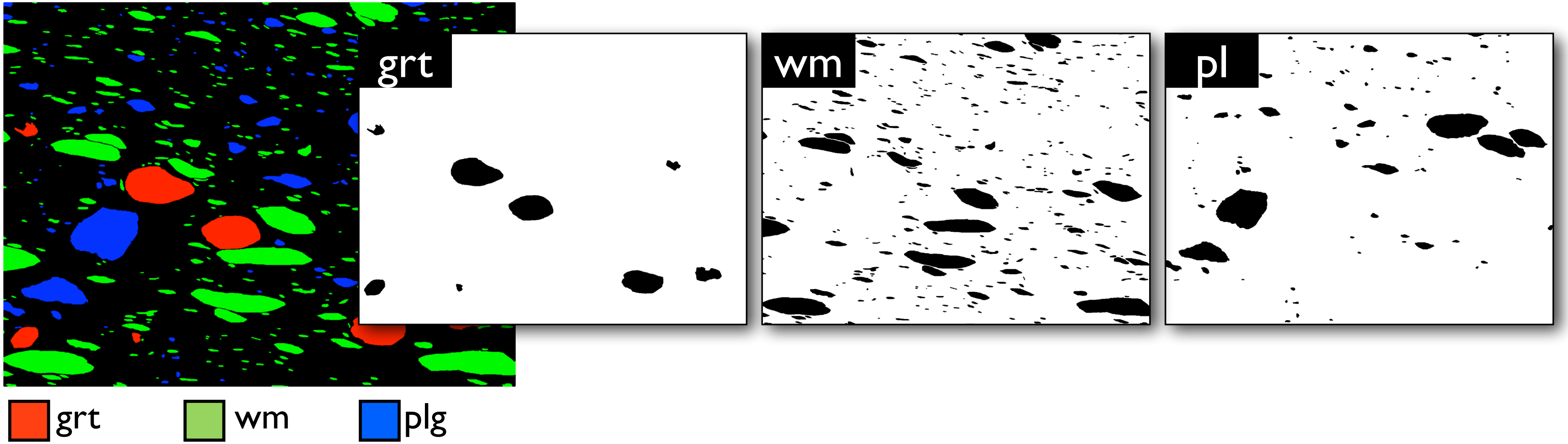
GV mode

● SF1 = P/Pequ

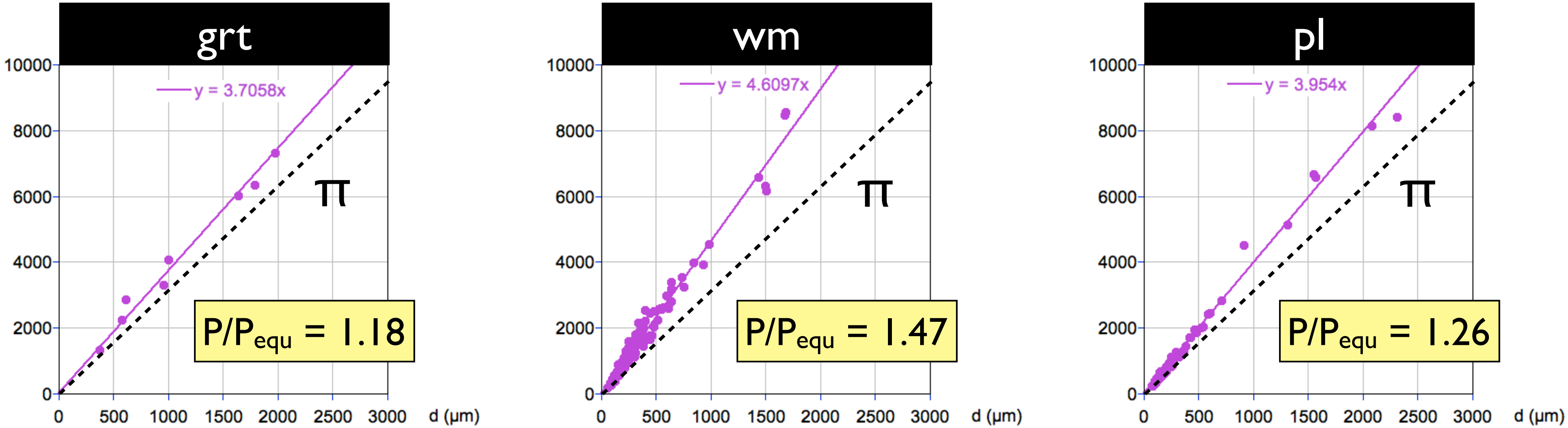
○ SF2 = A/Aequ

$P/P_{equ} \neq$ f(GV)
$A/A_{equ} \neq$ f(GV)

shape factor

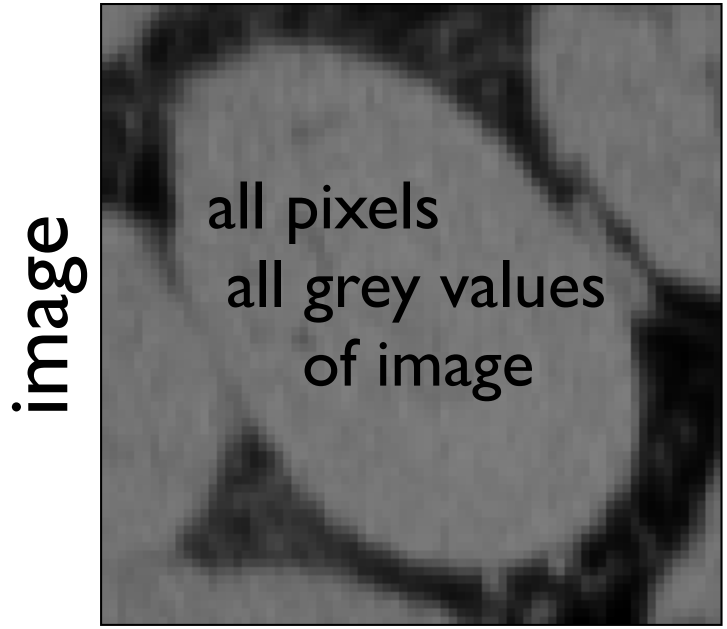


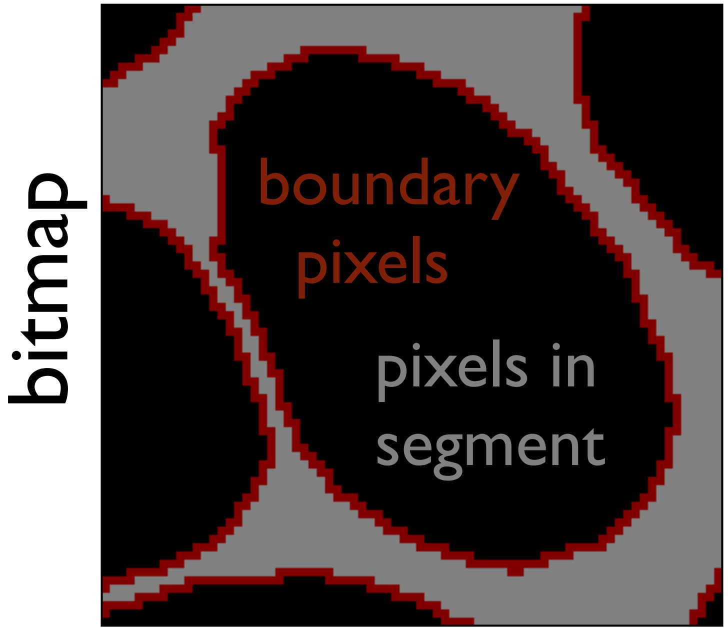
Perimeter vs. equivalent diameter

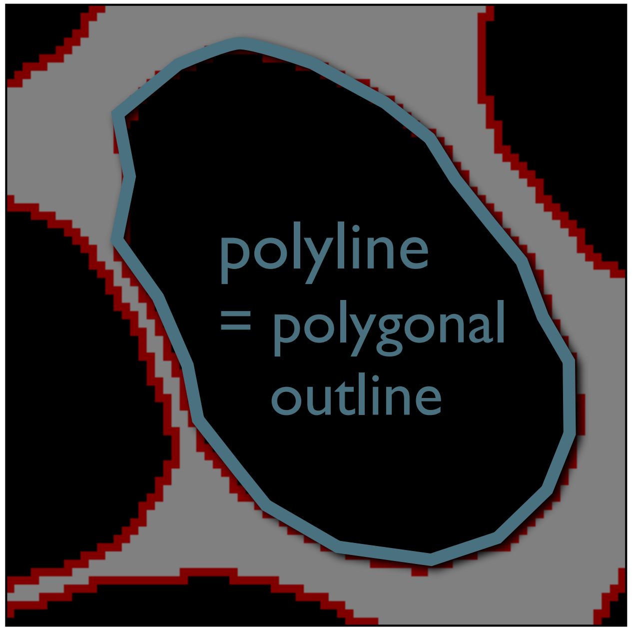


5
shape via fit ellipses

types of image analysis



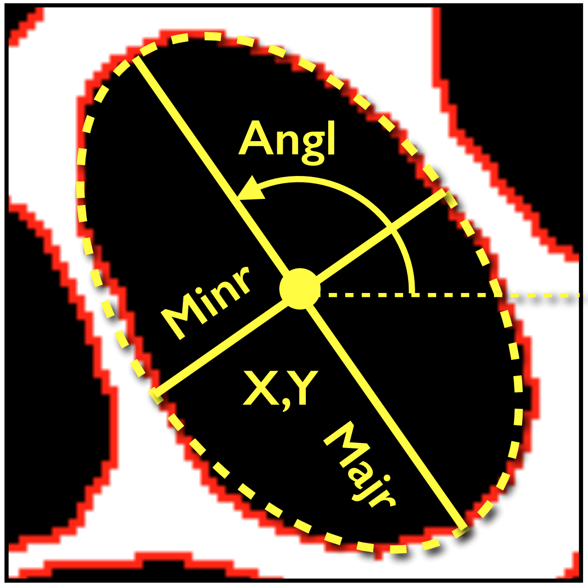




using best fit ellipses:

- aspect ratio, axial ratio
- orientation
- Rf-Phi

analysis using best fit ellipse



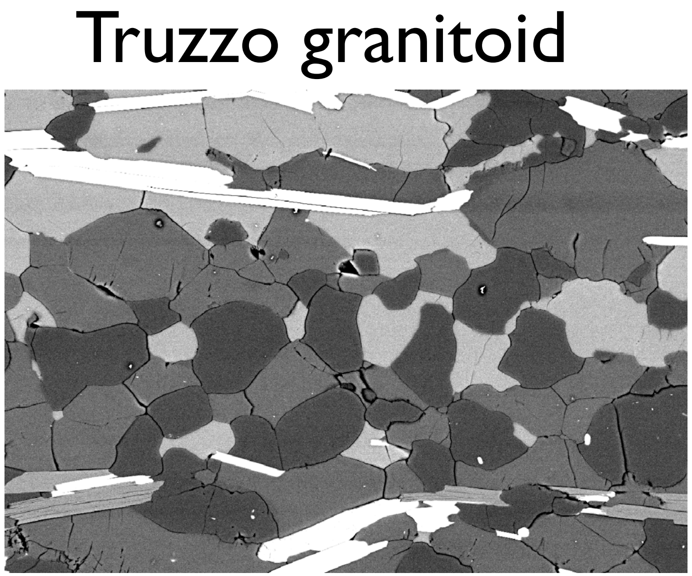
ellipse.p (NIH Image 1.62)
principal component analysis

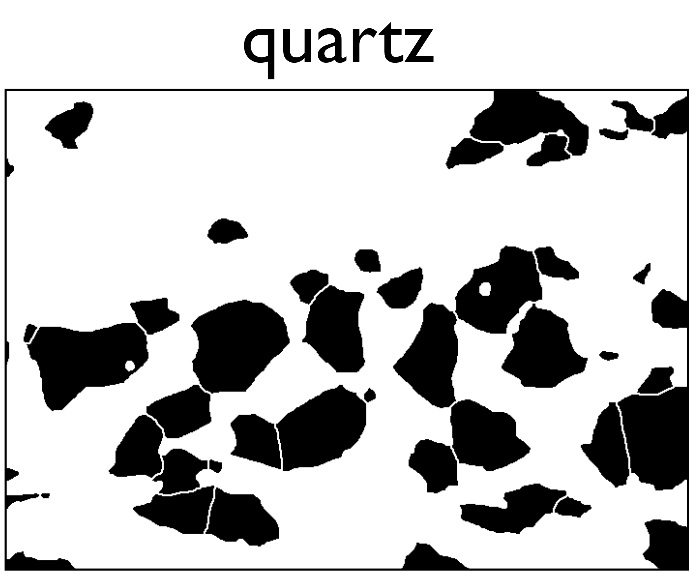
Best-fitting ellipse routines:
Bob Rodieck
Dep. of Ophthalmology
Univ. of Washington

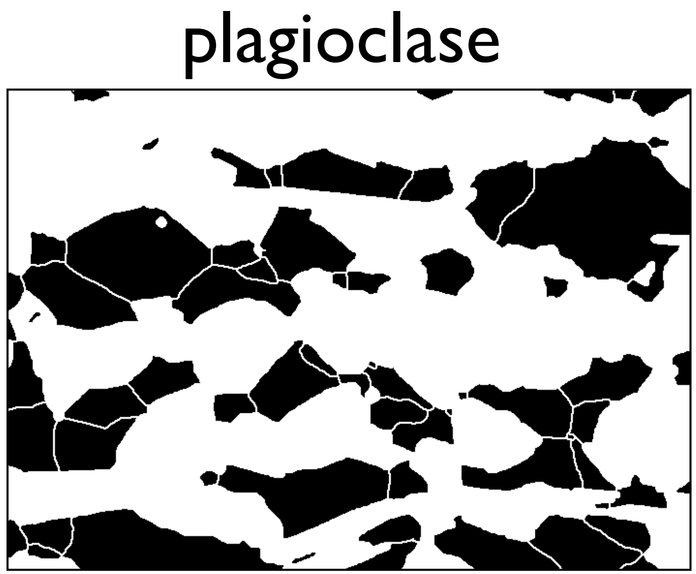
	best fit ellipse	units: (real / real)
Majr = a	long diameter of best fit ellipse = 2a	
	un-scaled / scaled	px / mm, µm, etc.
Minr = b	short diameter of best fit ellipse = 2b	
	un-scaled / scaled	px / mm, µm, etc.
Angl = φ	orientation of long diameter	° CCLW from pos. x-axis
X	X coordinate of center of gravity	
	un-scaled / scaled	px / mm, µm, etc.
Y	Y coordinate of center of gravity	
	un-scaled / scaled	px / mm, µm, etc.

measures (a, b, φ) are usually distributed

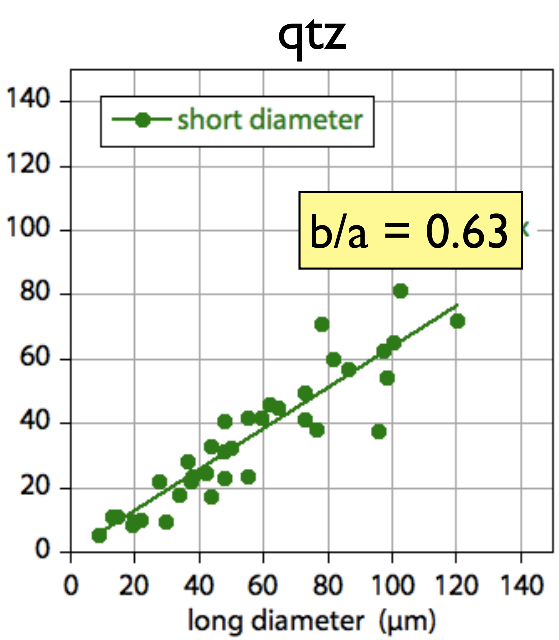
axial ratio

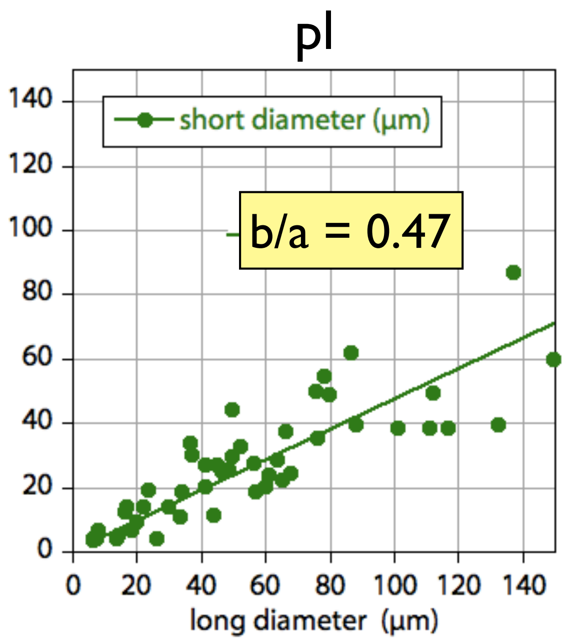




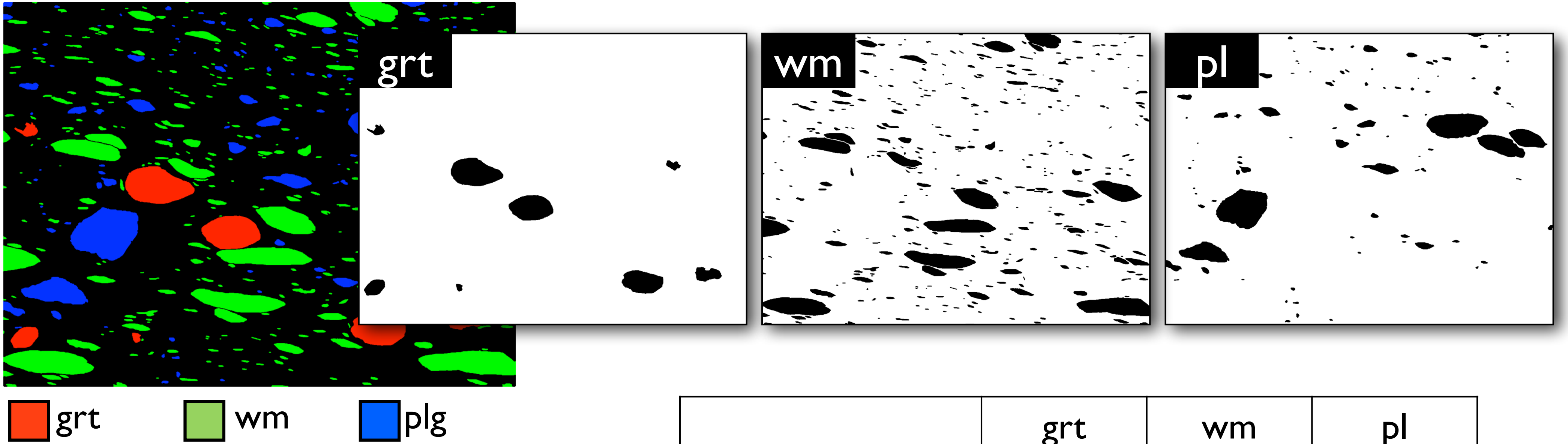


best fit ellipse:
short diameter
as f(long diameter)
b = f(a), slope = b/a



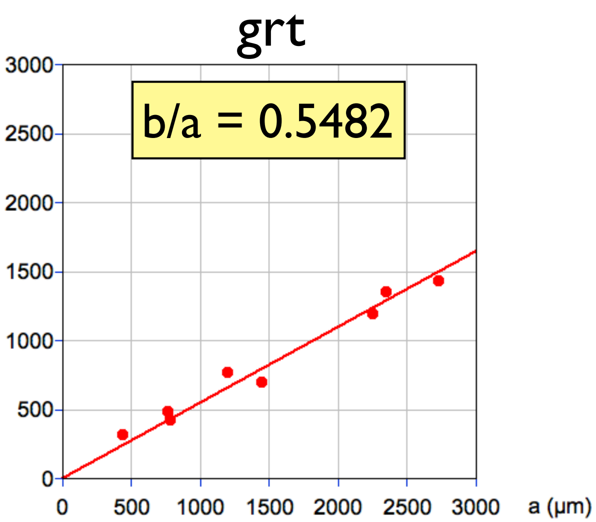


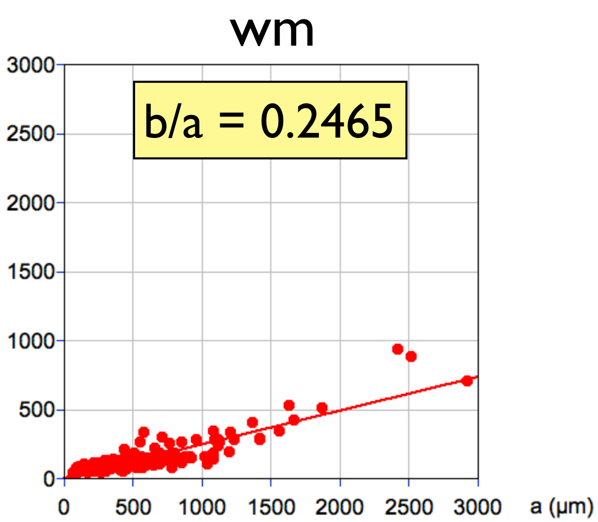
axial ratio

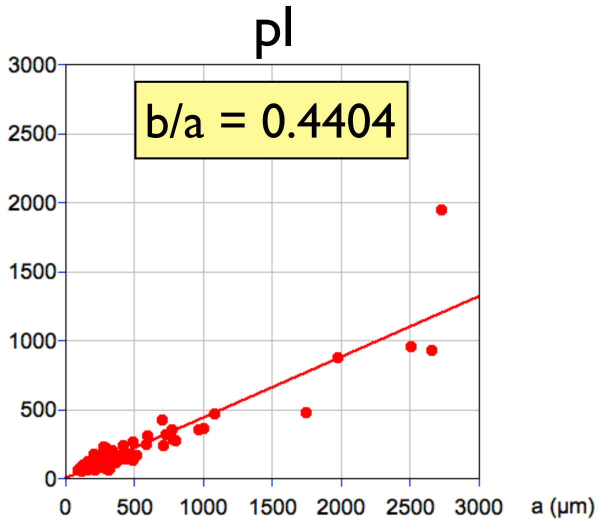


short axis vs. long axis

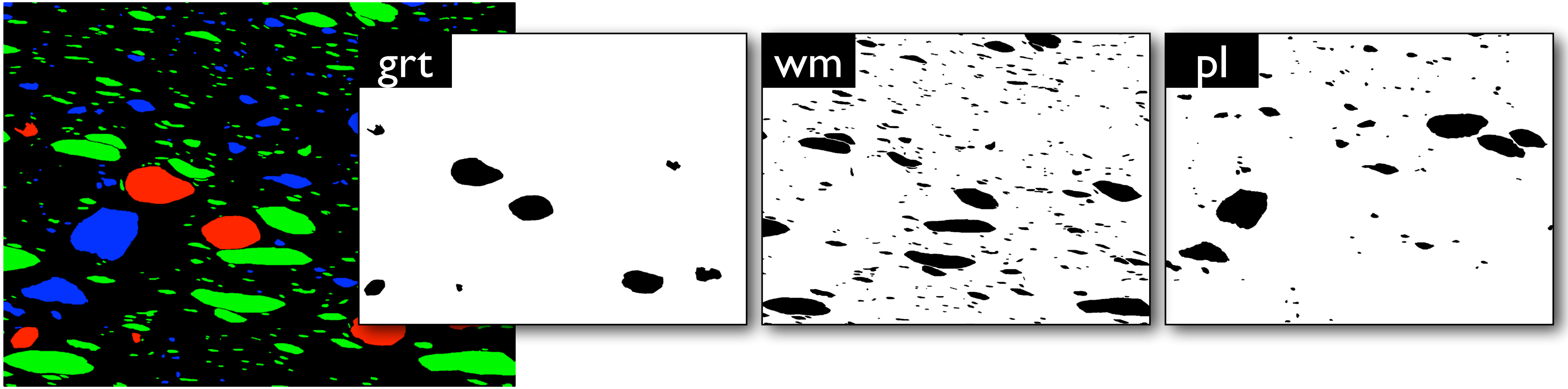
	grt	wm	pl
average b/a	0.59	0.32	0.49
mean(b) / mean(a)	0.56	0.27	0.45



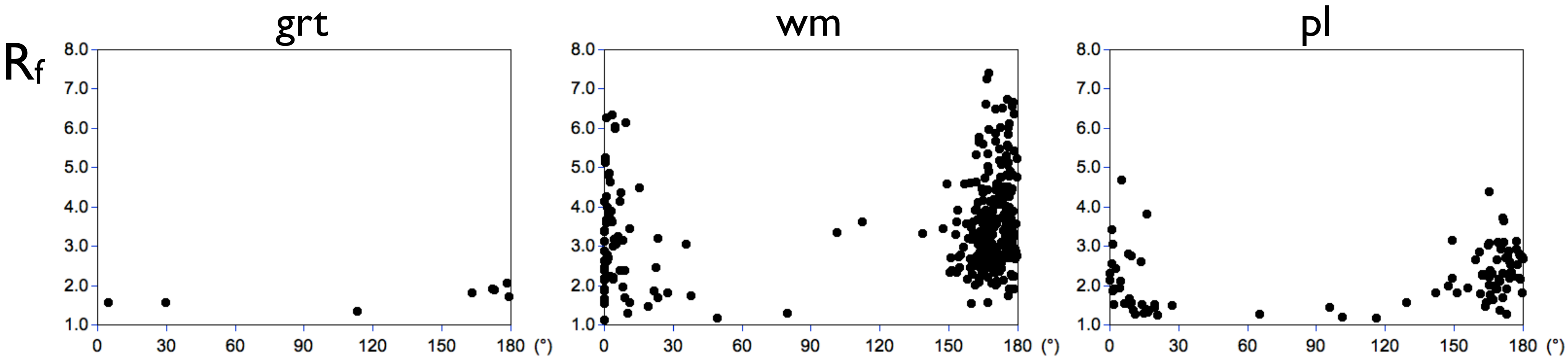




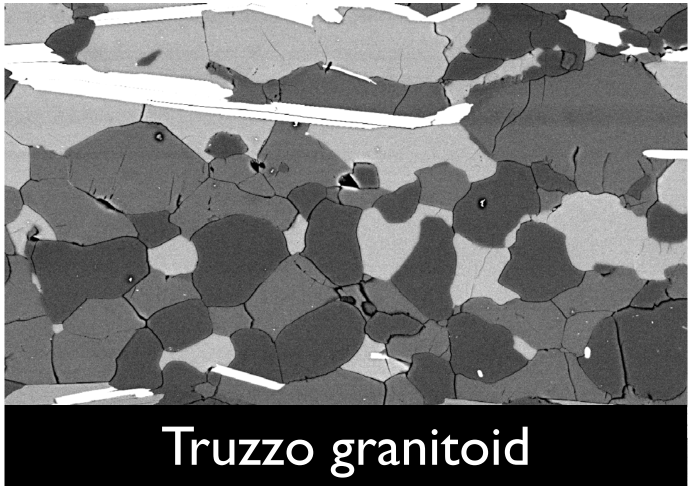
R_f /φ diagrams

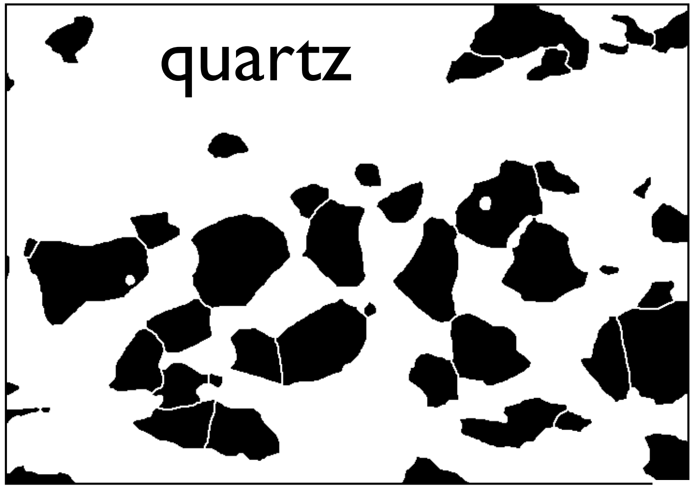


best fit ellipse:
aspect ratio, R_f, versus angle of orientation, φ

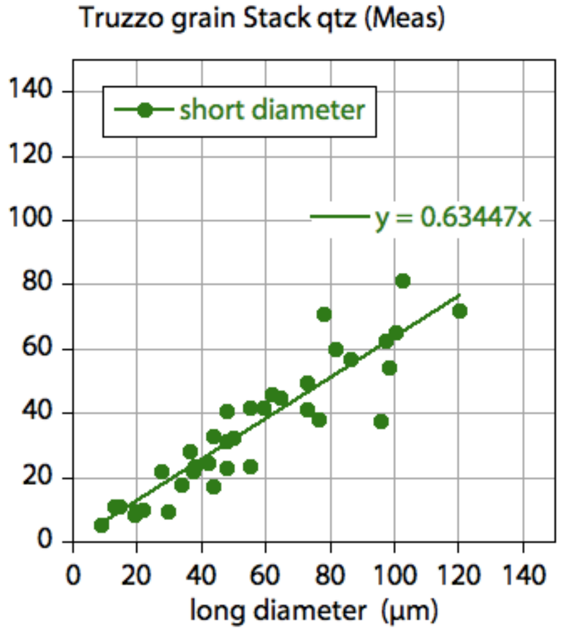


'the' average axial ratio ... ?

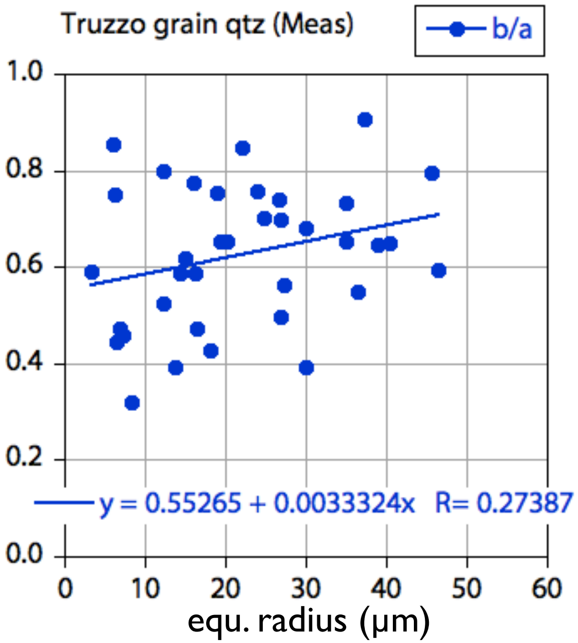




best fit ellipse:
short diameter
as f(long diameter)
b = f(a)
slope = b/a



	b/a
Minimum	0.31836
Maximum	0.90761
Sum	22.533
Points	36
Mean	0.62592
Median	0.64718
RMS	0.64225
Std Deviation	0.14593
Variance	0.021296
Std Error	0.024322
Skewness	-0.1501
Kurtosis	-0.75244



slope b(a)= 0.634

mean (b/a) = 0.626

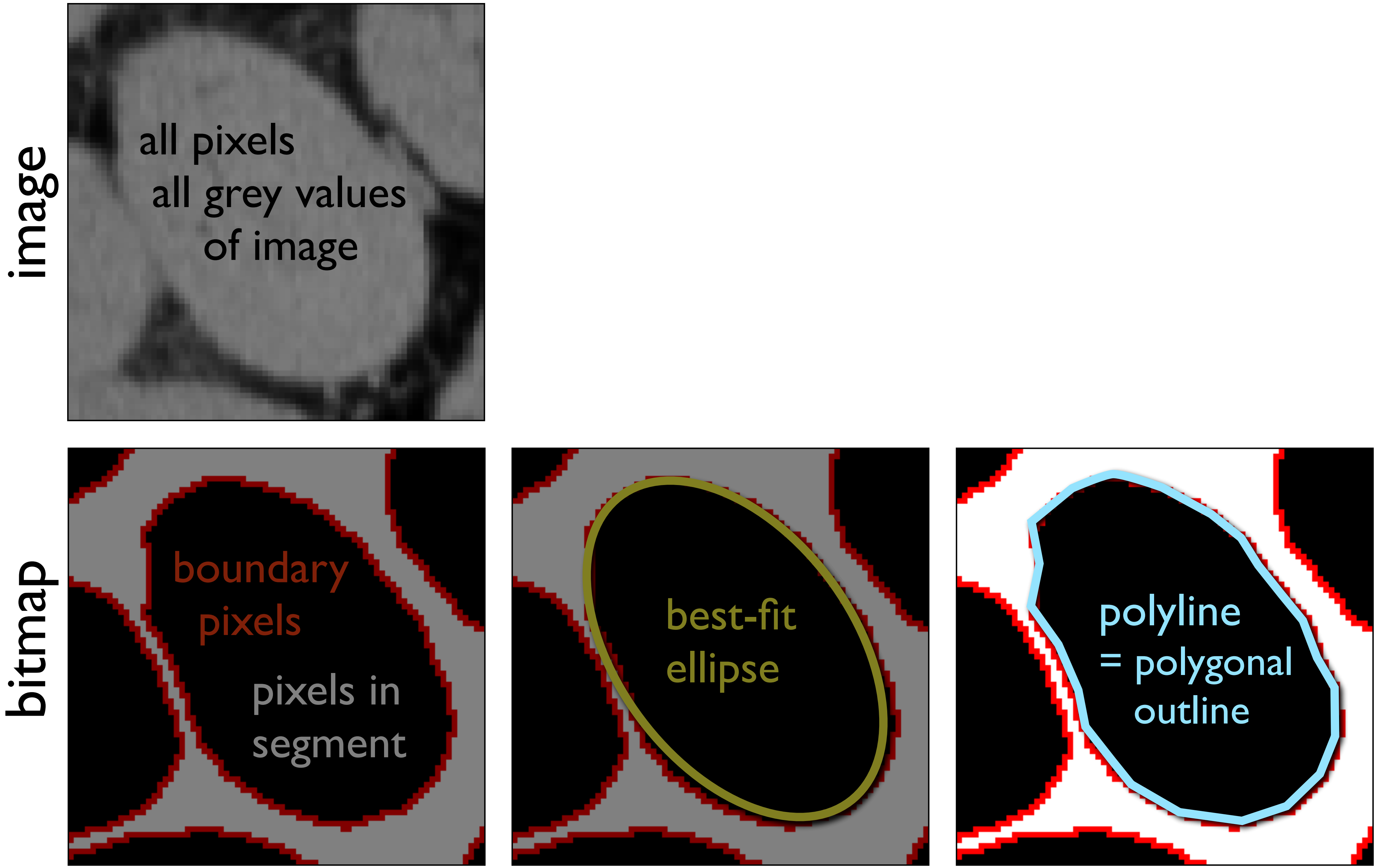
(b/a) = f(size)

6
shape of outlines

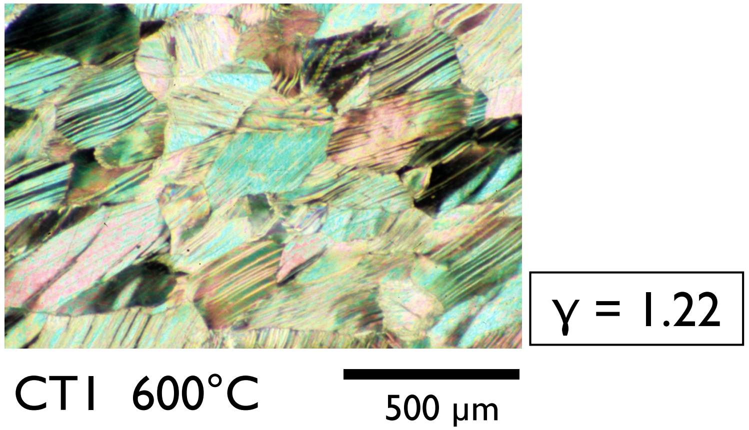
using outlines:

- PAROR particle fabrics
- SURFOR surface fabrics
- shape descriptors

analysis of segments

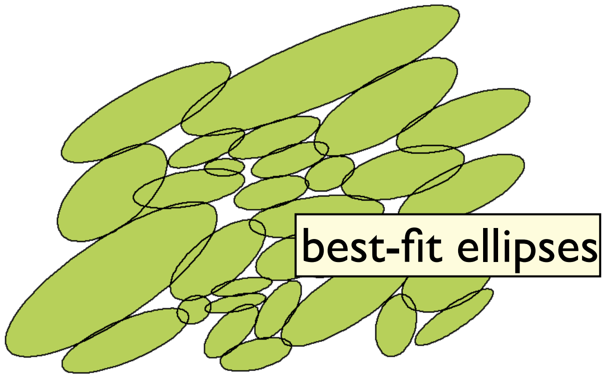


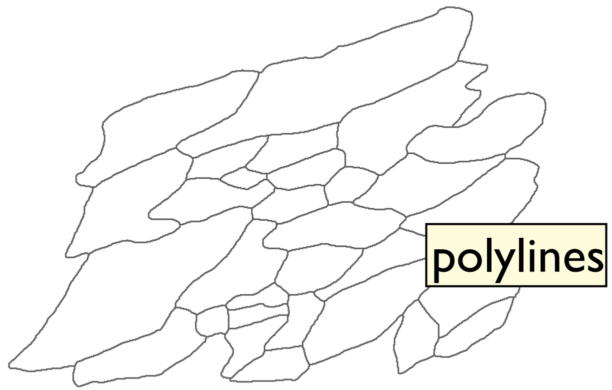
how to measure strain



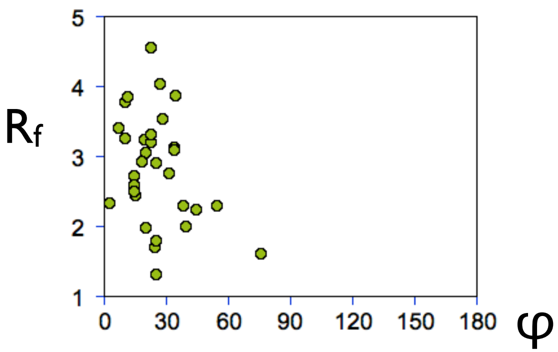
CT1 600°C

analysis of
... area and outline
... segment and segment boundary

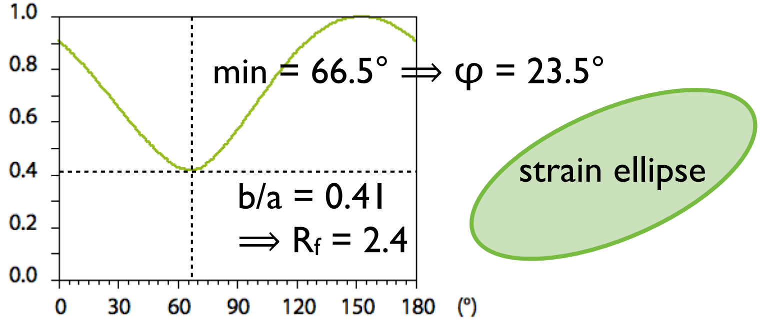




aspect ratio vs. orientation

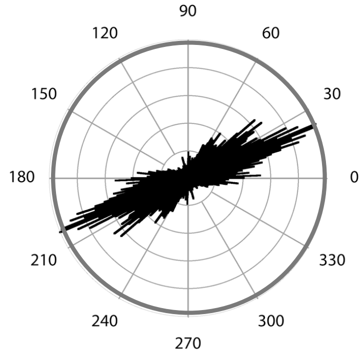


projection of particles



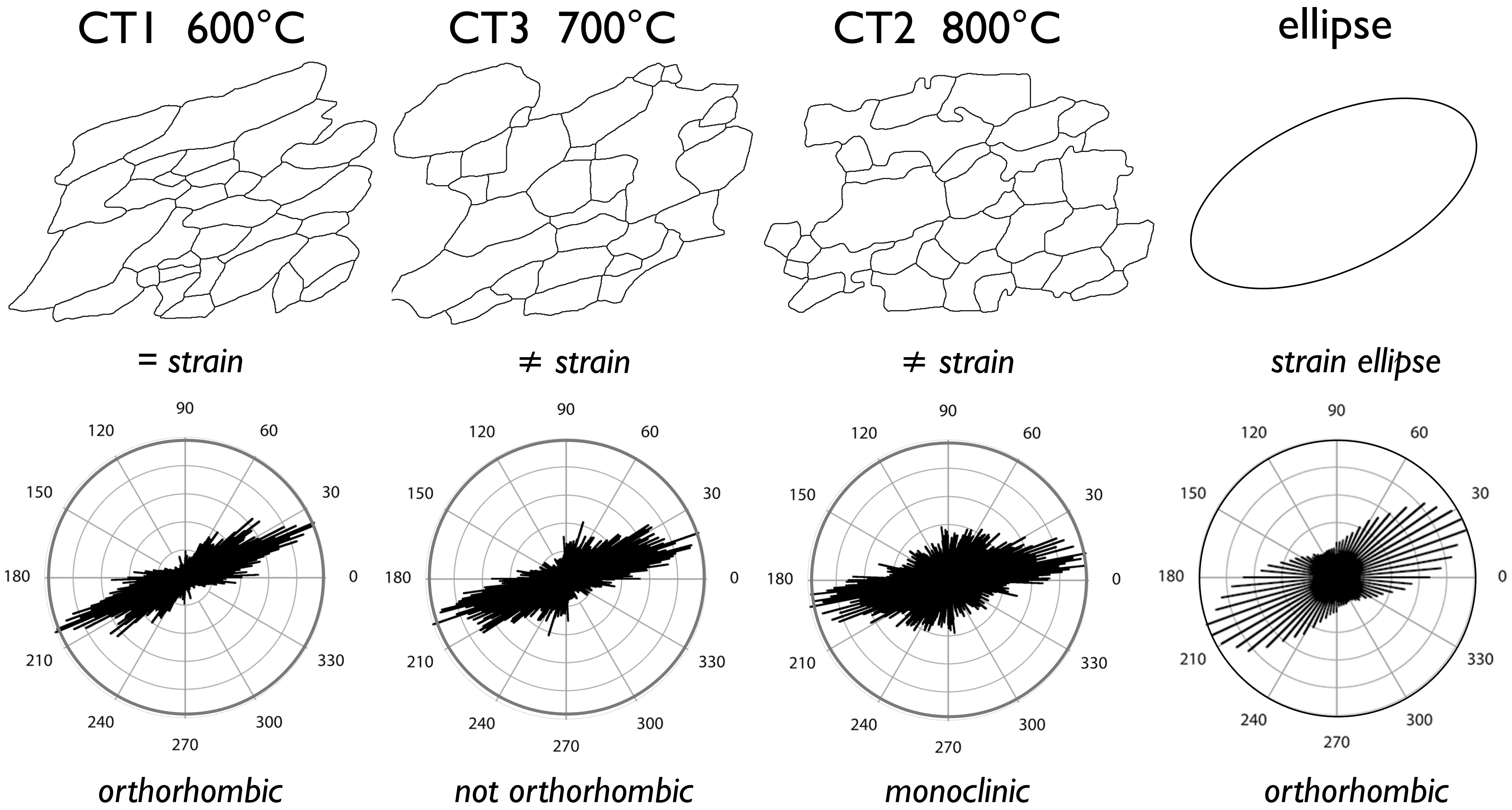
paror

orientation of outlines



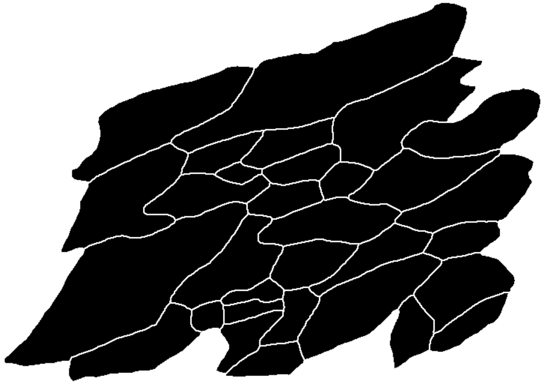
surfor

strain test

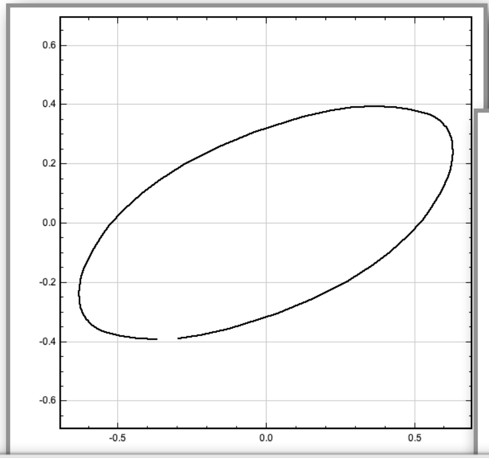


if grain boundaries are strain markers
⇒ surface ODF has orthorhombic symmetry

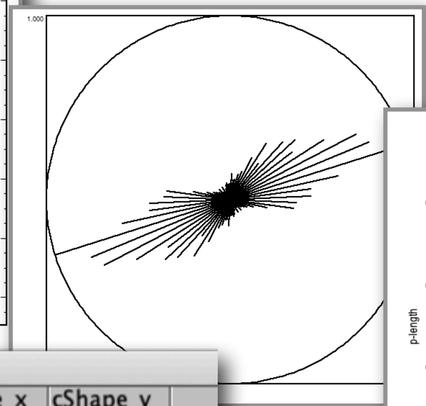
surfer (Jazy surfor)



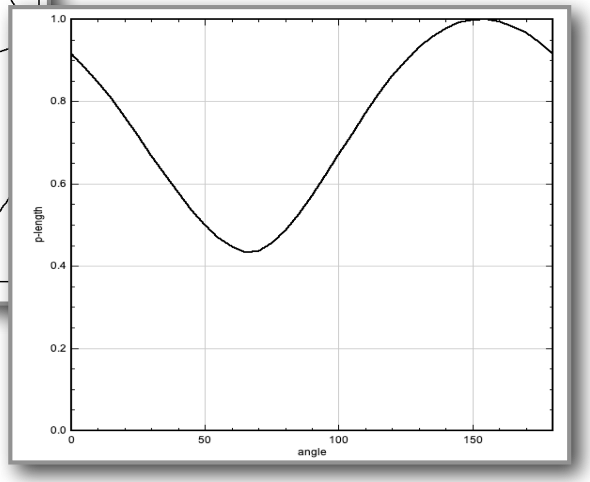
characteristic shape



rose diagram



projection curve A(α)

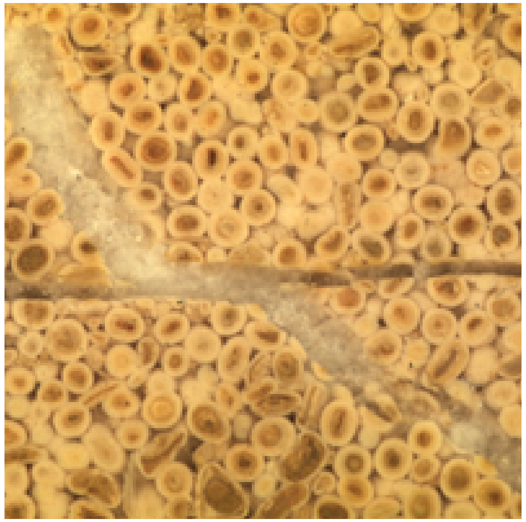


Results

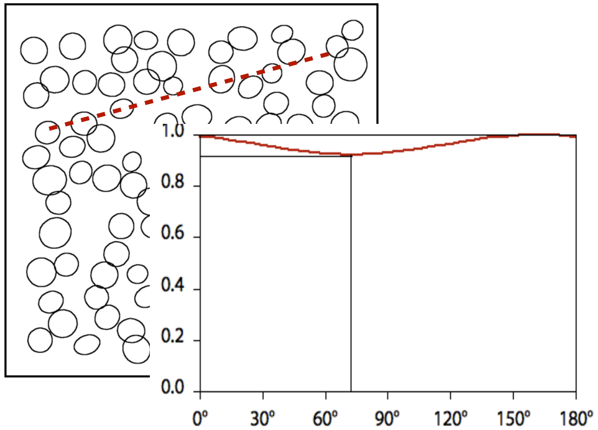
	projAngle	relProjLength	rose_x	rose_y	azi	rho	cShape_x	cShape_y
1	0.000	0.916	0.438	0.438	0.044	0.438	-0.296	-0.390
2	5.000	0.884	0.000	0.000	0.131	0.442	-0.296	-0.390
3	10.000	0.847	0.438	0.438	0.218	0.601	-0.222	-0.380
4	15.000	0.806	0.000	0.000	0.305	1.000	-0.222	-0.380
5	20.000	0.762	0.587	0.587	0.393	0.816	-0.124	-0.358
6	25.000	0.716	0.000	0.000	0.480	0.771	-0.124	-0.358
7	30.000	0.669	0.954	0.954	0.567	0.601	0.037	-0.307
8	35.000	0.622	0.000	0.000	0.654	0.424	0.037	-0.307
9	40.000	0.578	0.754	0.754	0.742	0.479	0.163	-0.255
10	45.000	0.535	0.000	0.000	0.829	0.422	0.163	-0.255
11	50.000	0.500	0.684	0.684	0.916	0.248	0.278	-0.195
12	55.000	0.470	0.000	0.000	1.004	0.360	0.278	-0.195
13	60.000	0.447	0.507	0.507	1.091	0.254	0.364	-0.141
14	65.000	0.434	0.000	0.000	1.178	0.165	0.364	-0.141
15	70.000	0.435	0.337	0.337	1.265	0.145	0.420	-0.097
16	75.000	0.454	0.000	0.000	1.353	0.112	0.420	-0.097
17	80.000	0.486	0.353	0.353	1.440	0.107	0.480	-0.043
18	85.000	0.525	0.000	0.000	1.527	0.140	0.480	-0.043
19	90.000	0.570	0.285	0.285	1.614	0.087	0.528	0.009
20	95.000	0.618	0.000	0.000	1.702	0.083	0.528	0.009
21	100.000	0.669	0.151	0.151	1.789	0.093	0.553	0.042

overall and local surface orientation

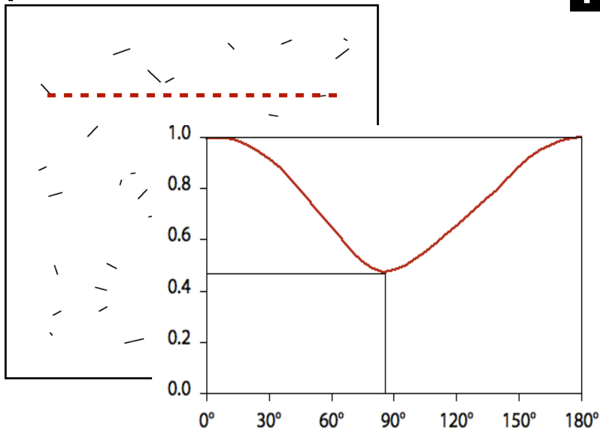
sedimentology



ooides



p.s. contacts

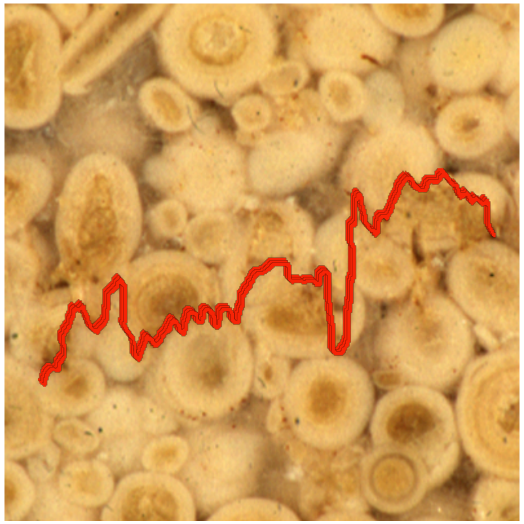


paror

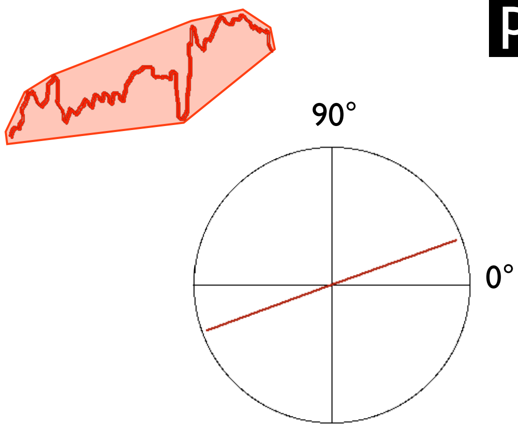
bulk orientation of ooides
⟹ crossbedding

bulk orientation of p.s.contacts
⟹ compaction direction

tectonics

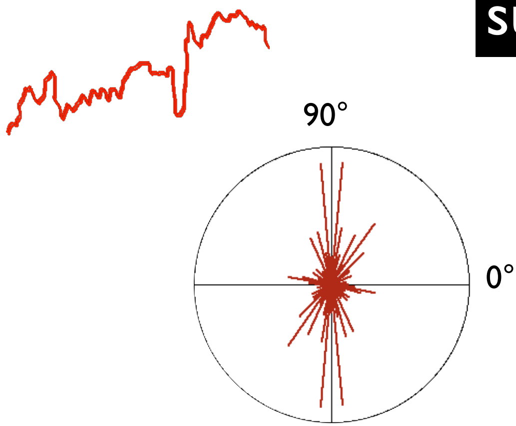


paror



overall orientation of stylolite
⟹ pre-existing fracture

surfor

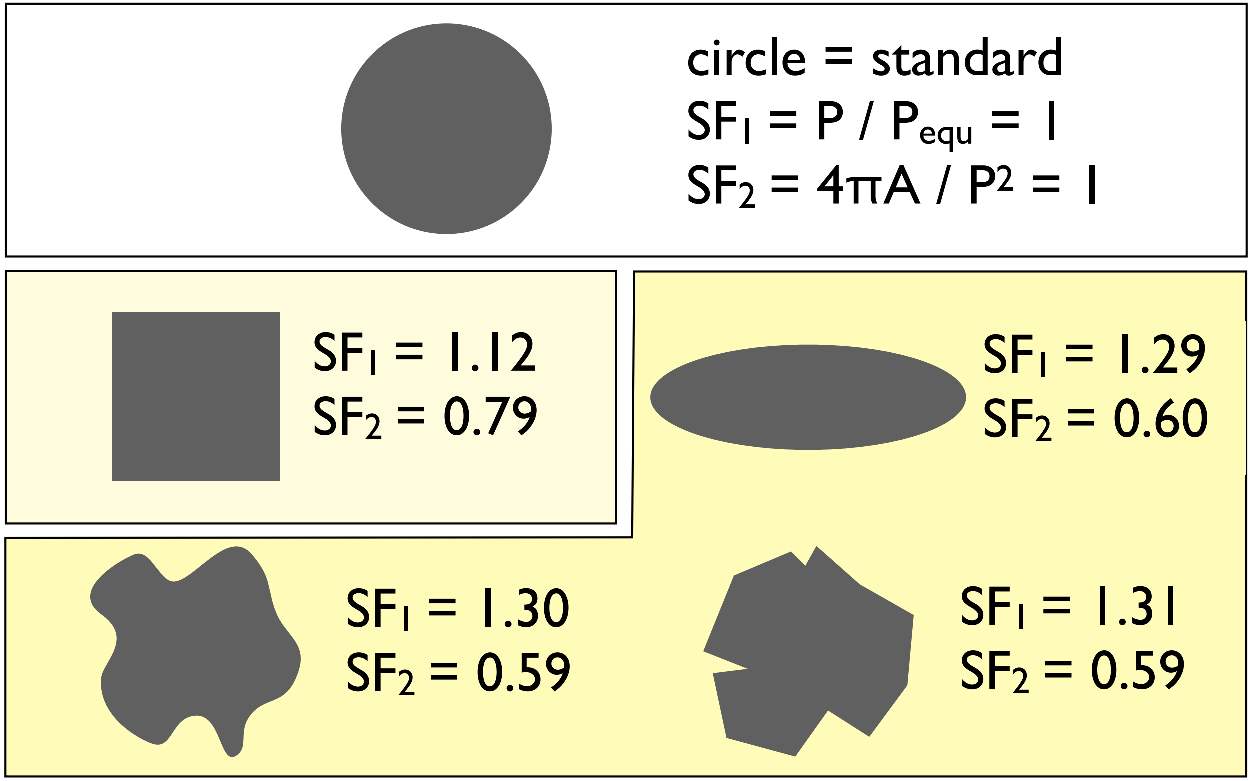


orientation of surface of rods
⟹ kinematic direction

quantifying shape:

- shape factors
- deltA, deltP (PARIS factor)

shape in relation to circle



shape factors:

SF1	perimeter ratio P / P_{equ}
SF2	area ratio $4\pi A / P^2$
A	measured area of shape
P	measured length of outline
P_{equ}	perimeter of area equivalent circle

circle:	isometric, fully convex, continuously curved
square:	isometric ($a / b = 1.00$), fully convex, angular
ellipse:	elongated ($a / b > 1.00$), fully convex, continuously curved
lobate shape:	isometric, convex-concave, continuously curved
angular fragment:	isometric, convex-concave, angular

shape descriptors in ImageJ

$$SF_1 = \frac{P}{P_{equ}} = \frac{P}{2\sqrt{\pi A}}$$

"Shape factor 1" (w/r to area equivalent circle)

$$a/b$$

"Aspect ratio"

$$SF_2 = \frac{A}{A_{equ}} = \frac{4\pi\ A}{P^2}$$

"Shape factor 2" "Circularity"

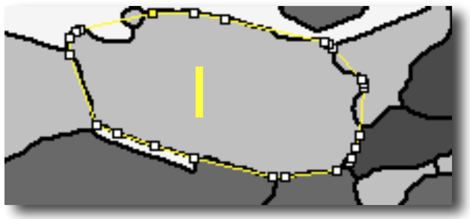
$$b/a = \frac{4A}{\pi \cdot a^2} = \frac{\pi\ ab}{\pi \cdot a^2}$$

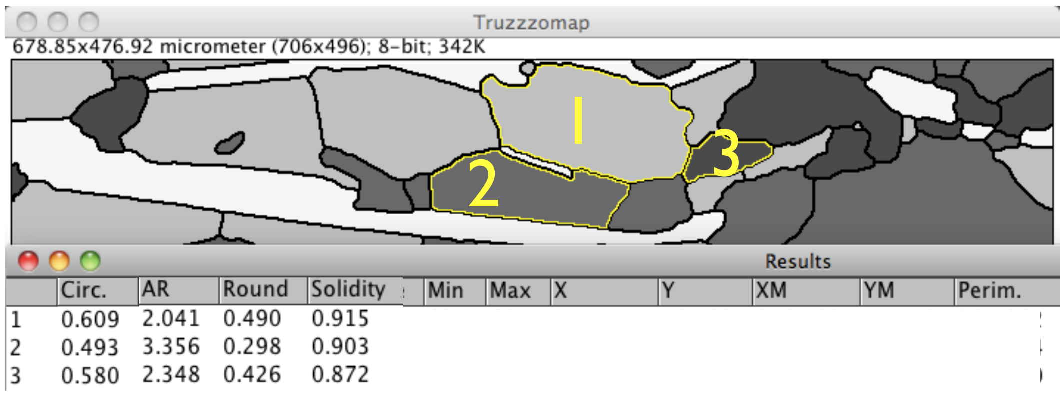
"Roundness" "Axial ratio"

$$A\ /\ A_{hull}$$

"Solidity"(w/r to convex hull)

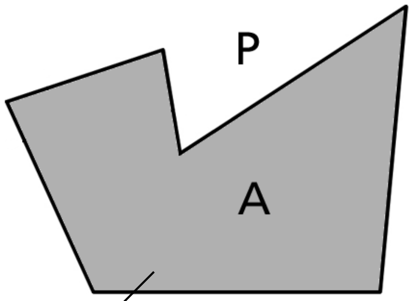
Edit > Selection > Convex Hull:





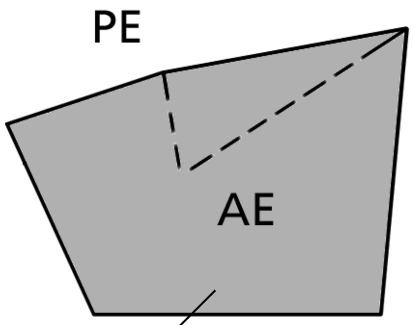
shape descriptors - shape factors

P (perimeter length)



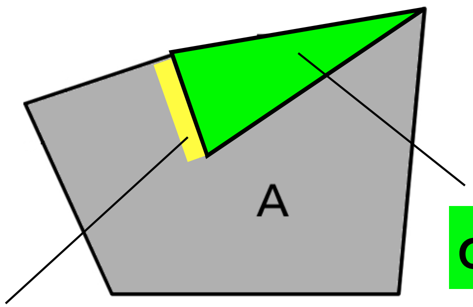
A (area)

PE (perimeter of envelope)



AE (area of envelope)

envelope: convex hull



deltA missing area

deltP excess perimeter

excess perimeter: deltP

$$\Delta P = P - PE \qquad (P \geq PE)$$

new!

$$\text{deltP (\%)} = \frac{\Delta P}{P} \cdot 100\%$$

$$\text{PARIS (\%)}^{1)} = \frac{2 \cdot \Delta P}{PE} \cdot 100\%$$

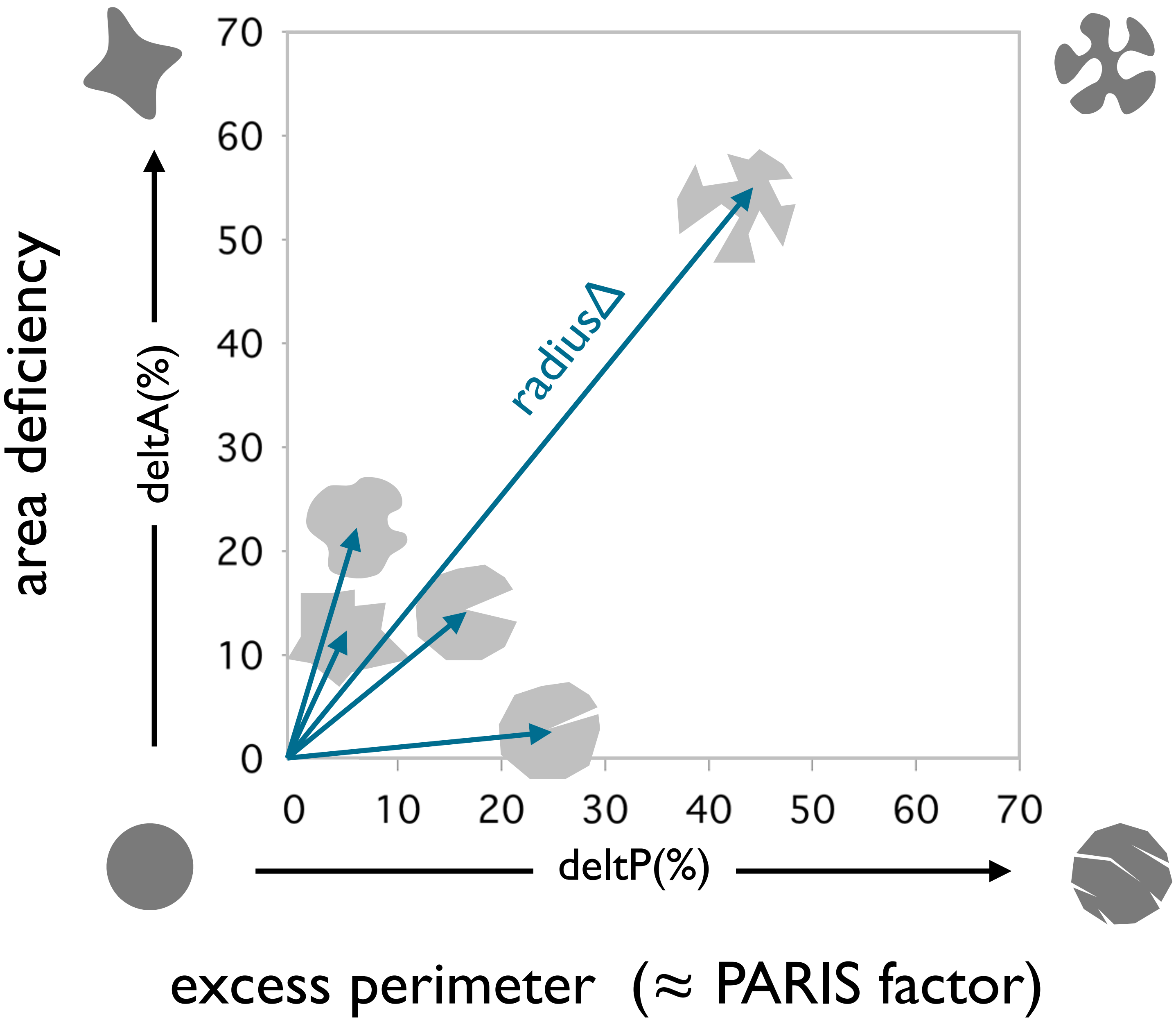
missing area: deltA

$$\Delta A = AE - A \qquad (A \leq AE)$$

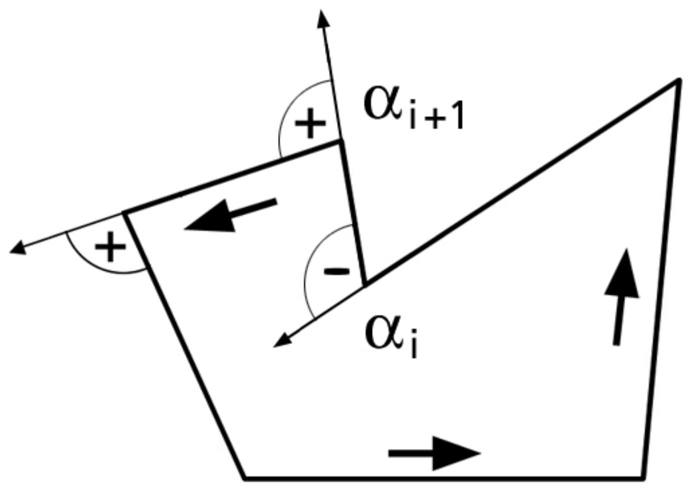
$$\text{deltA (\%)} = \frac{\Delta A}{A} \cdot 100\%$$

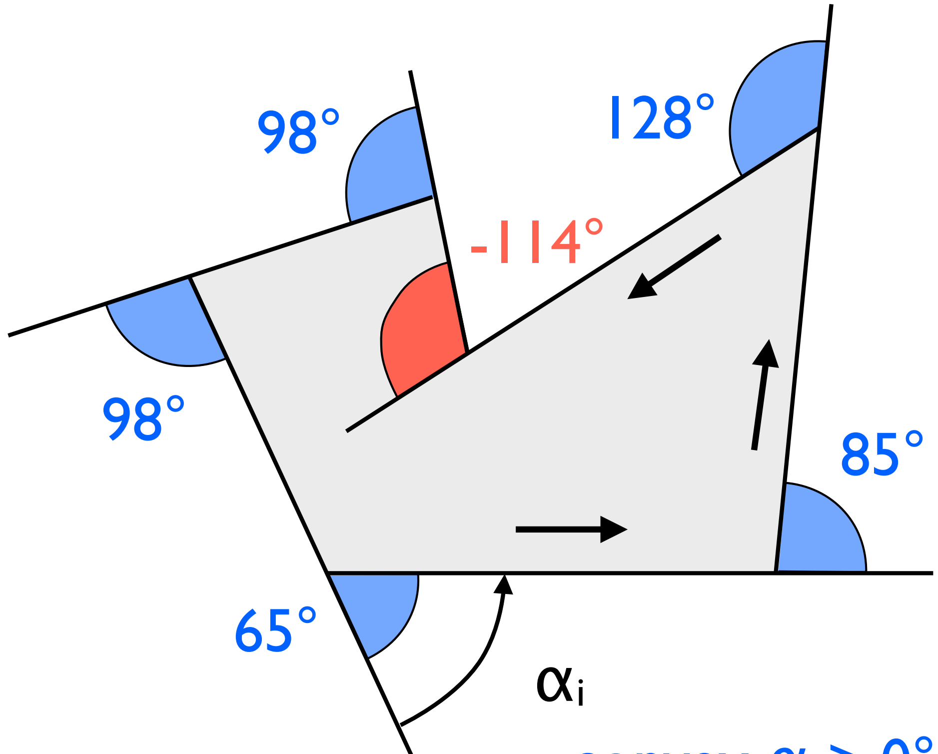
1) average relative indented surface, Panozzo & Hürlimann 1983

excess perimeter - area deficiency



shape descriptors - vertex angles





convex $\alpha > 0°$

concave $\alpha < 0°$

for any polygon: $\sum \alpha = 360°$

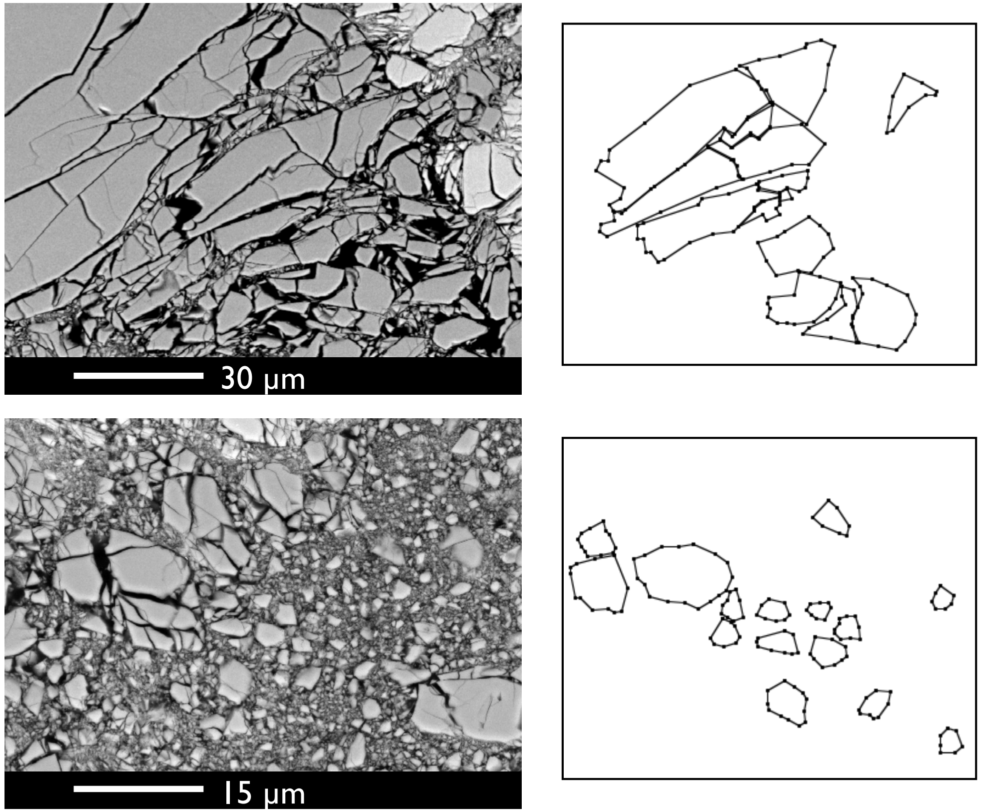
positive = closing

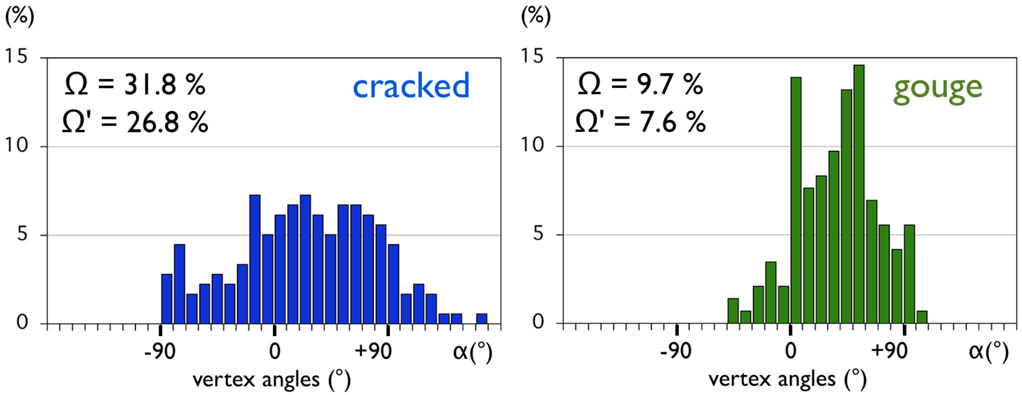
Ω(omega) $\sum [h(\alpha) \cdot \alpha]$ for $\alpha < 0°$

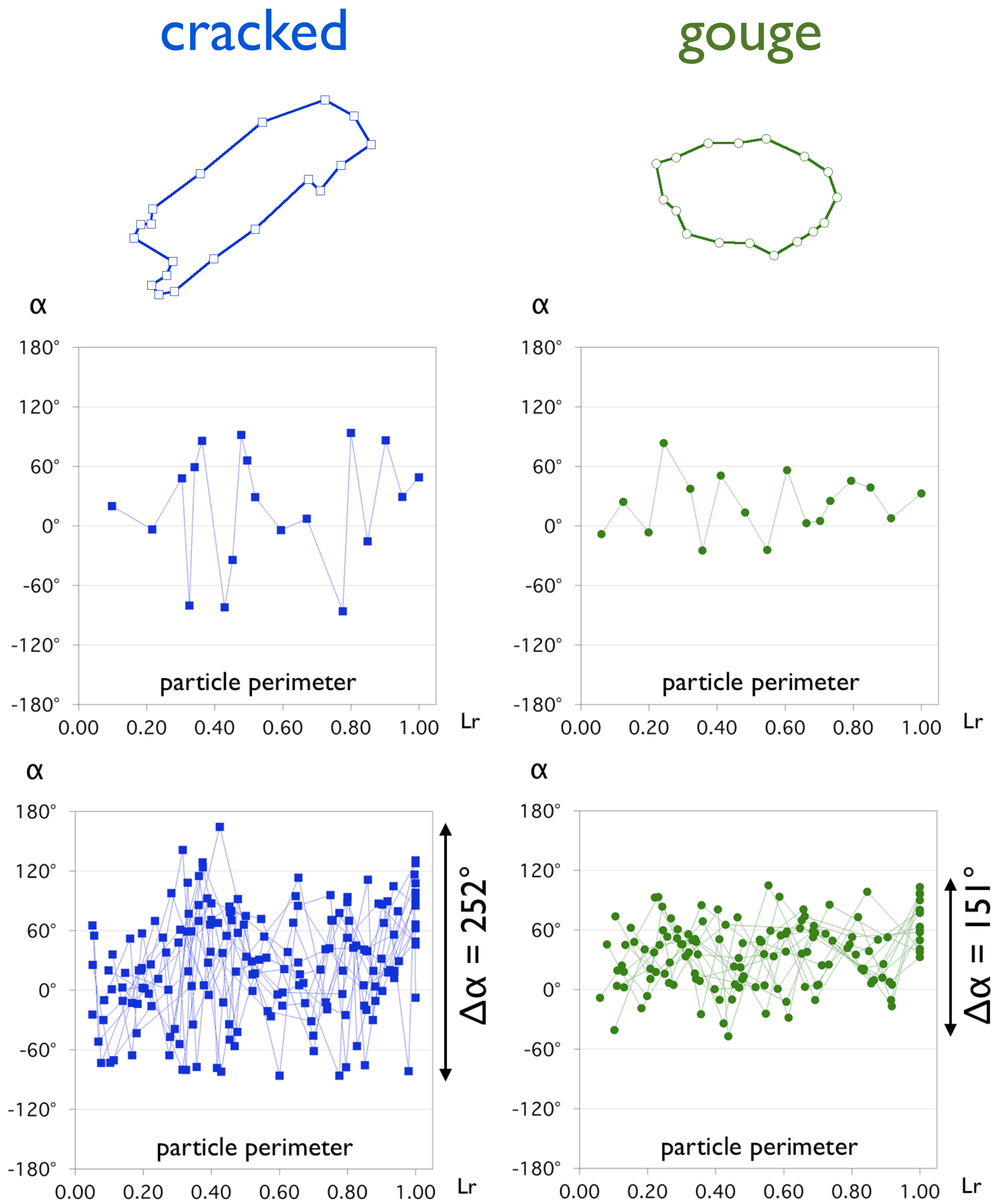
extreme values α_{max} and α_{min}

range of angles $\alpha_{max} - \alpha_{min}$

from angular to rounded



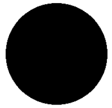
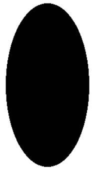
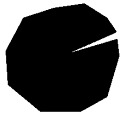
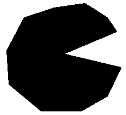
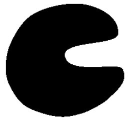




histogram of vertex angles

vertex angles along outline

shape descriptors for test shapes

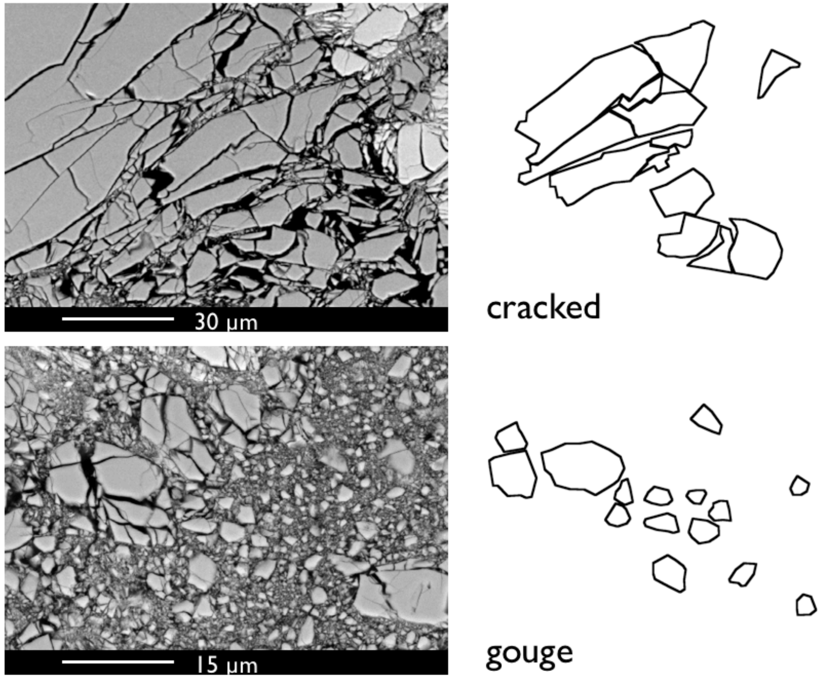
definition	ImageSXM ishapes	ImageJ							
b/a	axial ratio	Roundness	1.00	0.50	1.00	0.94	0.96	0.94	0.89
a/b	aspect ratio	Aspect ratio	1.00	2.00	1.00	1.06	1.04	1.06	1.12
$B(\alpha)_{max}/B(\alpha)_{min}$ *)	hull ratio	(Feret/MinFeret)	1.00	2.00	1.41	1.14	1.14	1.14	1.15
P/P_{equ}	shape factor 1	$(\text{Circularity})^{-2}$	1.00	1.12	1.13	1.35	1.38	1.40	2.25
A/A_{equ}	shape factor 2	Circularity	1.00	0.80	0.79	0.55	0.53	0.51	0.20
$(A(\alpha)-B(\alpha))/A(\alpha)$ *) $=2 \cdot (A_{hull}-A)/A_{hull}$	PARIS factor (%)		0	0	0	43	40	48	136
$(P-P_{hull})/P$	deltP (%)		0	0	0	18	17	19	41
$(A_{hull}-A)/A$	deltA (%)	((A/Solidity)-A)/A	0	0	0	2	11	14	54
A/A_{hull}		Solidity	1.00	1.00	1.00	0.97	0.89	0.87	0.64

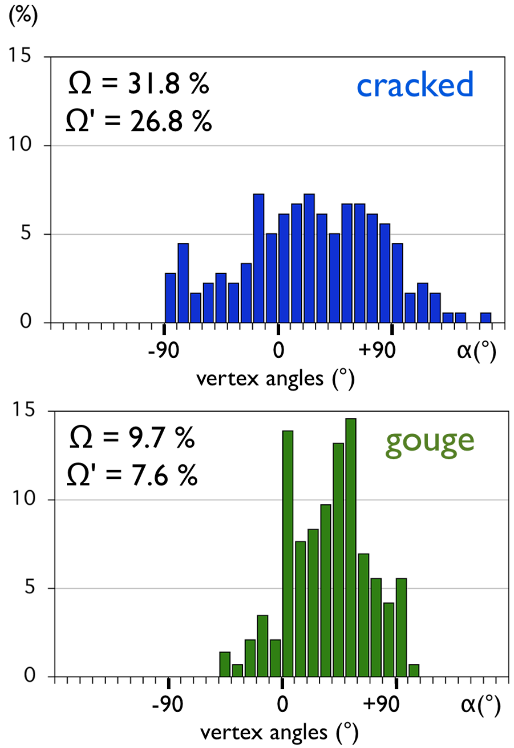
*) A(α) line projection (surfor)
B(α) area projection (paror)

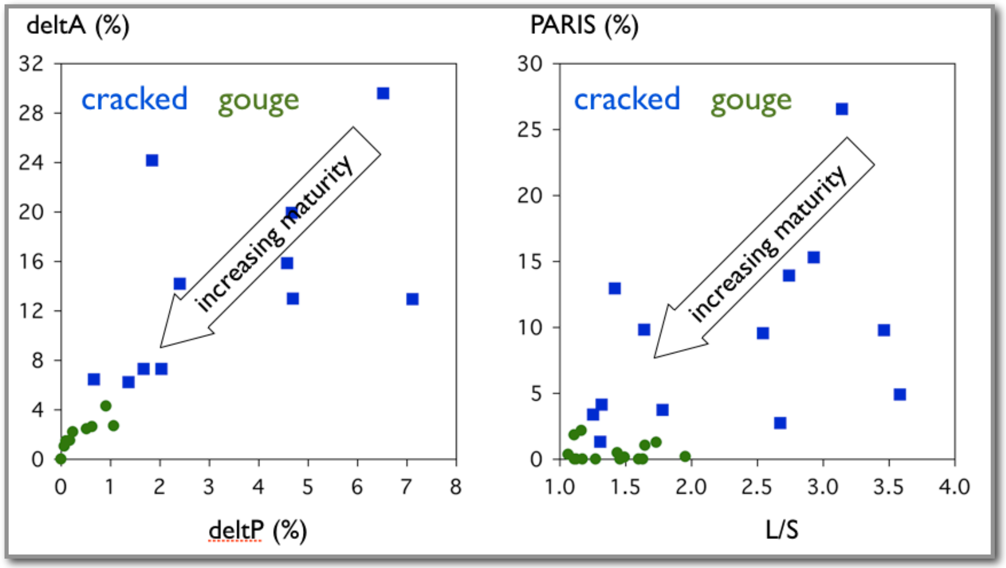
applications

- fault rocks
- crystalline rocks

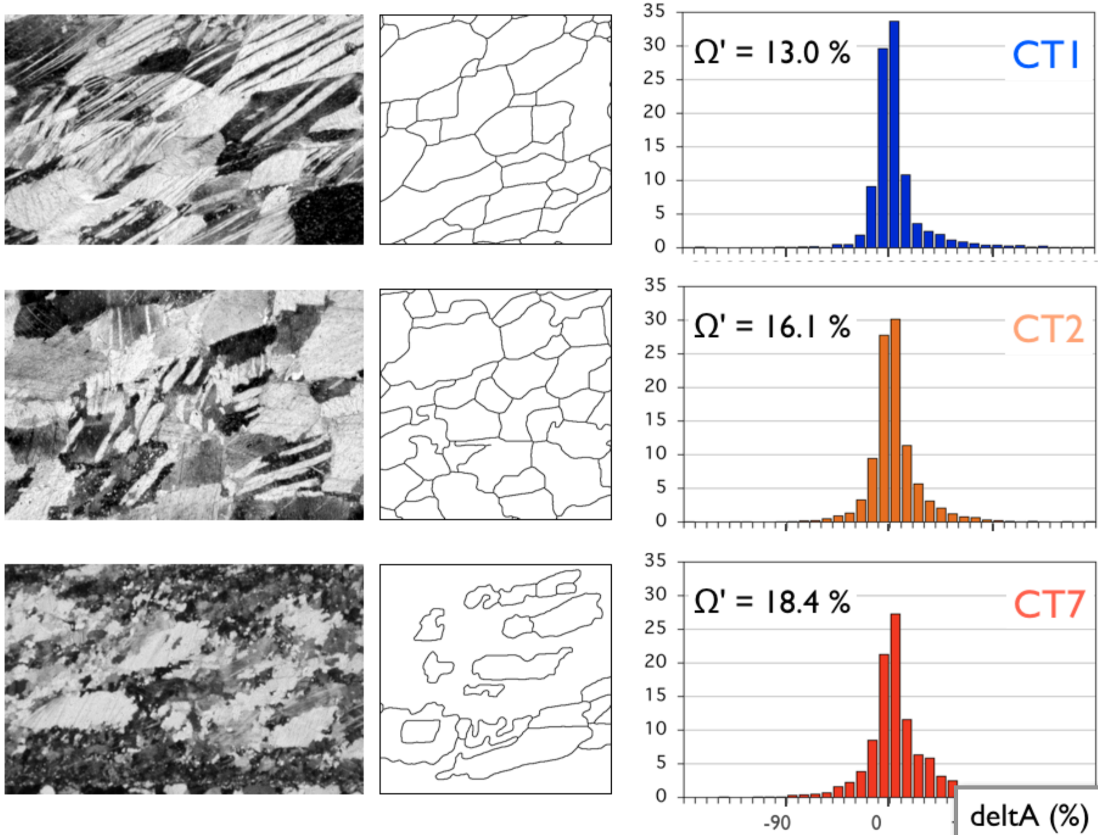
shape analysis of cracked and gouge

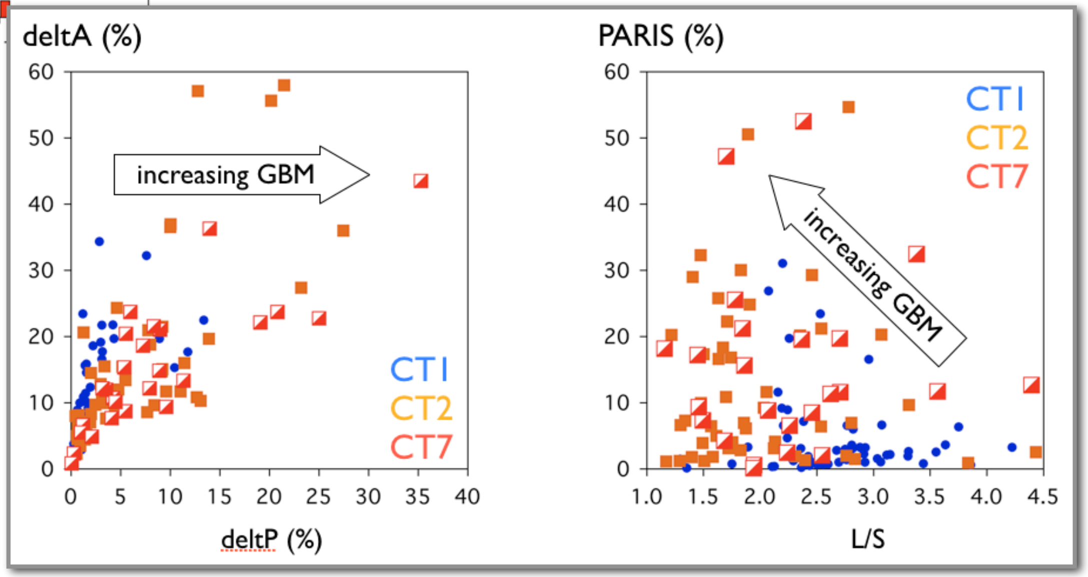




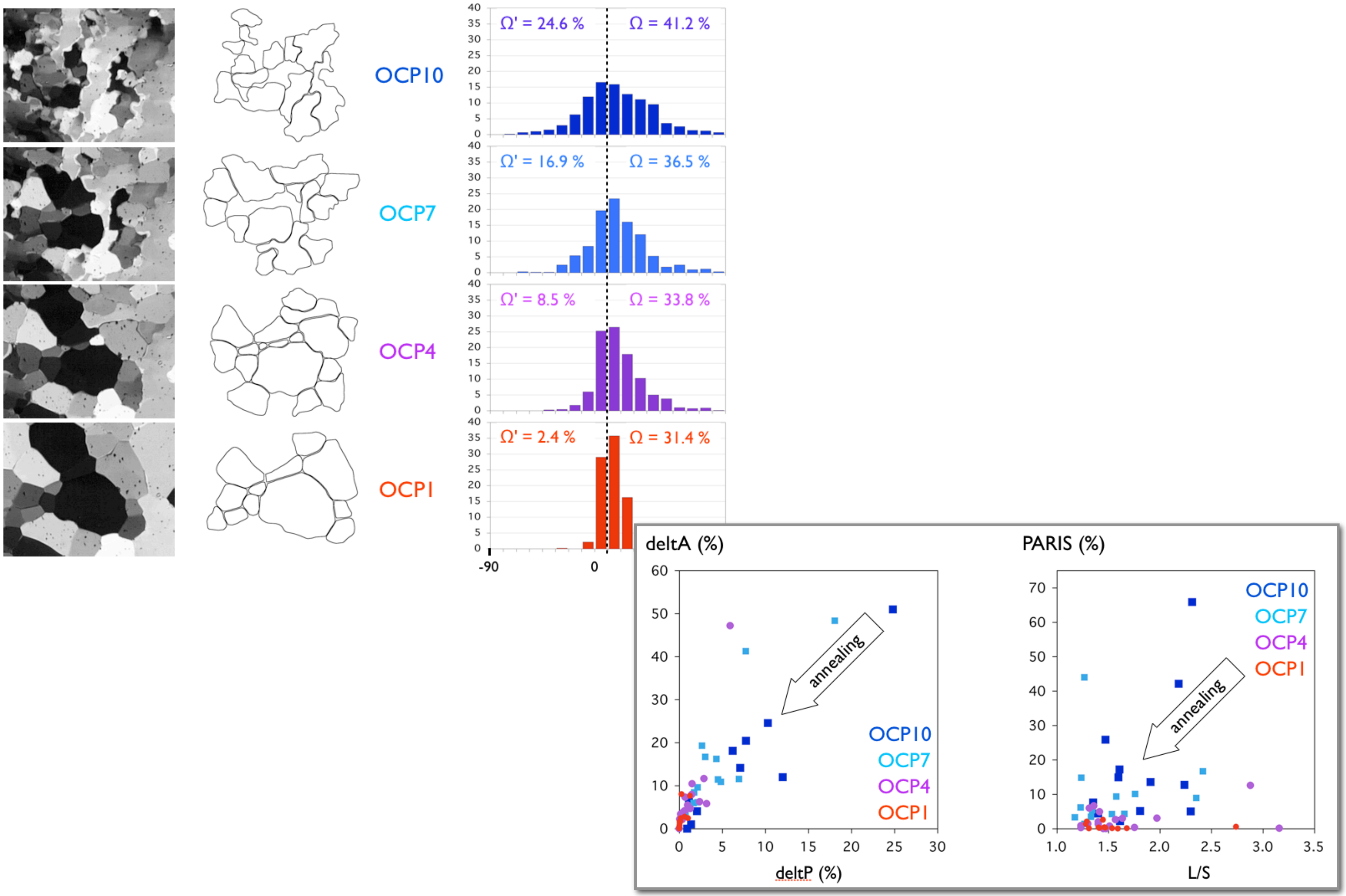


dynamic recrystallization





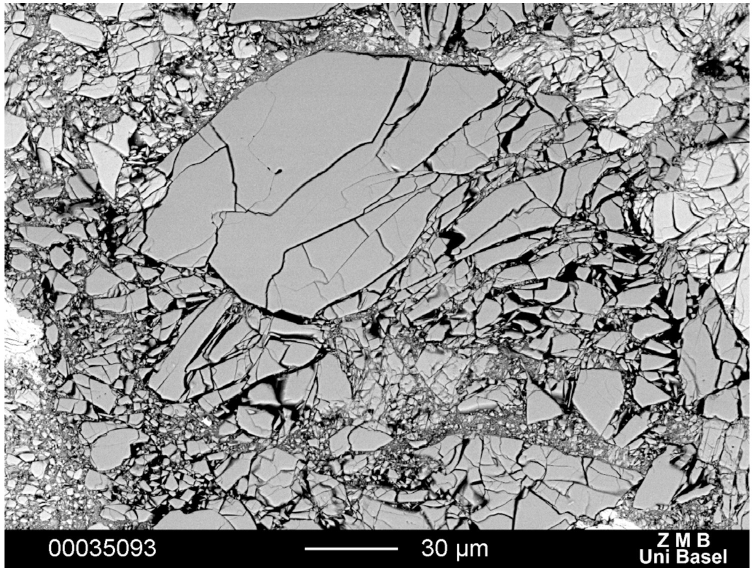
static annealing



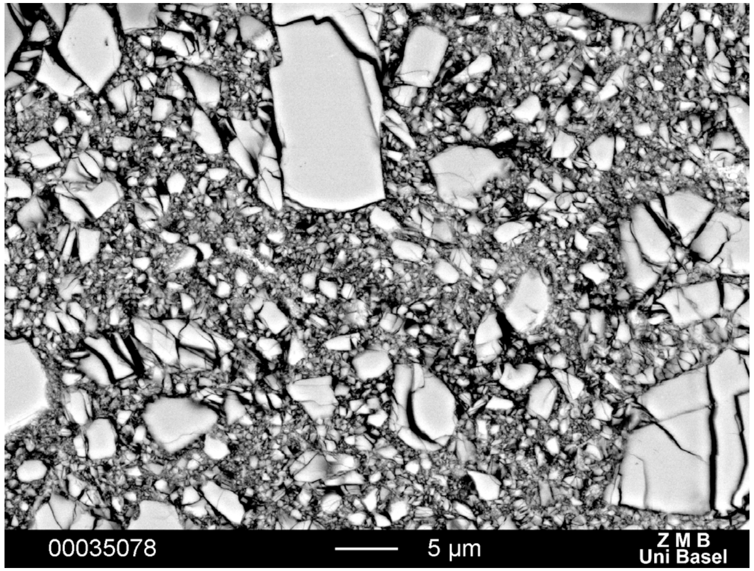
7
visualisation

visualizing results:
- property mapping

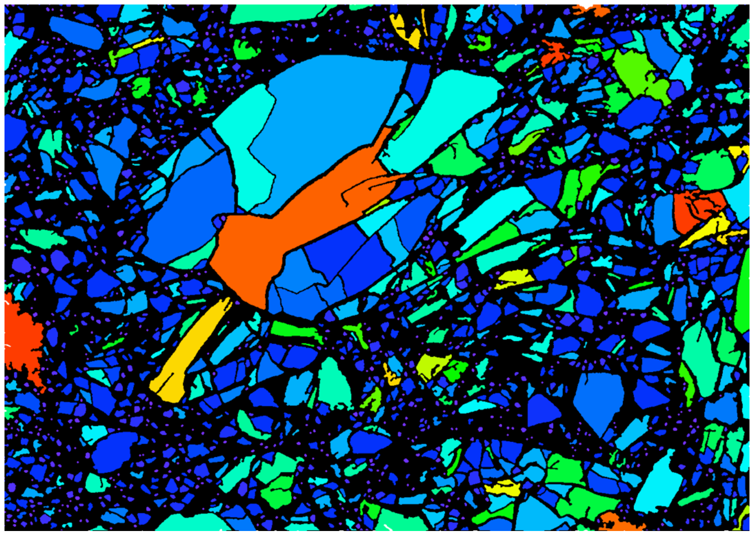
seeing is believing

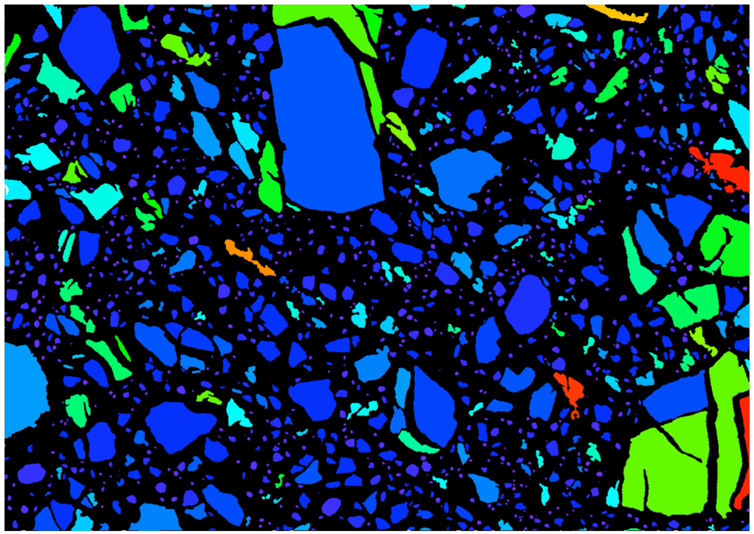


cracked material

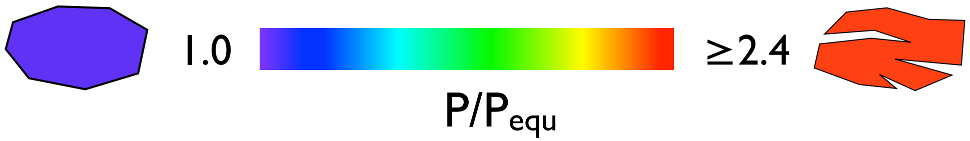


gouge material

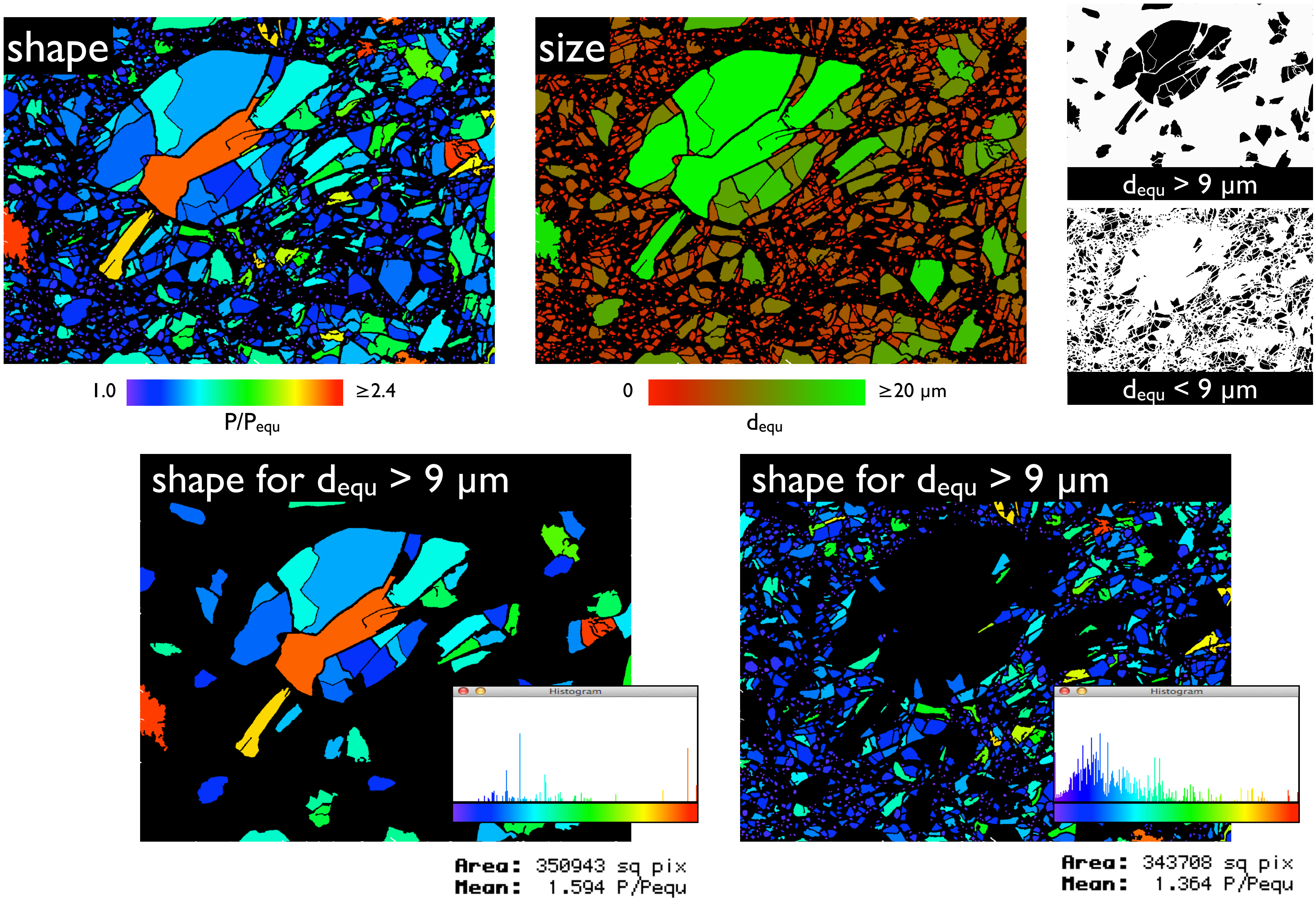




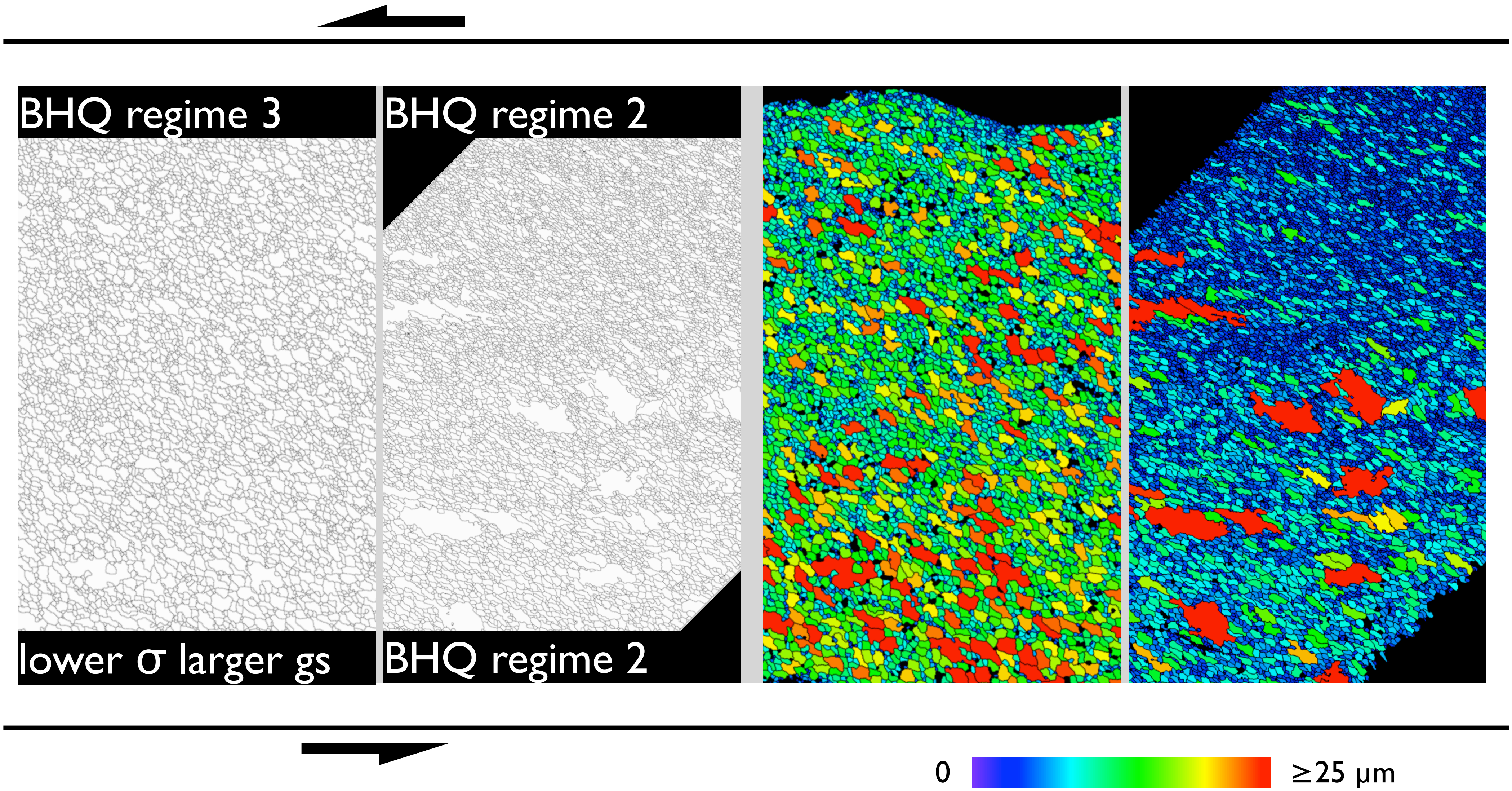
grain shape mapping (shape factor 1)



intersecting properties



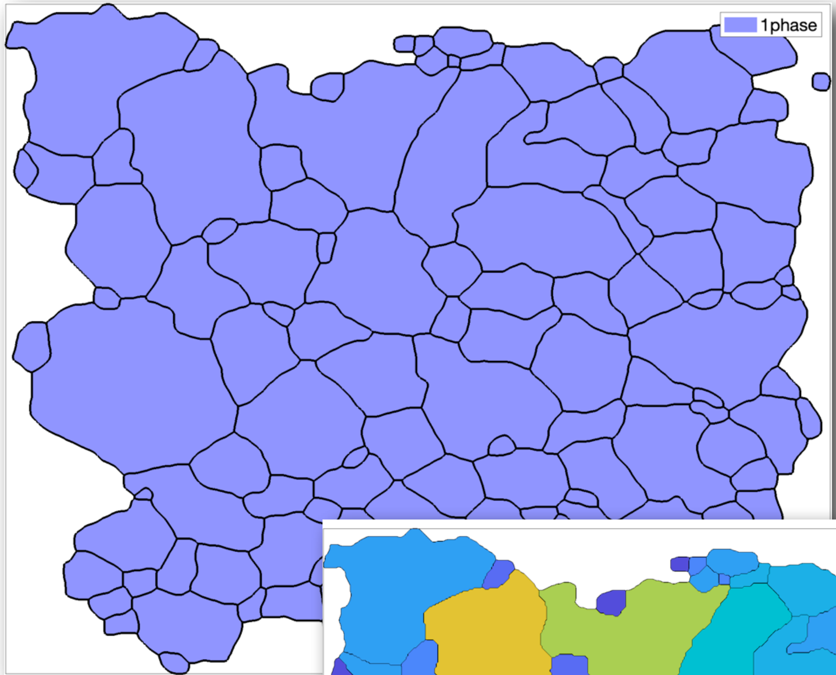
checking 2D grain size



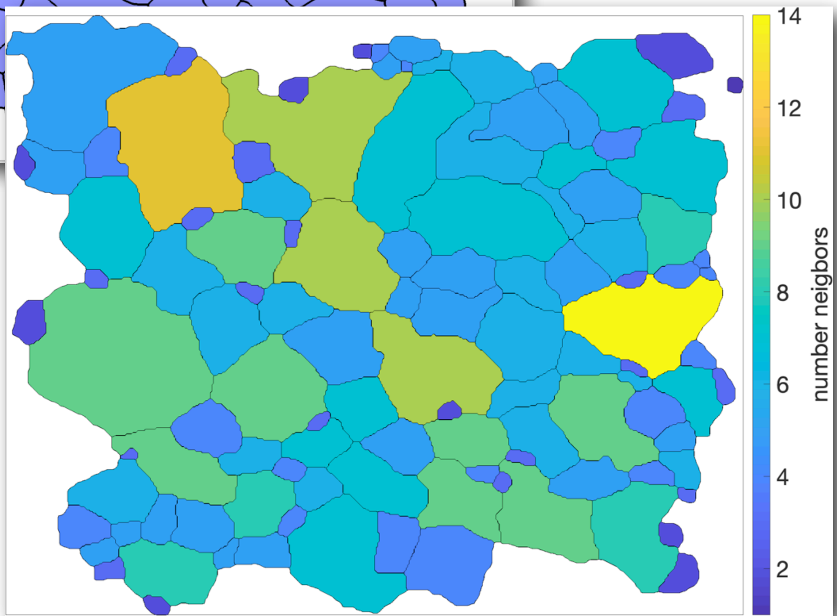
shear experiments on Black Hills quartzite

visualization from data base

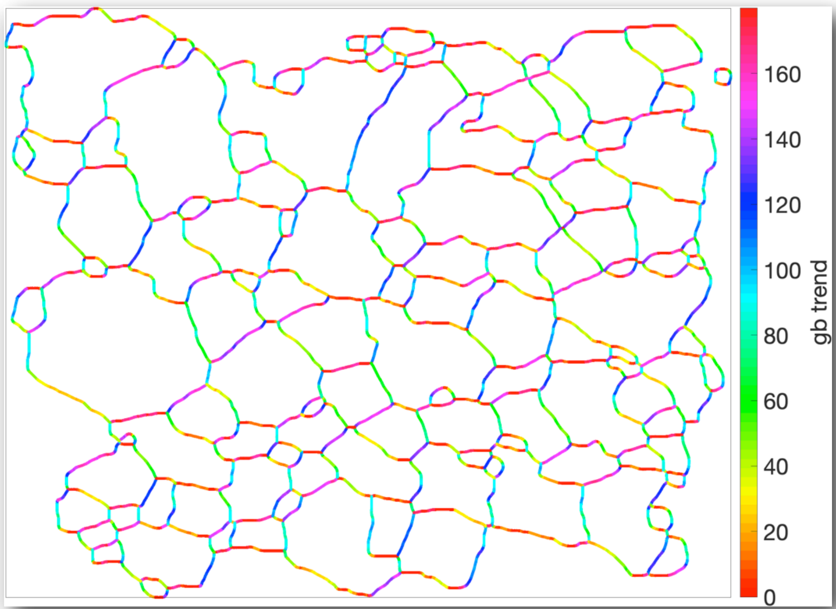
segmented image



ask Rüdiger ...
:-)



neighbor count



grain boundary trend

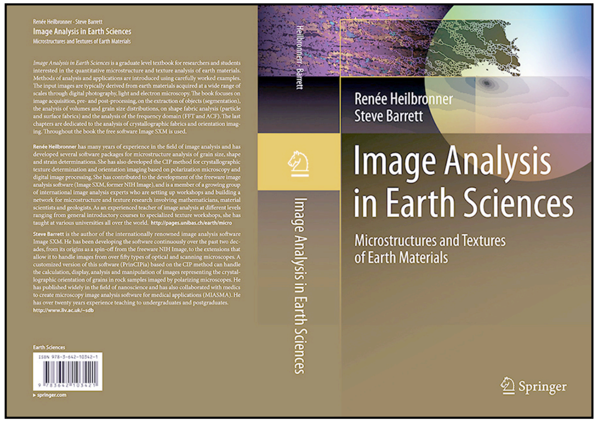
8
software & support

literature

Heilbronner, R. and Barrett, S. (2014)
Image Analysis in Earth Sciences
Microstructures and Textures of Earth Materials.
Spinger Verlag, Heidelberg

https://earth.unibas.ch/micro
(https://micro.earth.unibas.ch)
→ Textbook → download of figures

ISBN: 978-3-642-10342-1 (Print)



ISBN: 978-3-642-10343-8 (Online)

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→ FIGURES 1 corr
→ FIGURES 2
→ FIGURES 3
→ FIGURES 4

→ FIGURES 5
→ FIGURES 6
→ FIGURES 7
→ FIGURES 8
→ FIGURES 9

→ FIGURES 10
→ FIGURES 11
→ FIGURES 12 corr
→ FIGURES 13 corr

→ FIGURES 14 corr
→ FIGURES 15
→ FIGURES 16
→ FIGURES 17

→ FIGURES 18 corr
→ FIGURES 19 corr
→ FIGURES 20 corr

→ FIGURES 21
→ FIGURES 22 corr
→ FIGURES 23 corr

'corr' = corrected w/r to printed book

available / recommended programs

Software	what it does	where to get it
ImageJ / Fiji	Image analysis	https://fiji.sc/
Image SXM	Image analysis	https://www.liverpool.ac.uk/~sdb/ImageSXM/
paror (Fortran)	Particle fabric analaysis	https://micro.earth.unibas.ch → Software
surfor (Fortran) or Jazy_surfor	Surface fabric analaysis	https://micro.earth.unibas.ch → Software
ishapes (Fortran)	Shape descriptors	https://micro.earth.unibas.ch → Software
stripstar (Fortran) or Jazy_stripper	2D-3D grainsize analysis	https://micro.earth.unibas.ch → Software
PolyLX (python)	Microstructures analysis	https://github.com/ondrolexa/polylx
grain size toolbox (python)	Grain size analyis	https://marcoalopez.github.io/GrainSizeTools/
Matlab	Image processing toolbox	https://mathworks.com

macros - and where to get them

Image SXM	ImageJ / Fiji	
Lazies (Renée Heilbronner)	Jazies (Rüdiger Kilian)	what they do:
Lazy ACF-Tiles.txt	Jazy_ACF.ijm	Tesselation of ACFs in stack with microstructure
Lazy Analyze.txt		Sets options for Analyze: b/a, r, d equ etc.
Lazy CIP-LUTs.txt		Luts for CIP images (orientation images)
Lazy ColorVoronois.txt		Converts Hugo-Ledoux-slices to test fabrics
Lazy Contacts.txt	Jazy_Voronoi.ijm	Calculates contact frequencies (spatial distribution)
Lazy D-map.txt	Jazy_D-mapping.ijm	Maps slope of fractal gsd in bitmaps
Lazy Digitize.txt		Primitive digitizing tool
Lazy EBSD.txt		Converts EBSD map to c-axis orientatio map
Lazy ErodeDilate.txt	Jazy_erodilate.ijm	Structural filtering
Lazy GrainBoundaries.txt	Jazy_boundaries.ijm	Segmentation: pre-, post-process, etc. yields grain map
Lazy GrainMap.txt	Jazy_whatever_map.ijm	Maps properties (size, orientation,.. etc.) into image
Lazy Lighting.txt	Jazy_background.ijm	Performs background correction
Lazy LUTs.txt	Jazy_LUT.ijm	Macro for LUT manipulation, live segmentation
Lazy MapRedirect.txt		Analysis (Analyze) for bitmap and corresponding grey scale
Lazy Re-Size.txt		Re-sizing of images to desired resolution, width, etc.
	Jazy_surfor.ijm	Surface orientation (= surfor)
	Jazy_stripper.ijm	2D-3D conversion of GSD (= stripstar)
	Jazy_XY_export_header.ijm	Export of particle outlines, raw and smoothed
	Jazy_Env_map.ijm	Shape factors based on convex hull

Lazy macros (SXM macro language) https://micro.earth.unibas.ch → Software → Macros
Jazy macros (imageJ macro language) https://github.com/kilir/Jazy_macros

end

shape