A few case studies using MTEX to analyse orientation data

MTEX - workshop
Chemnitz, 2016

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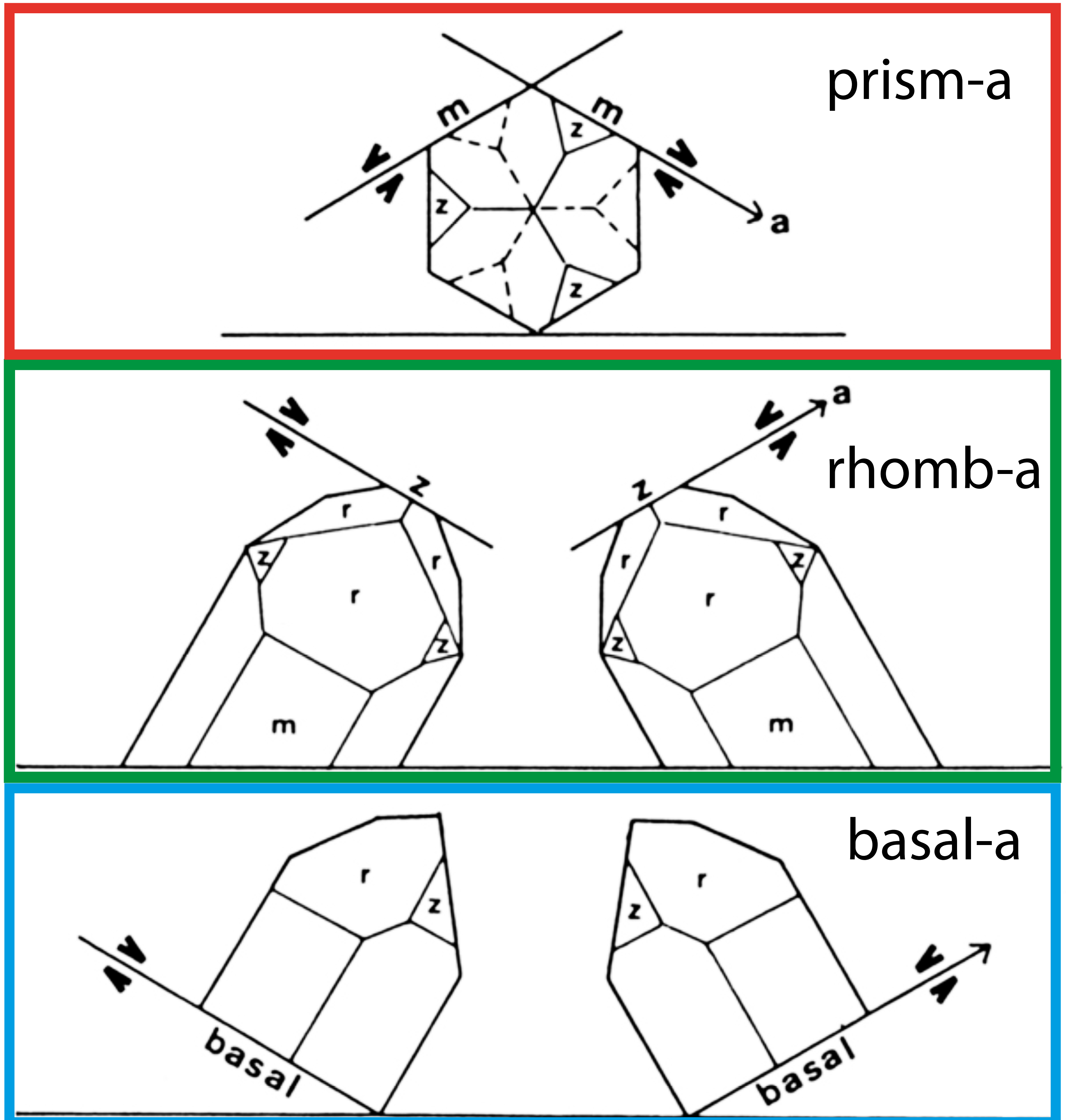
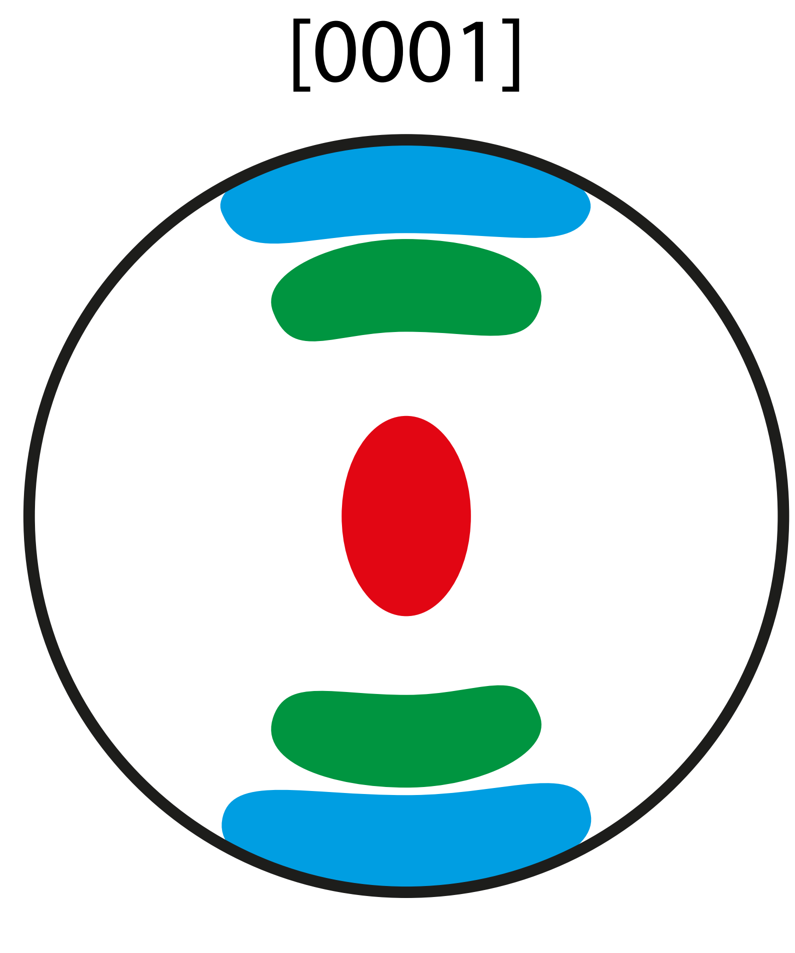
University Basel

Part 1:
Analyzing low angle boundaries in a naturally deformed quartz vein

Predicting quartz slip systems from c-axis pole figures? Does that really (always) work?

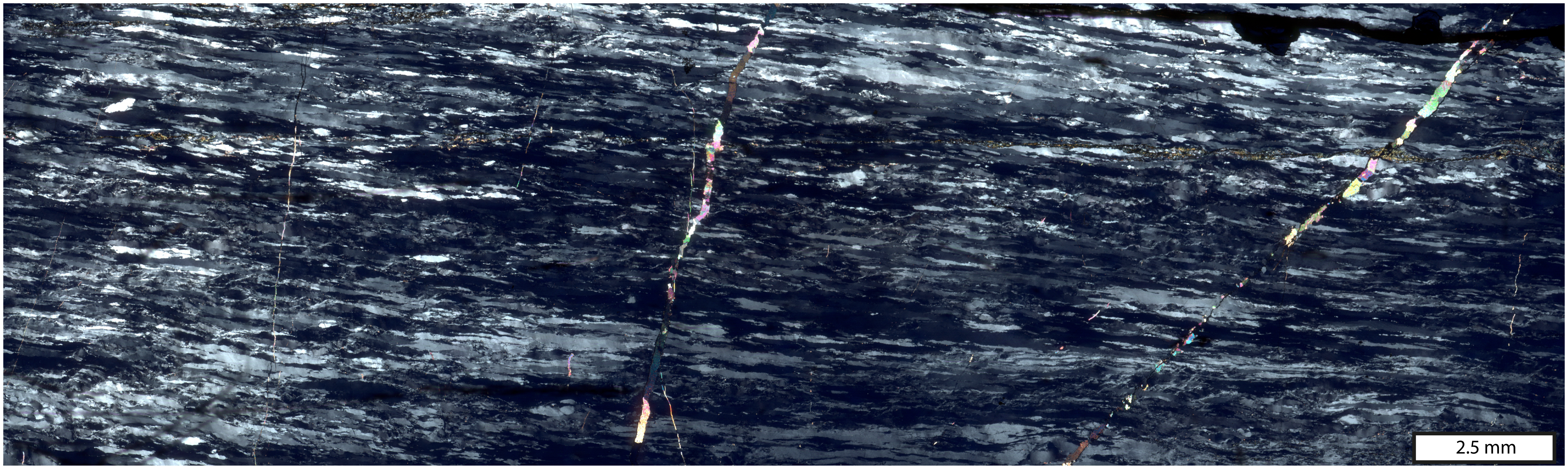


after Schmid & Casey, 1986



⊥ foliation
II lineation

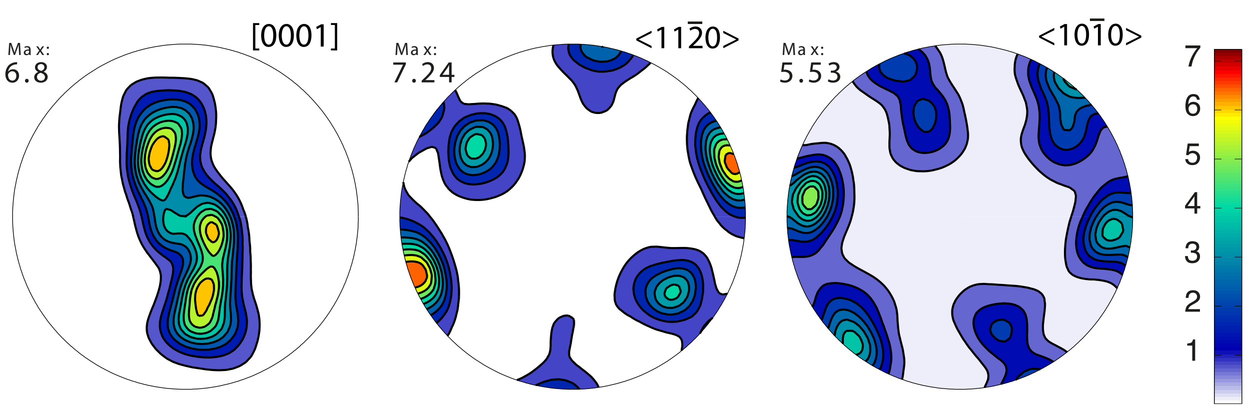
Quartz vein from footwall of the Mohave Wash detachment fault (Chemehuevi Mountains): highly deformed, almost no dynamic recrystallization



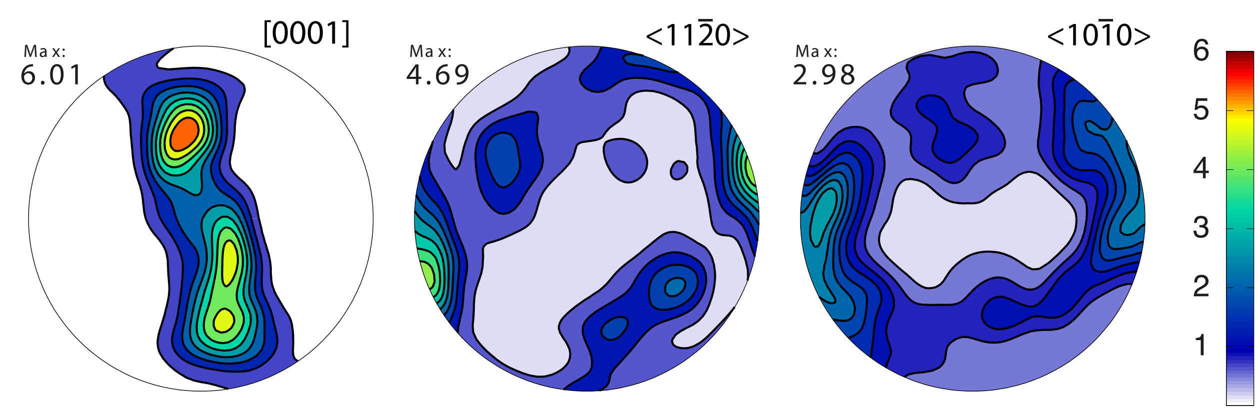
light micrograph, ×-pol

bulk texture

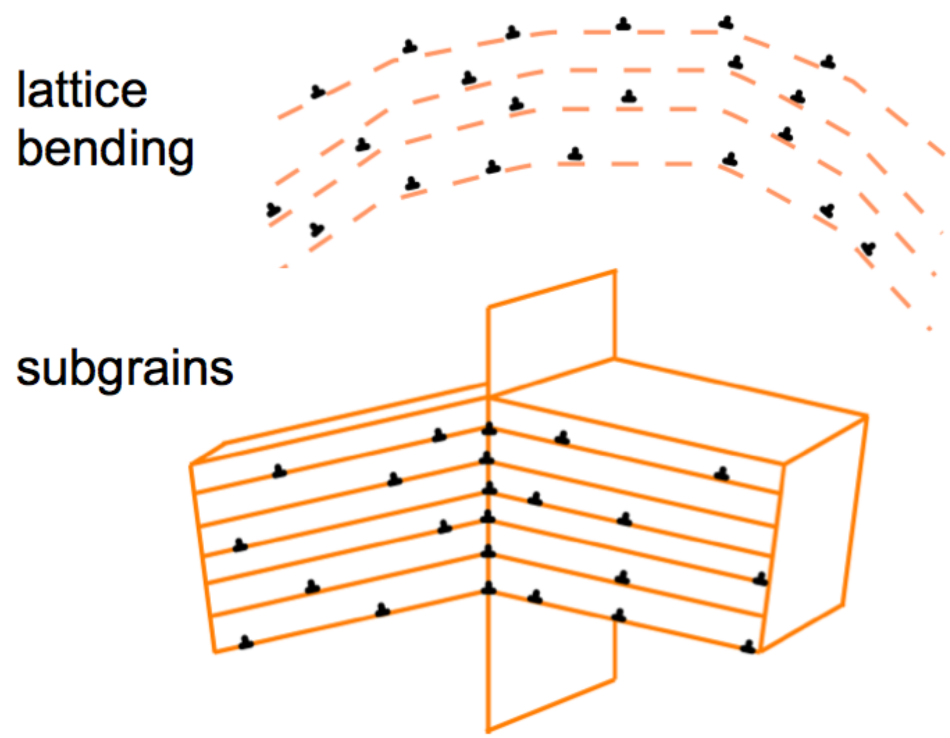
area weighted (total 11*6 mm2 @ 10 μm steps)

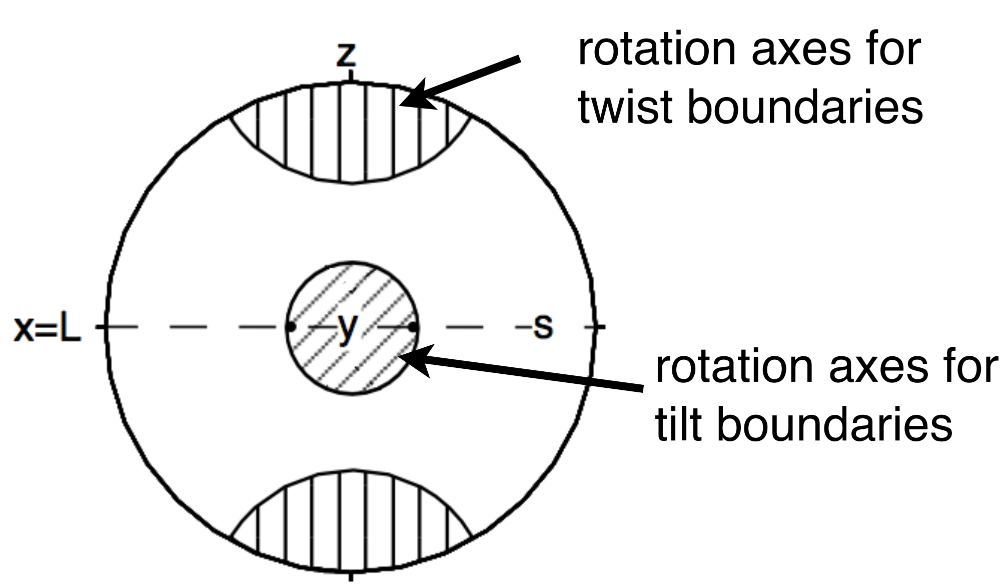


frequency weighted (1793 grains > 10 pts)



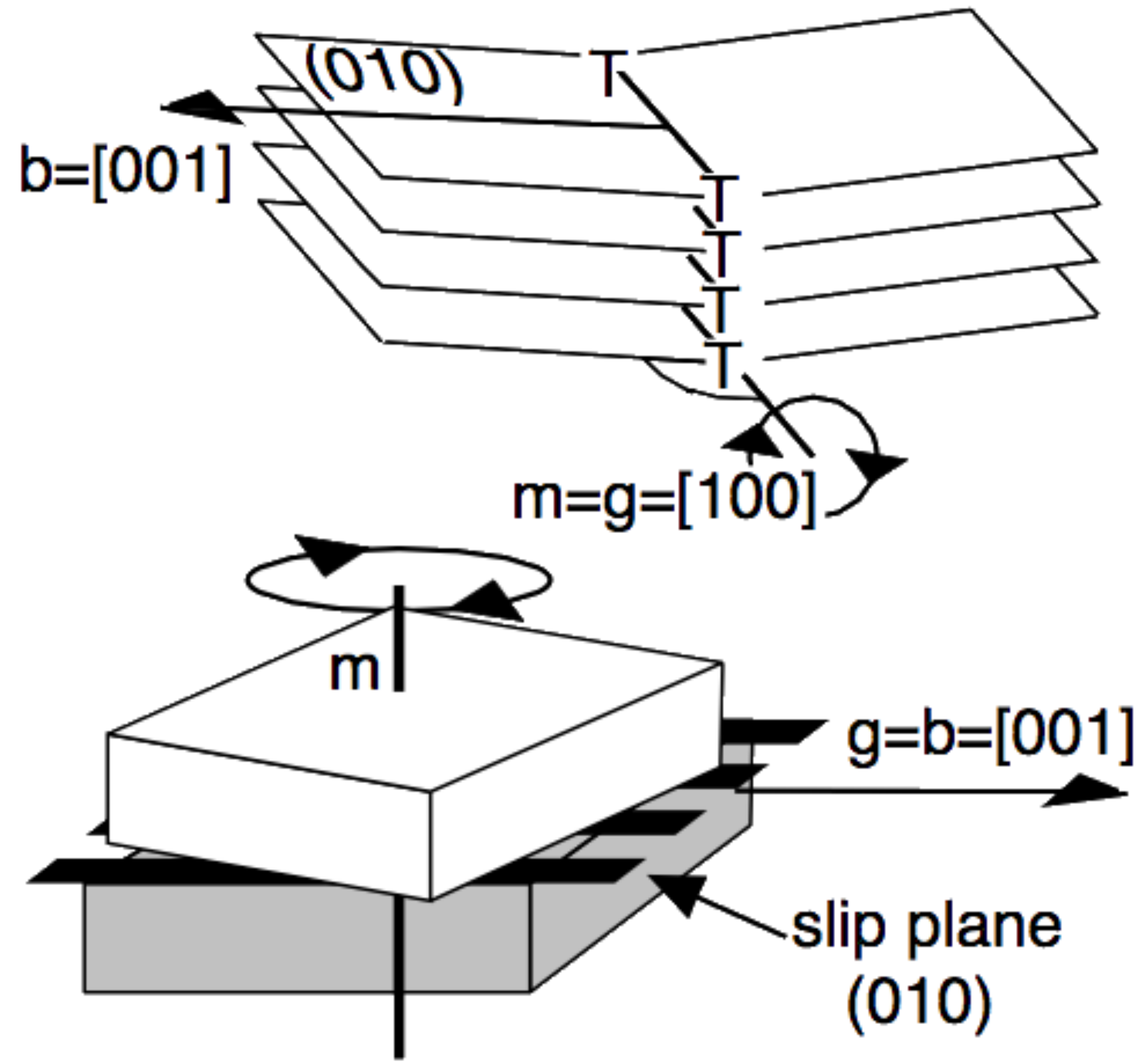
Continuous lattice bending and subgrain boundaries:





kinematic/strain reference frame

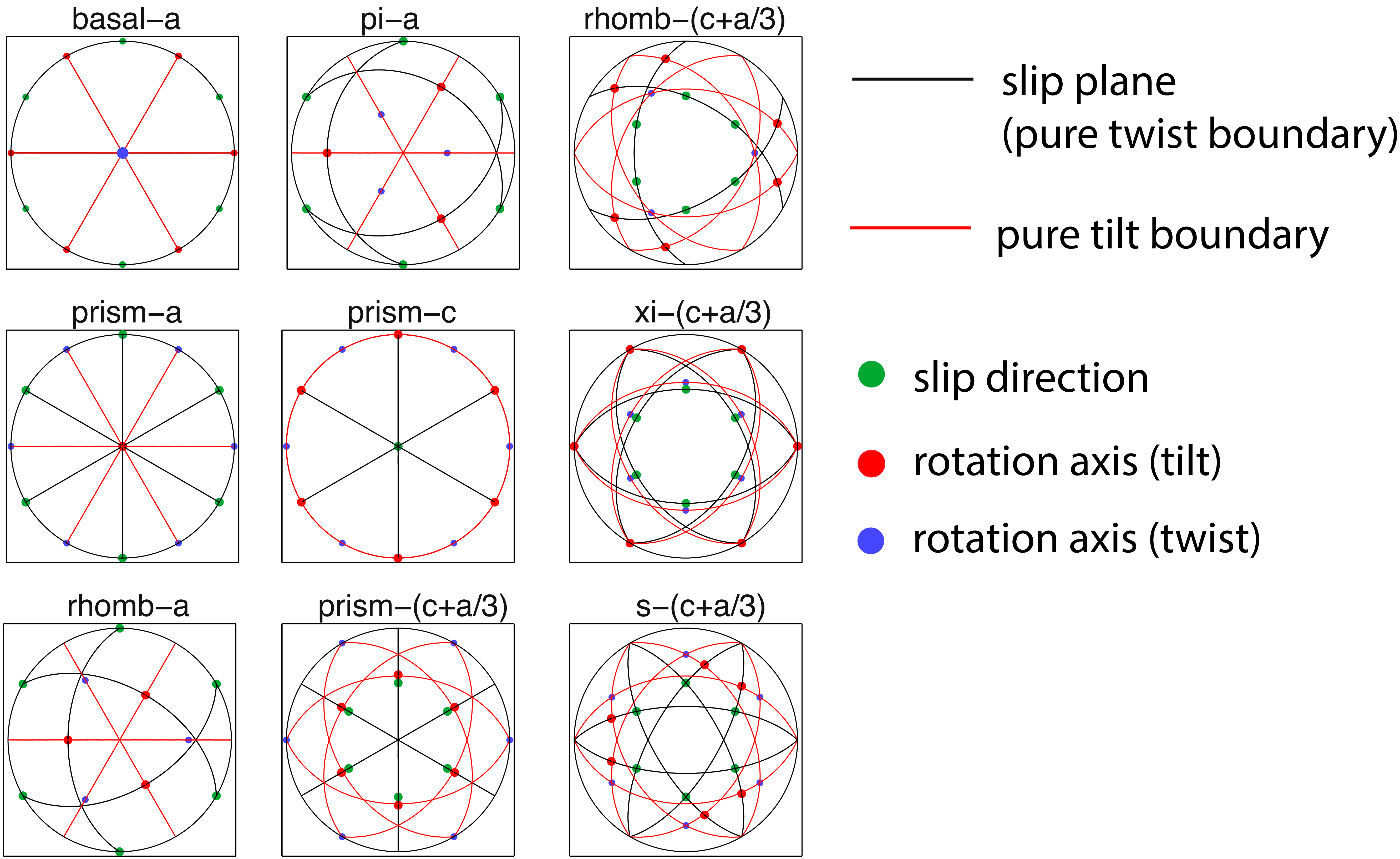
tilt boundary: rotation axis ll boundary and ⊥ slip direction



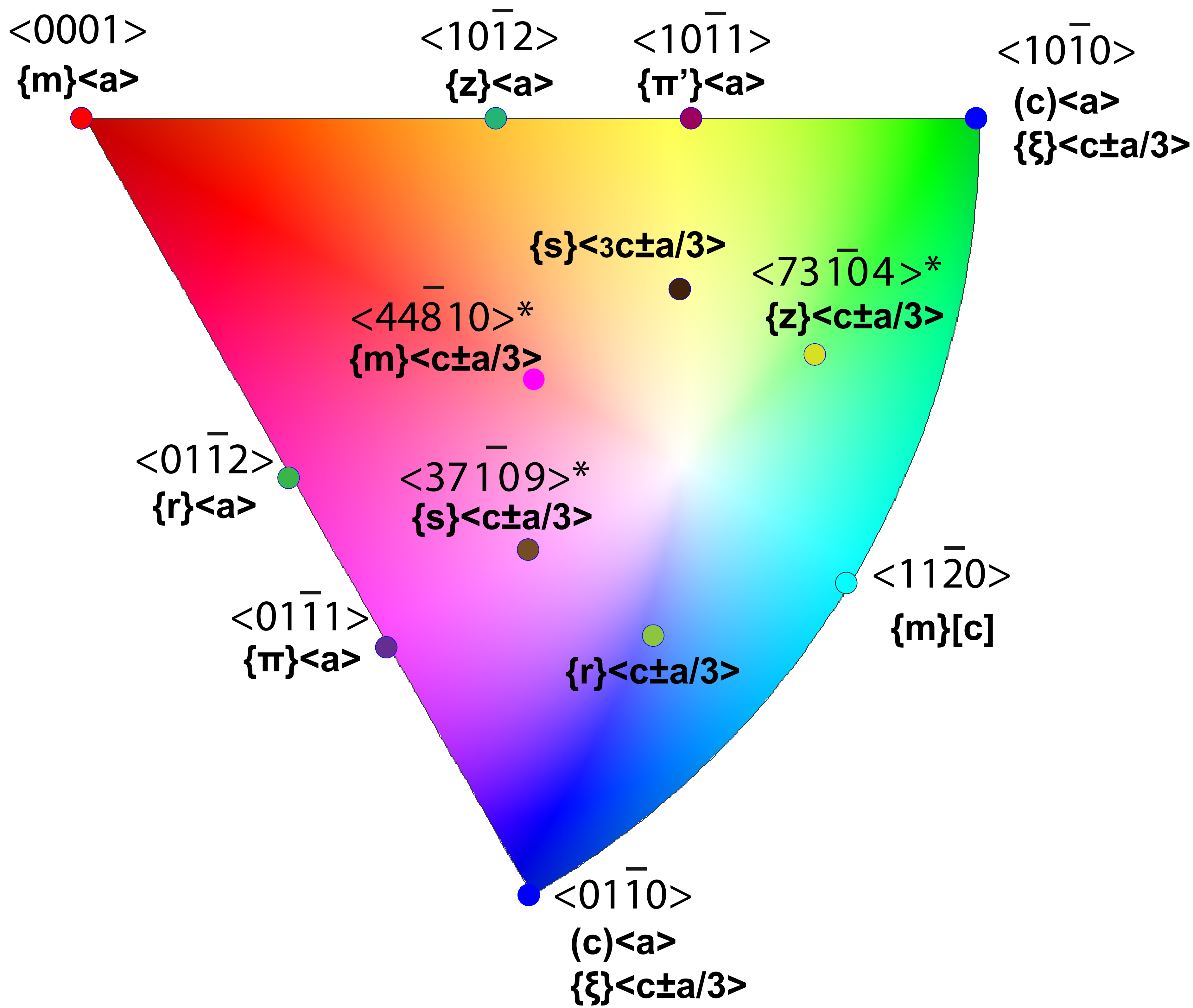
twist boundary: rotation axis ⊥ boundary and ⊥ slip direction

sketch from Kruse et al. 2001

Subgrain boundary end-members for some reasonable or at least theoretically possible slip systems



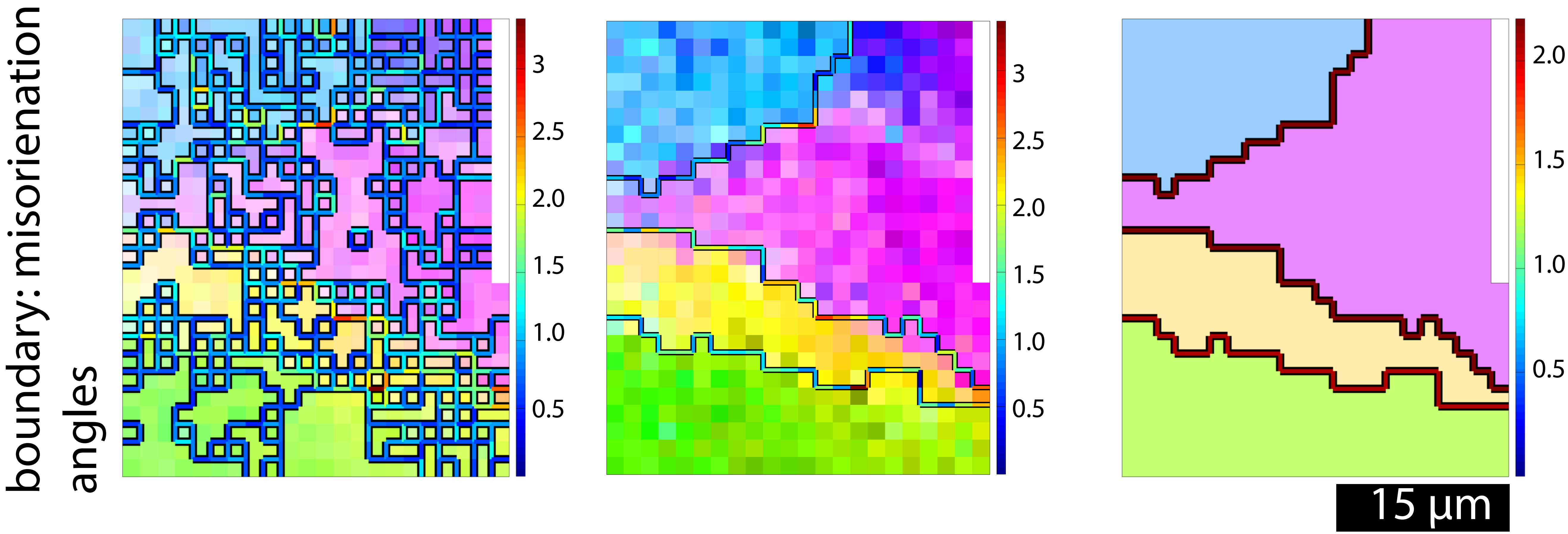
Rotation axes for pure tilt boundaries in quartz



Segmentation of low angle boundaries:

angular threshold — adapted FMC — mean cluster orientation

orientation color coding: IPF wrt. mean orientation

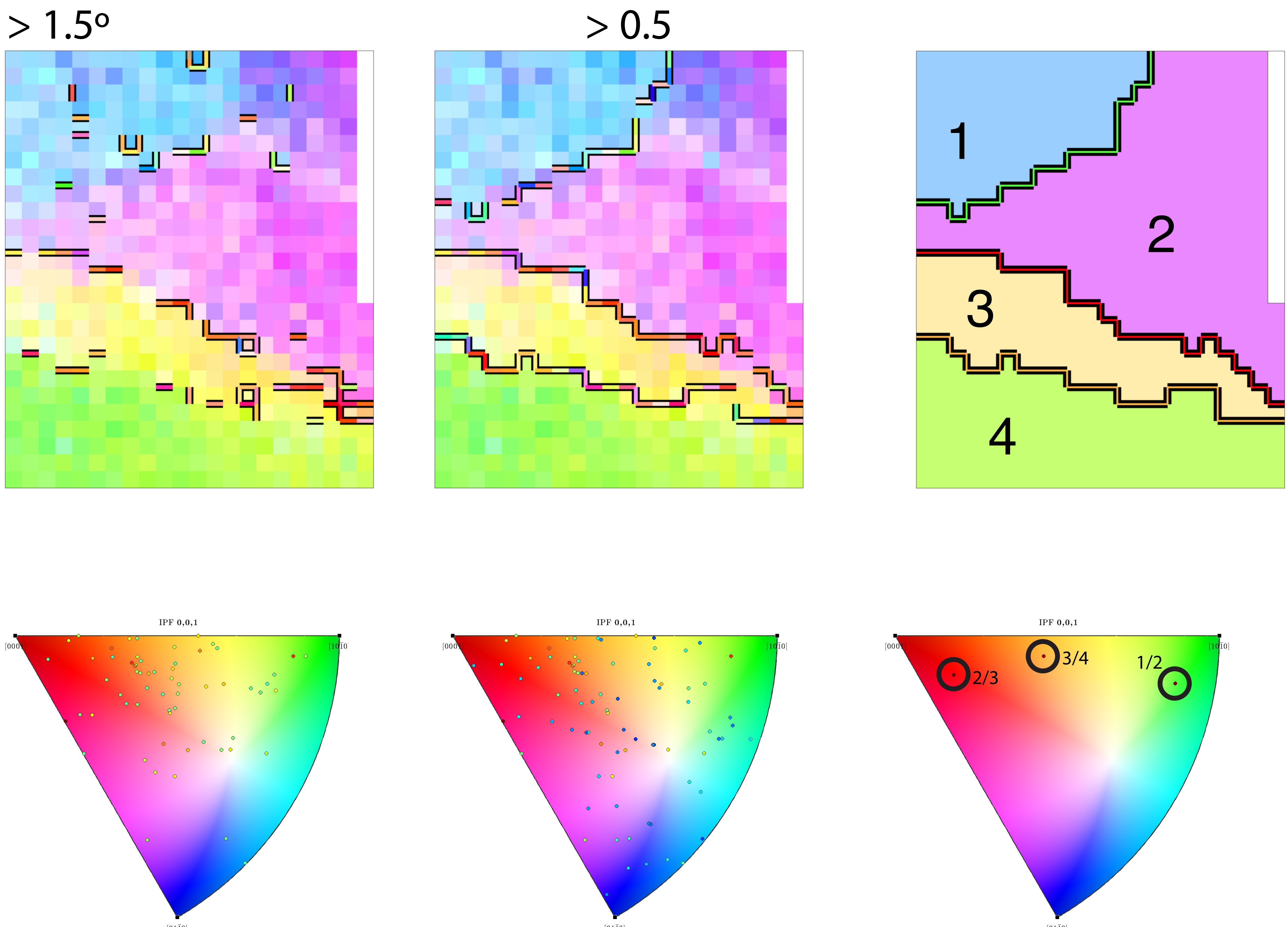


In case segmentation by FMC does not produces the desired results, it might be worth tweaking parameters found in EBSDAnalysis/@EBSD/private/gbc_FMC.m

See McMahon et al. 2013 for explication of parameters.

boundary: misorientation axes
(crystal ref. frame)

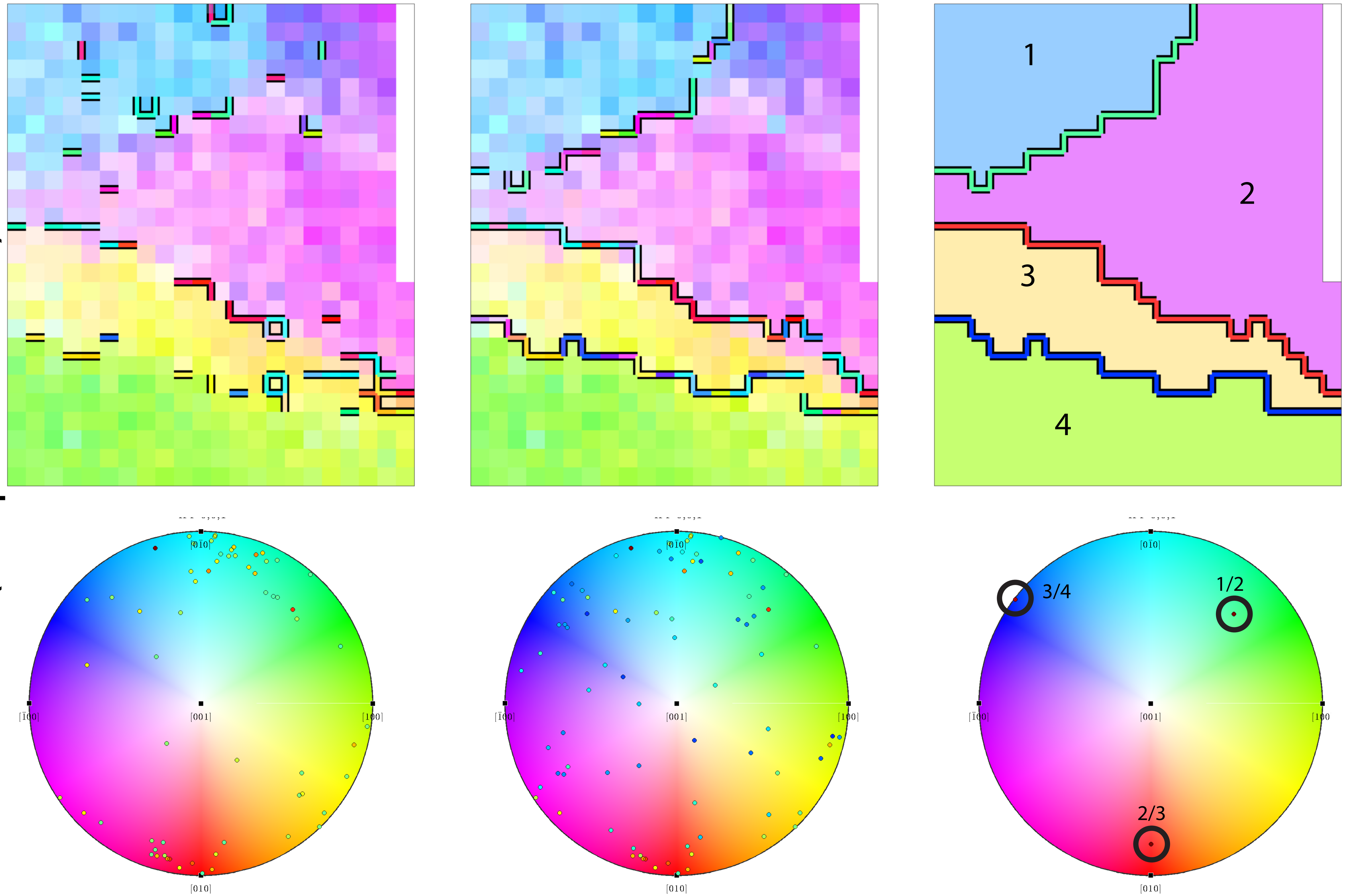
boundaries with misorientation angle



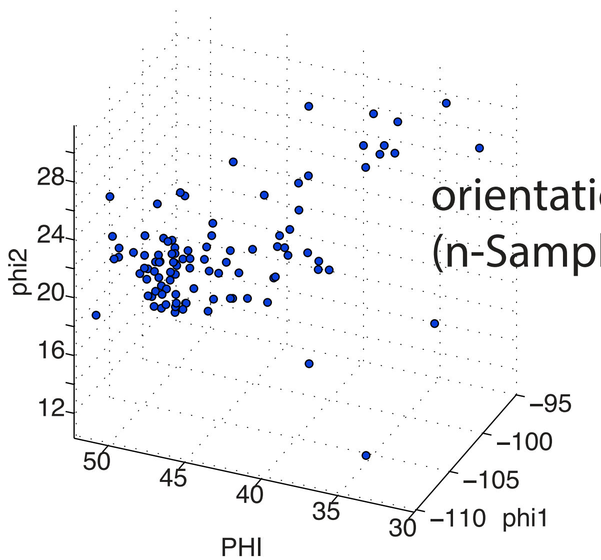
boundaries with misorientation angle:

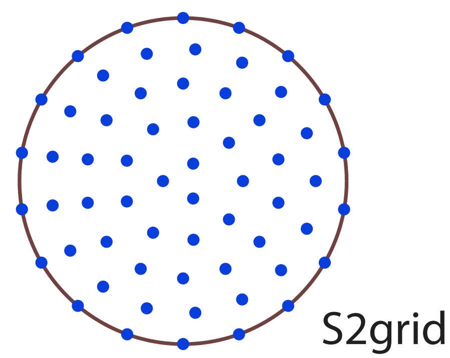
>1.5° > 0.5°

boundary misorientation axes (sample ref. frame)



How to treat “continuous” lattice bending?

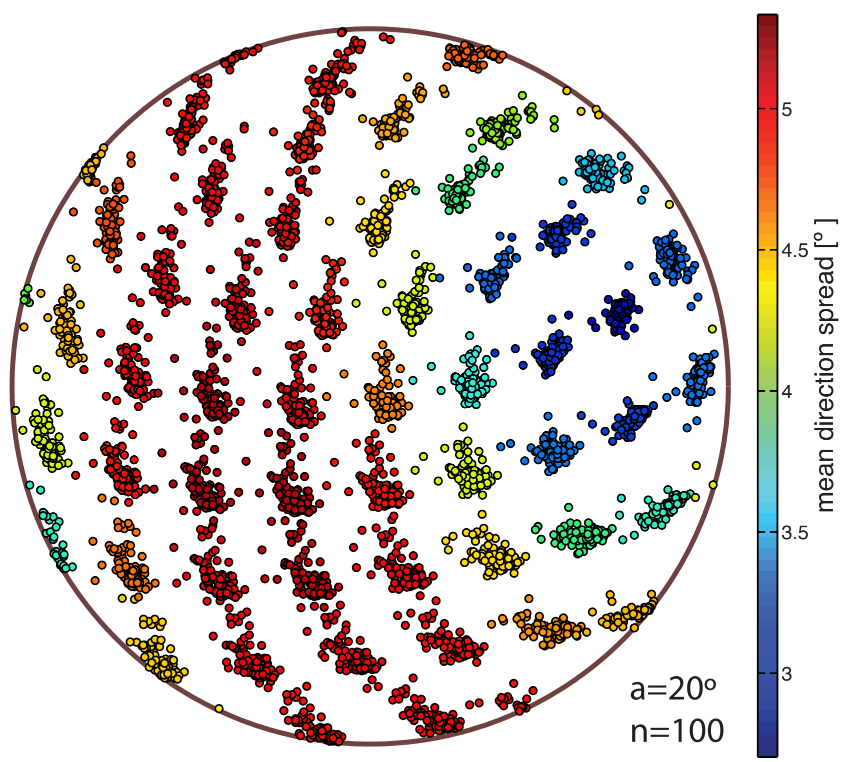




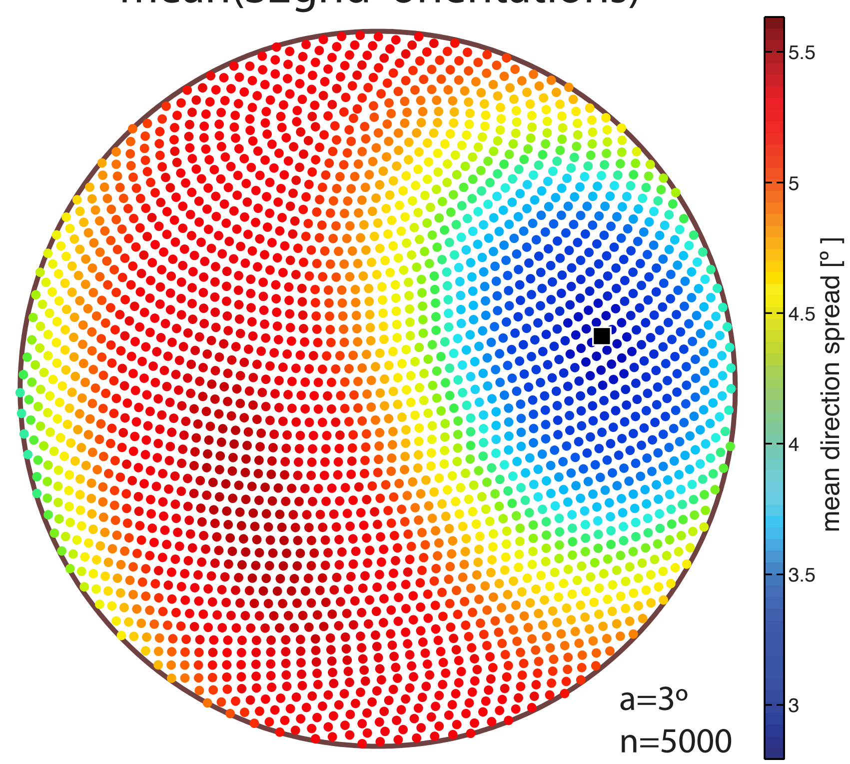
1. dispersion axes
2. mdf

...

S2grid*orientations



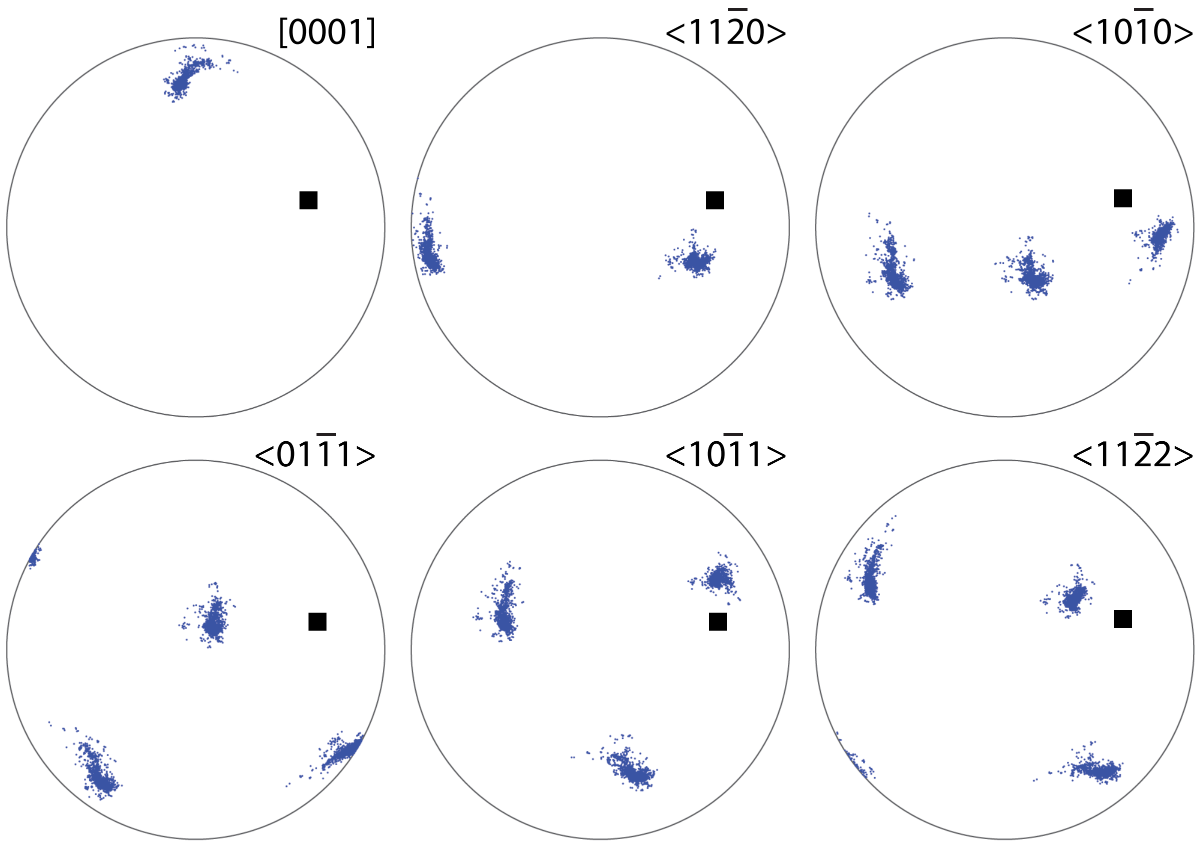
mean(S2grid*orientations)



color coding = mean direction spread

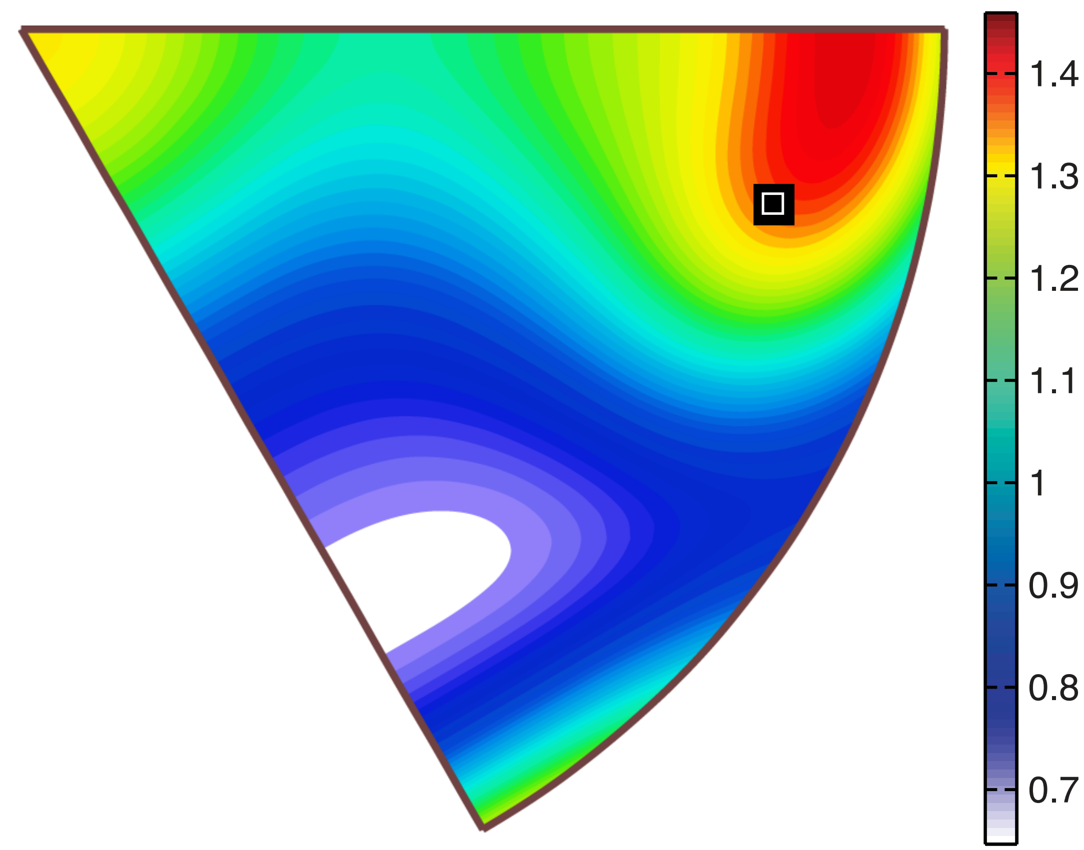
$$\sqrt{\frac{\sum angle\left(o_{mean}, o_i\right)^2}{n_i}}$$

obtaining the dispersion axis



pole figure of deformed single grain and axis of minimum direction spread - sample reference system

axis distribution of mdf of deformed single grain and dispersion axis - crystal reference system



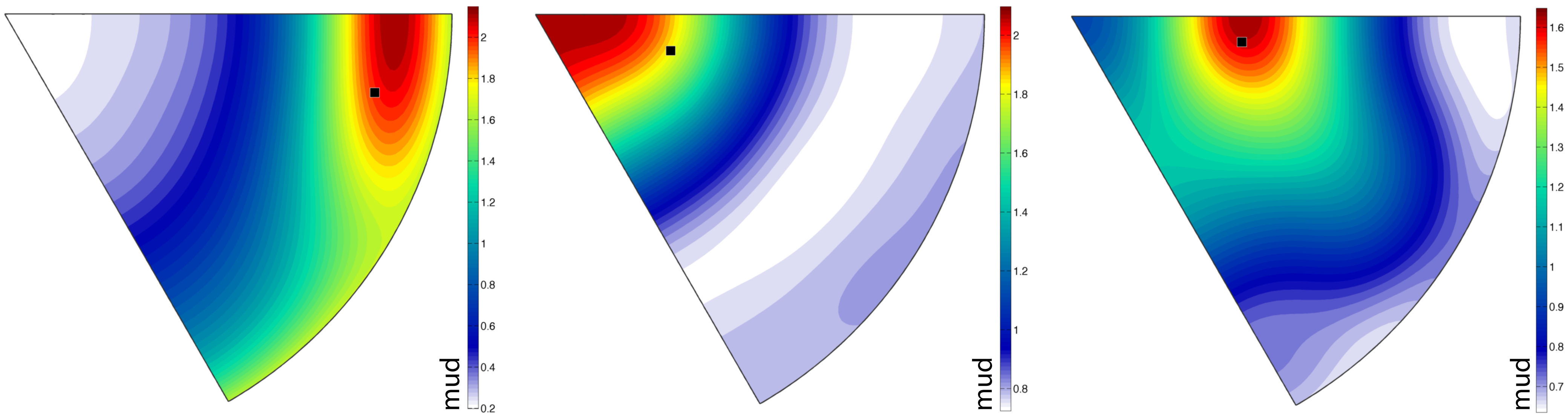
Testing the dispersion axis on very low angle boundaries

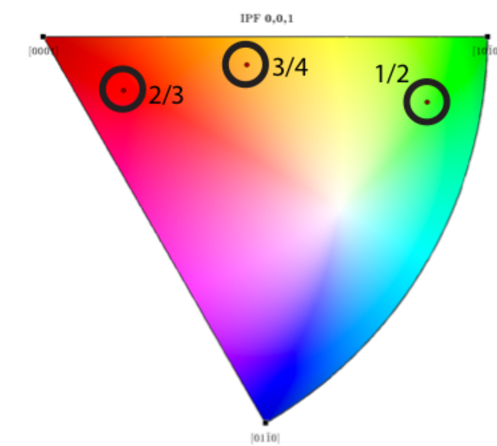
subgrain/ cluster pairs ≈ misorientation between clusters/subgrains

pair 1/2 pair 2/3 pair 3/4

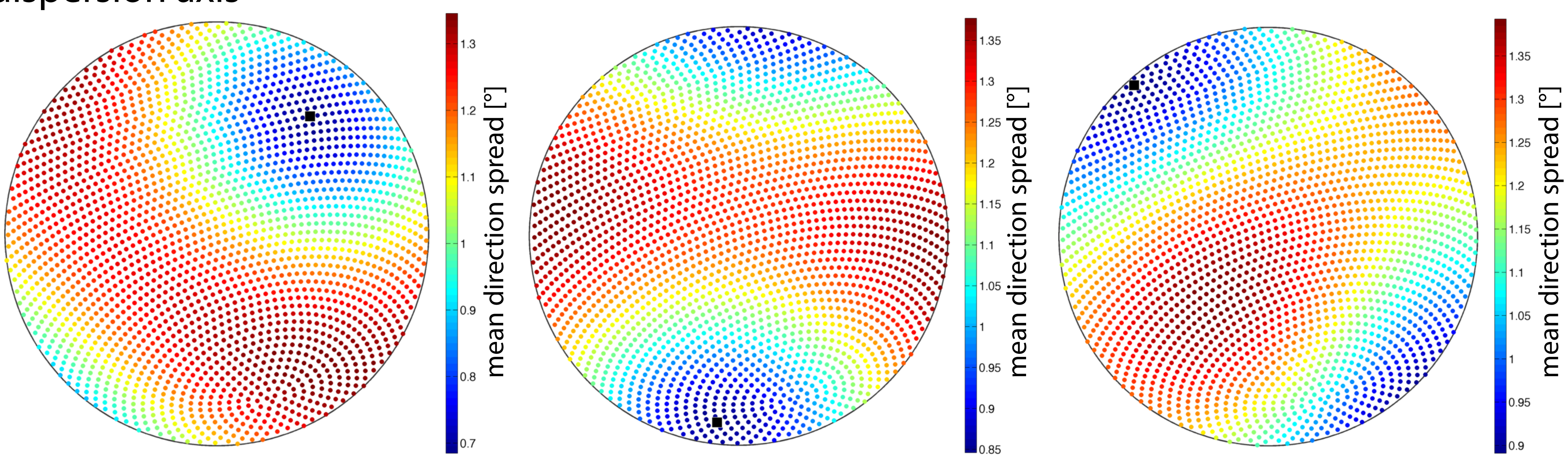
axes obtained from boundary misorientation:

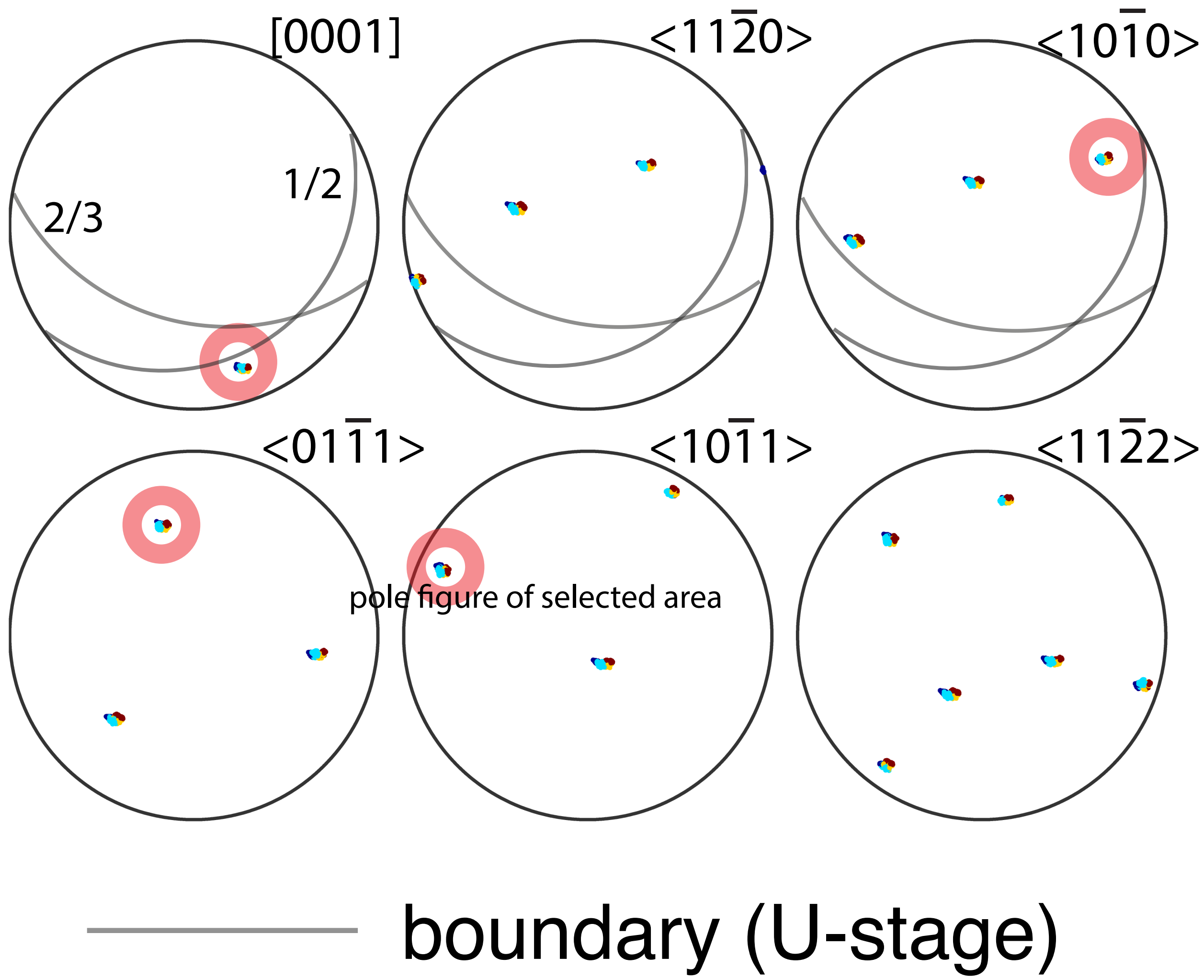
uncorrelated axis distribution of mdf

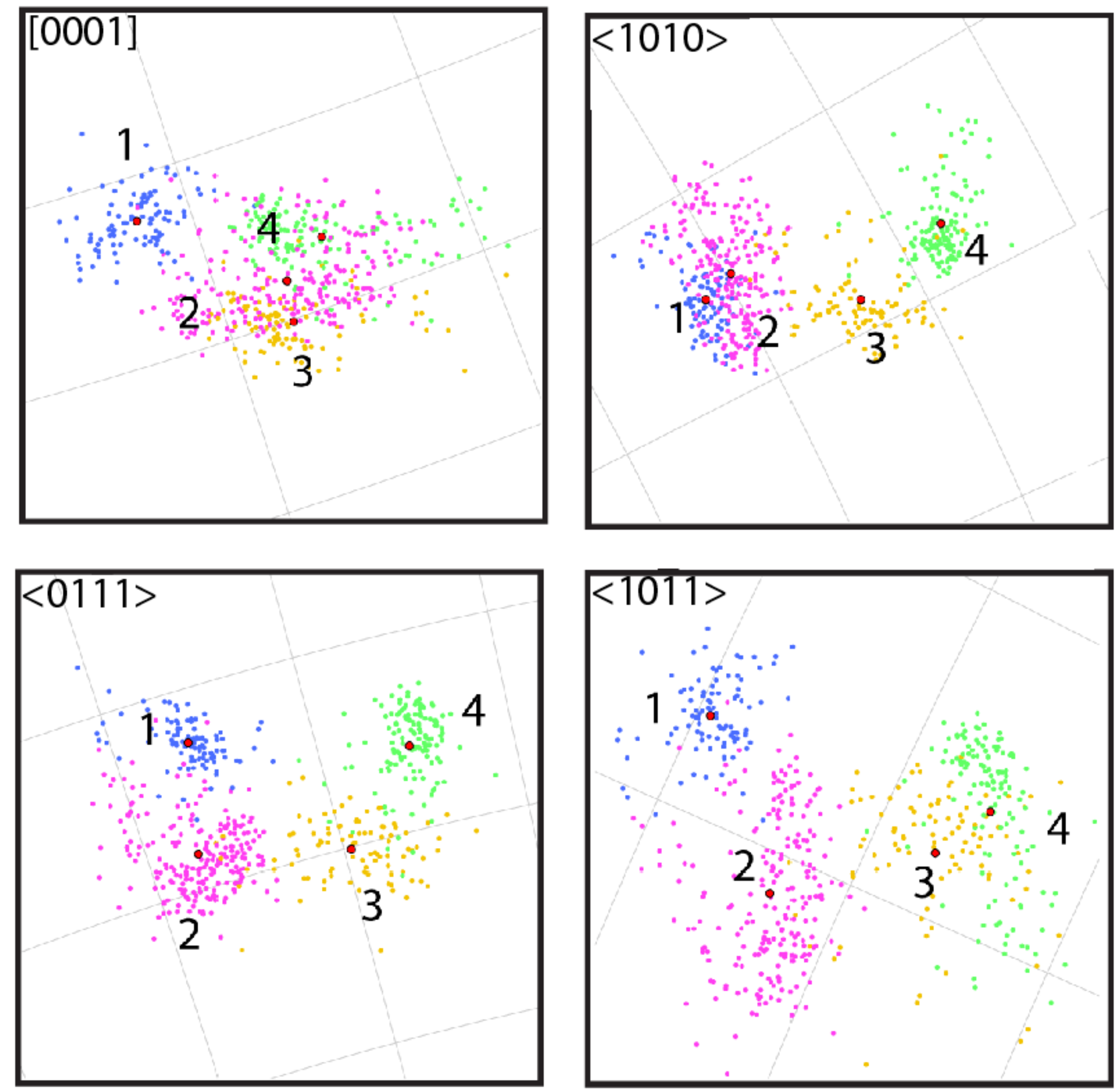




dispersion axis



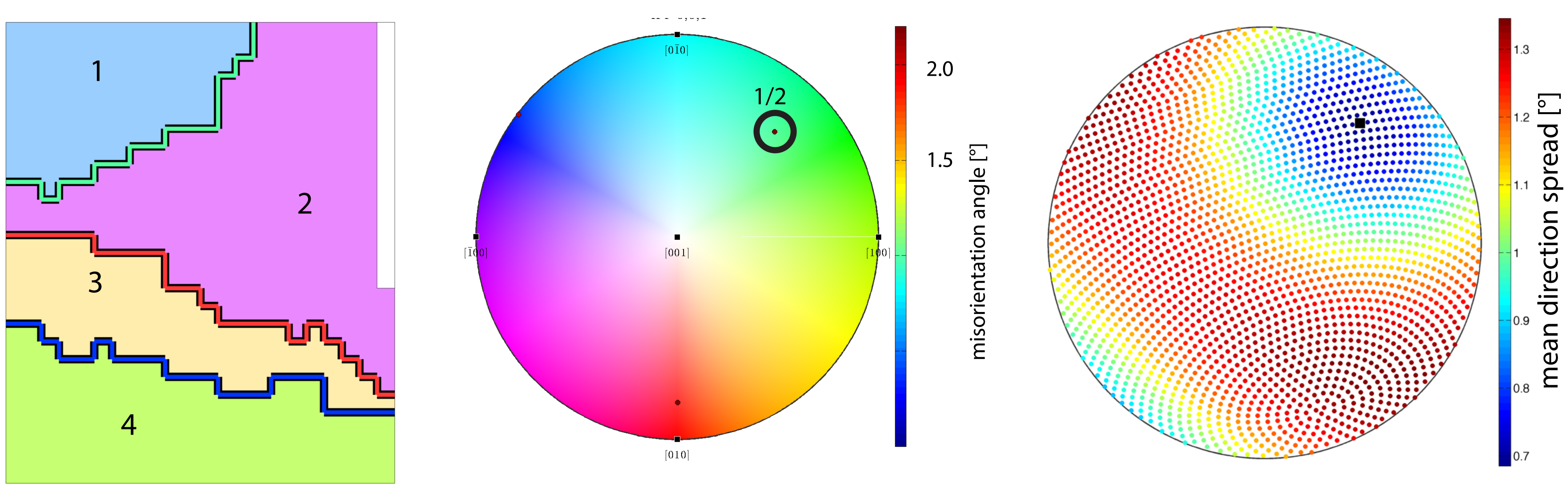


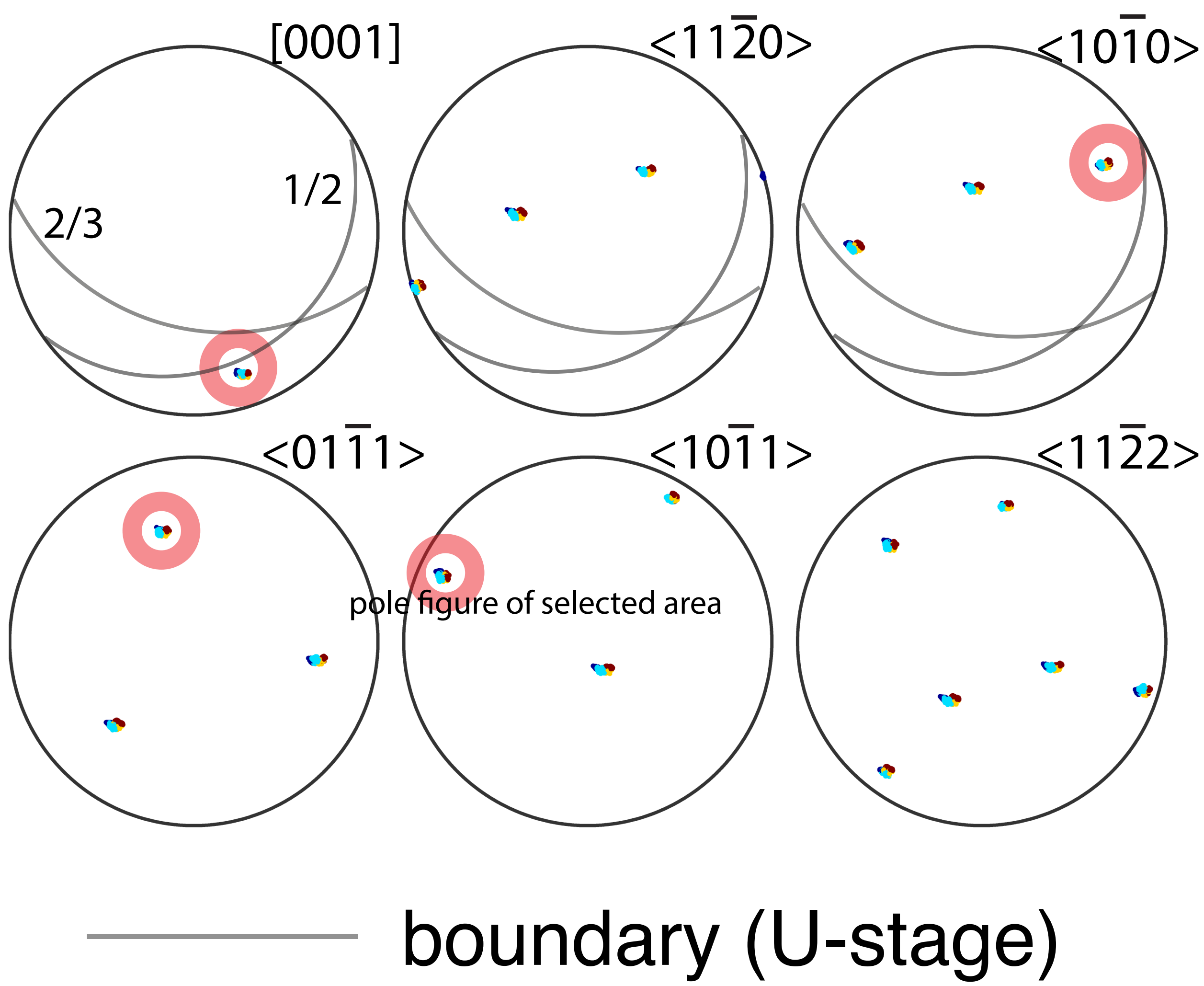


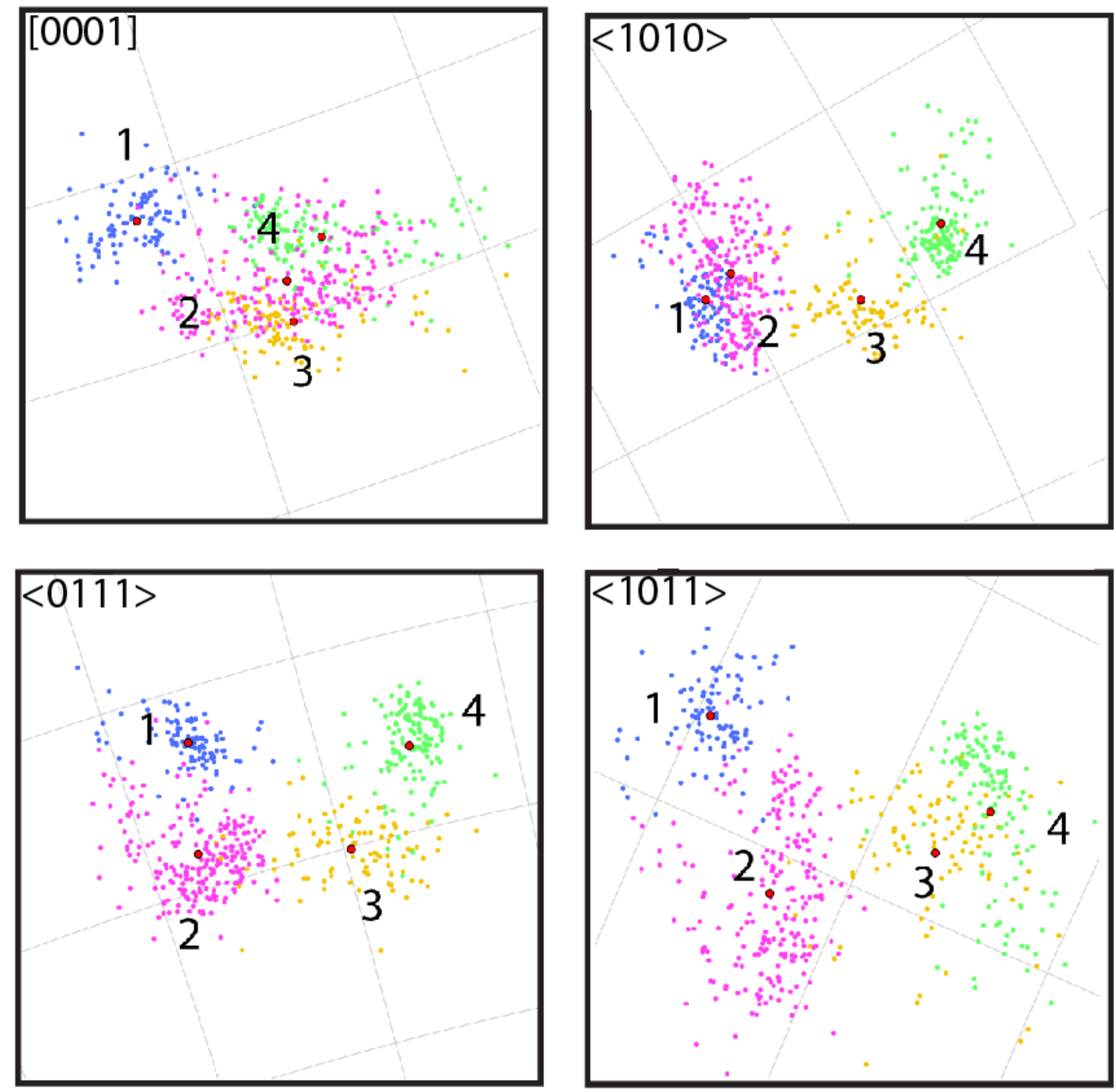
pole color = mean grain color (IPF)

3° grid

pair 1/2







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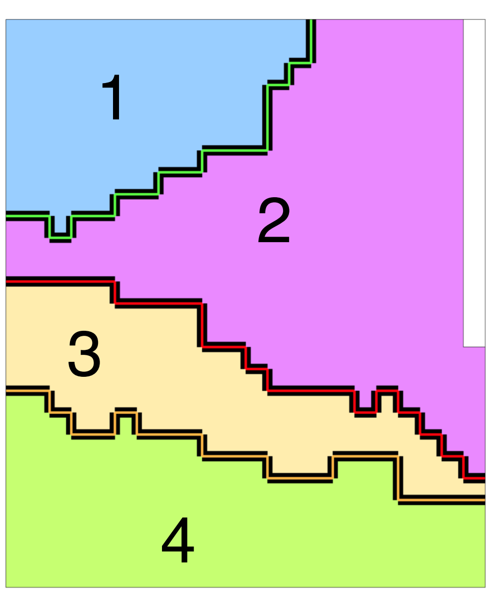
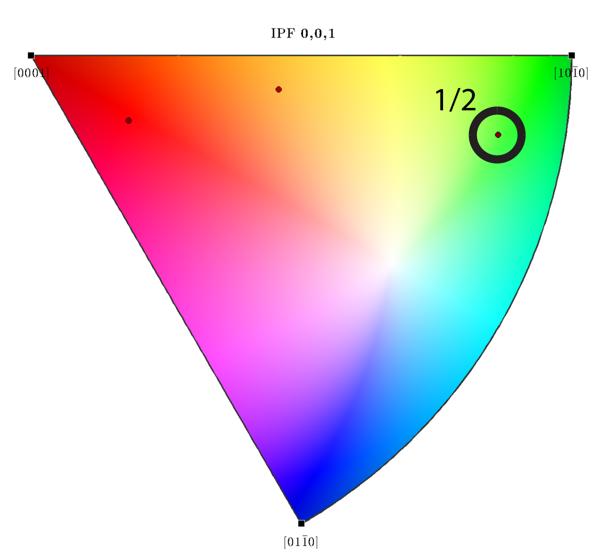
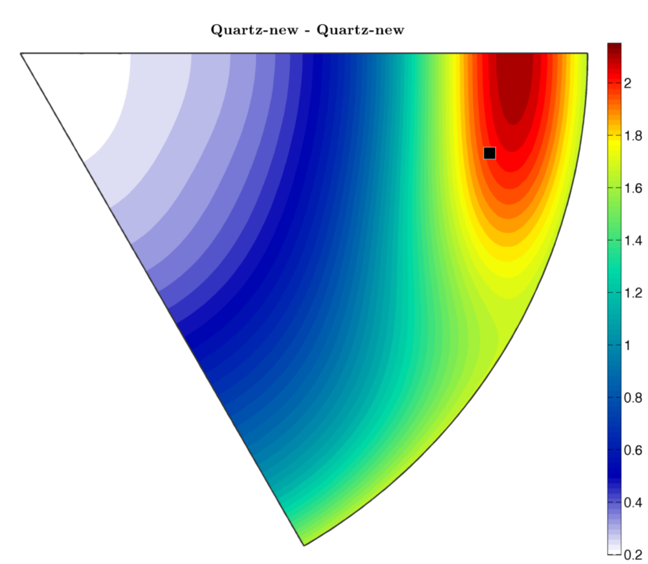
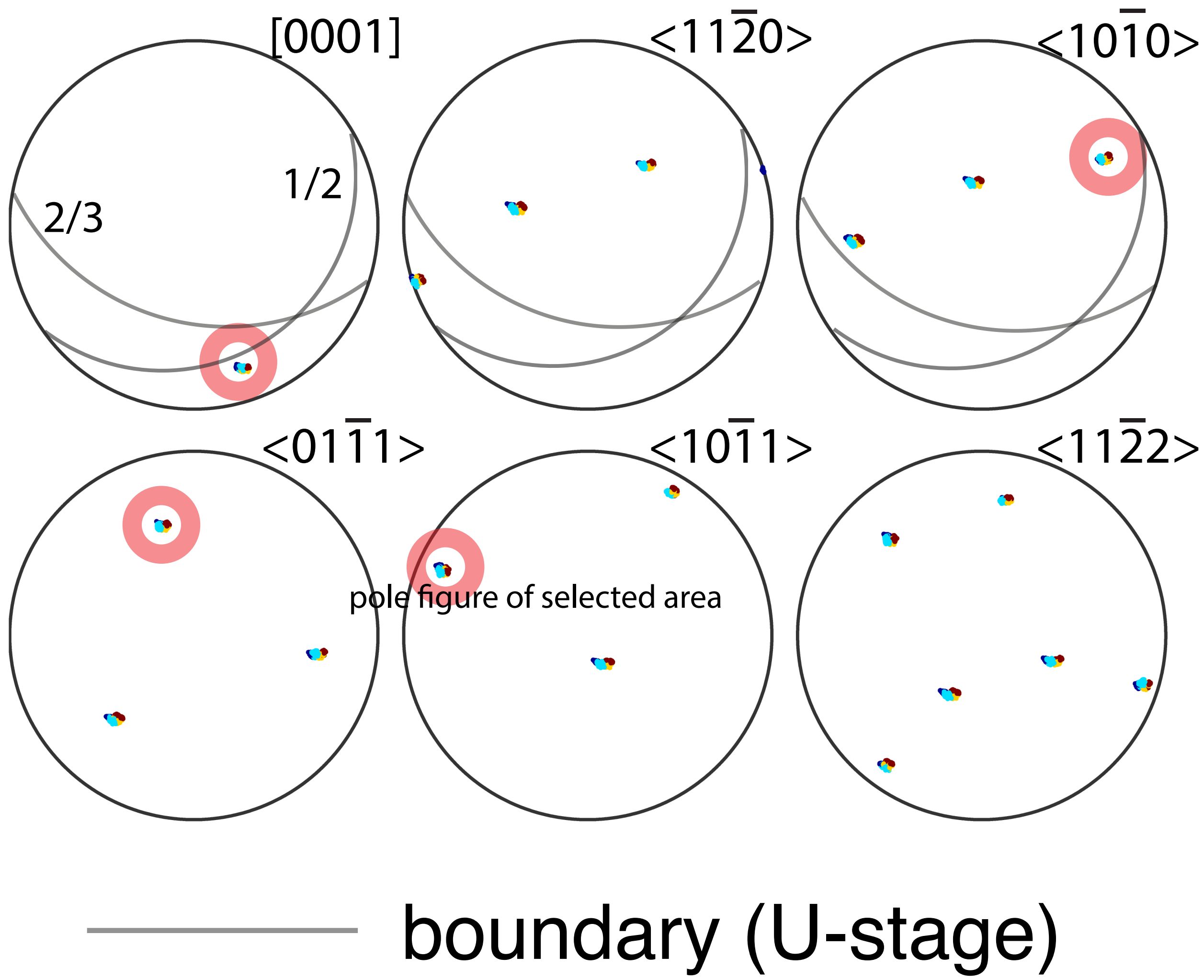
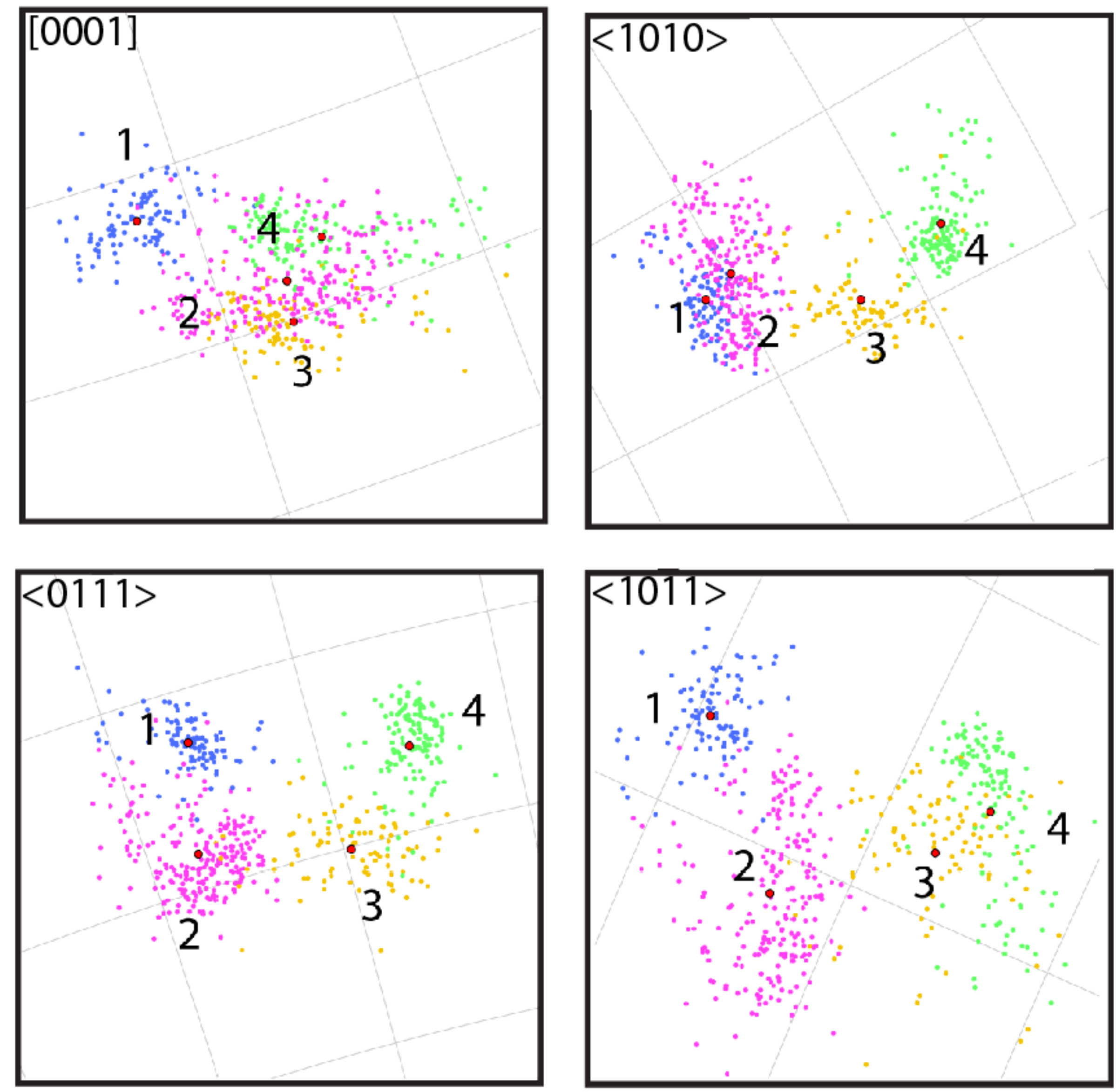






boundary (1/2): tilt character, could be related to basal-a or some more exotic slip-system

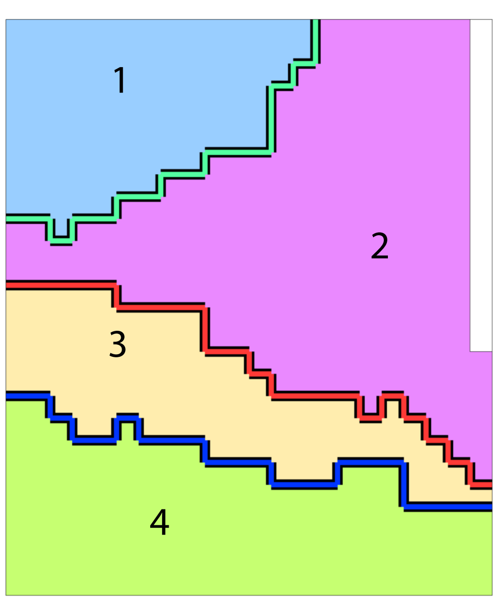


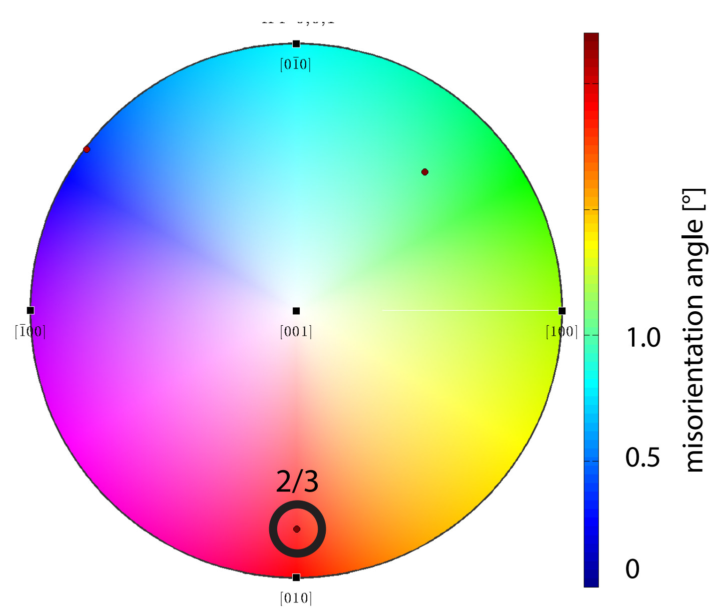


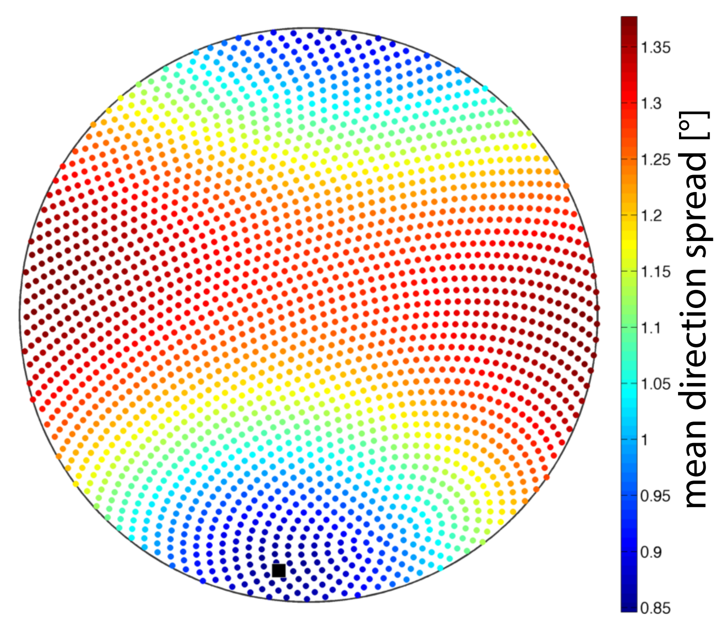
pole color = mean grain color (IPF)

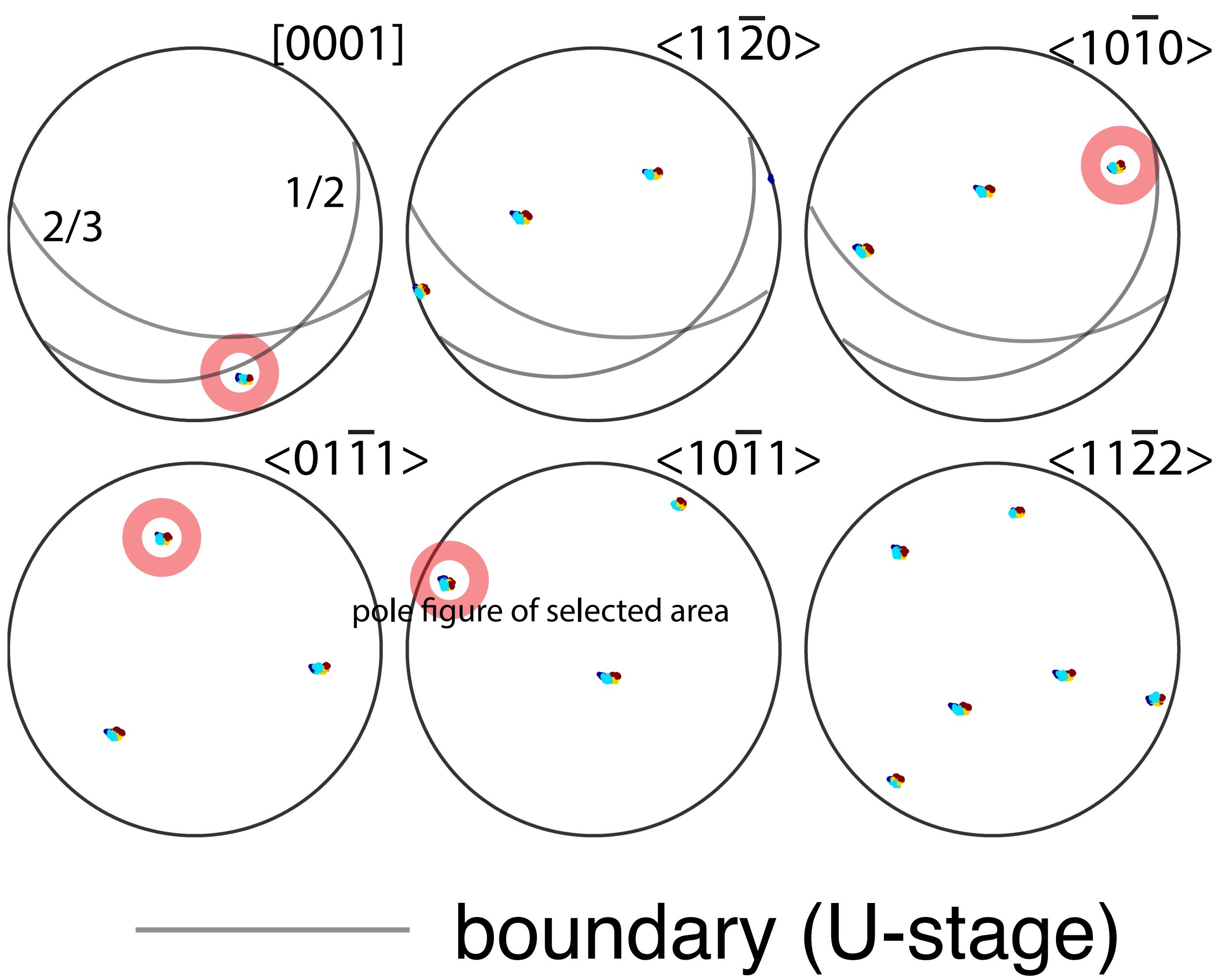
3° grid

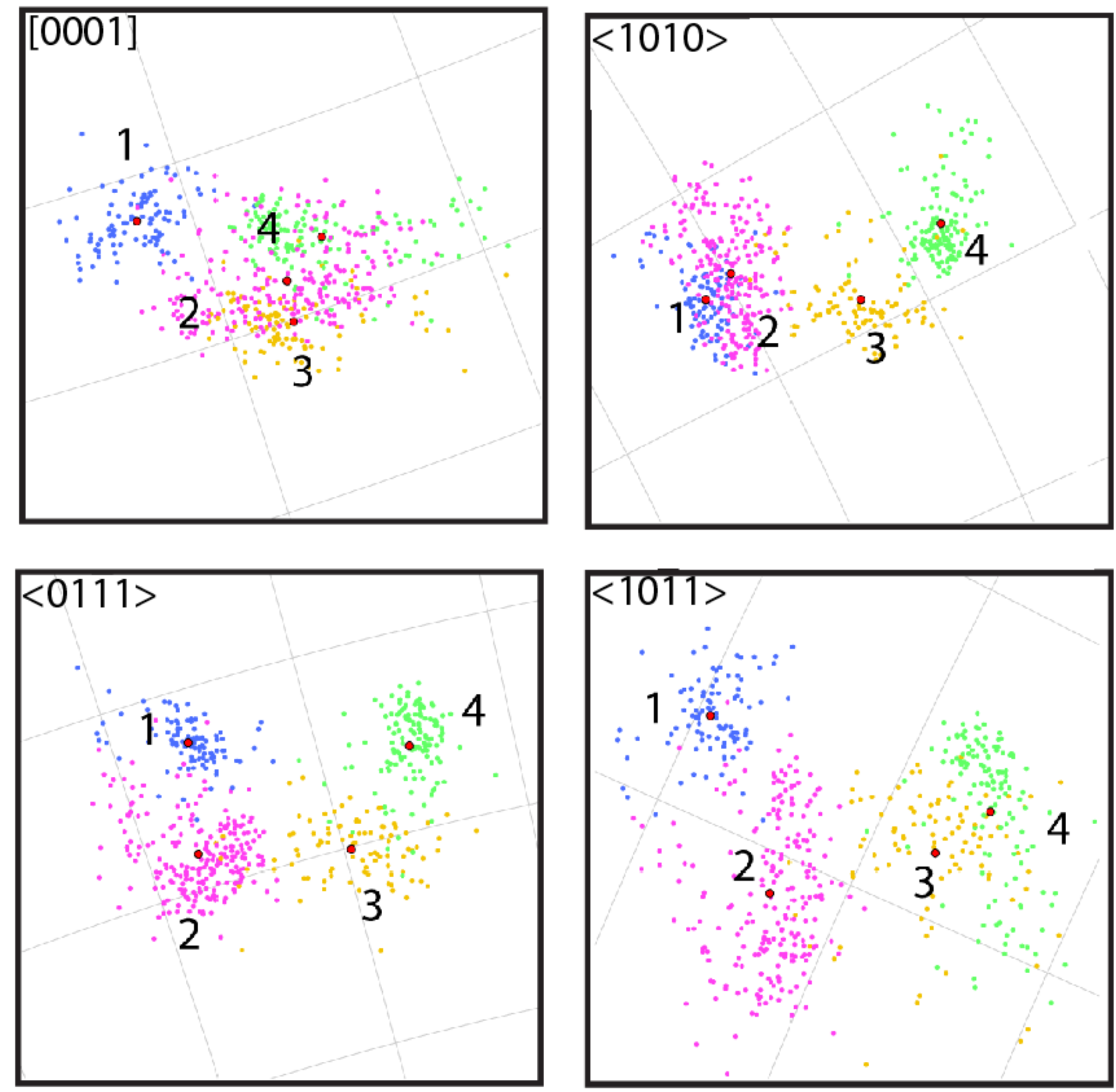
pair 2/3





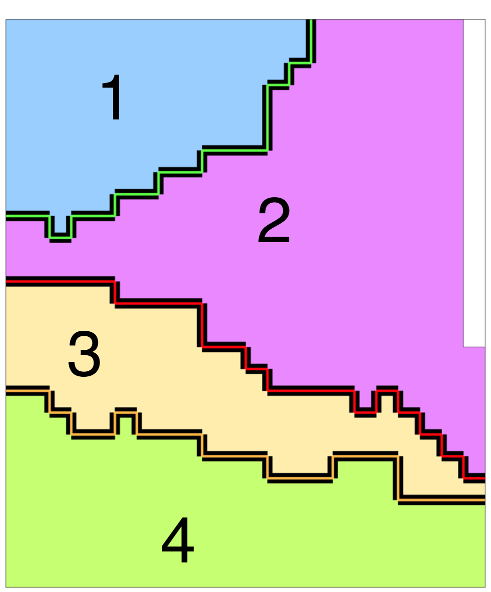


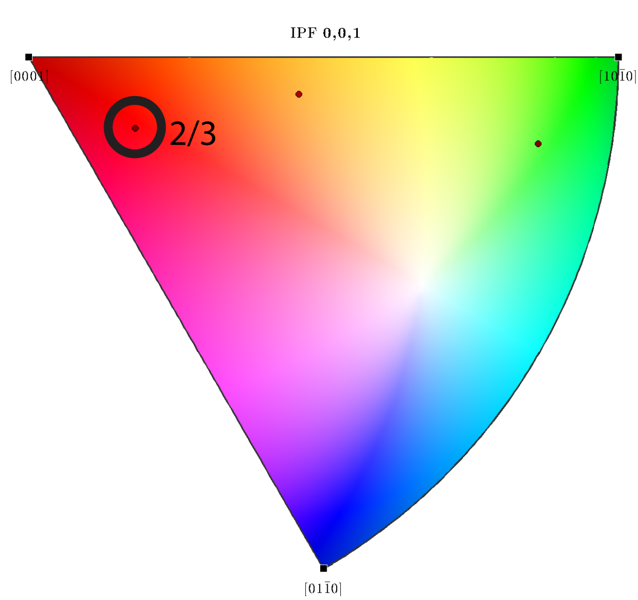


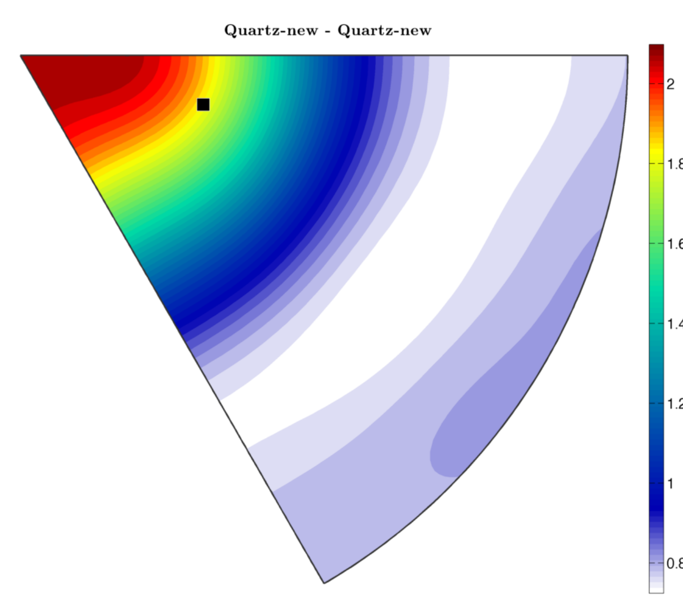


pole color = mean grain color (IPF) 3° grid

pair 2/3

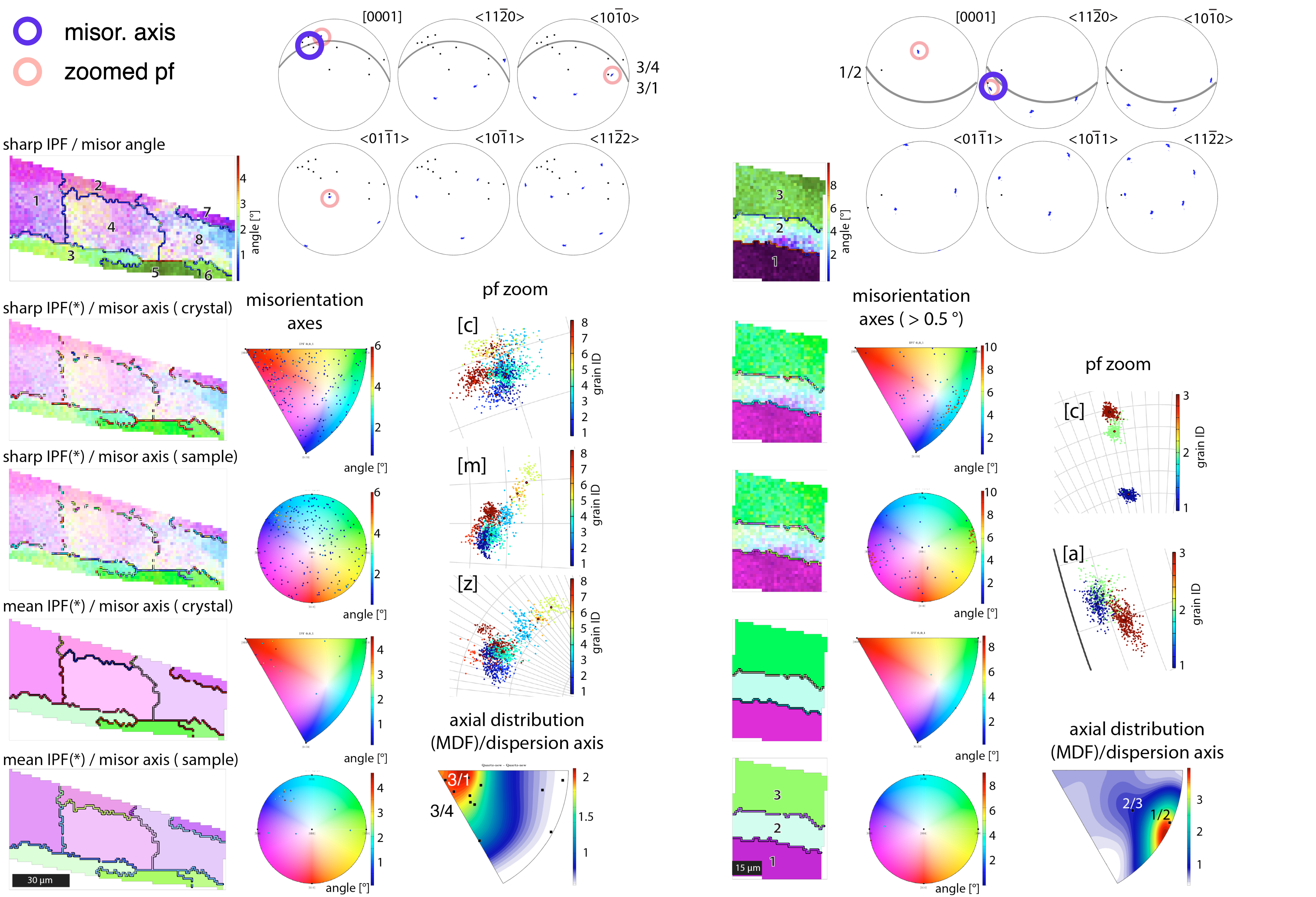






boundary (2/3): tilt character, could be related to prism-a

all sorts of boundary/axis relations are found: mostly tilt character



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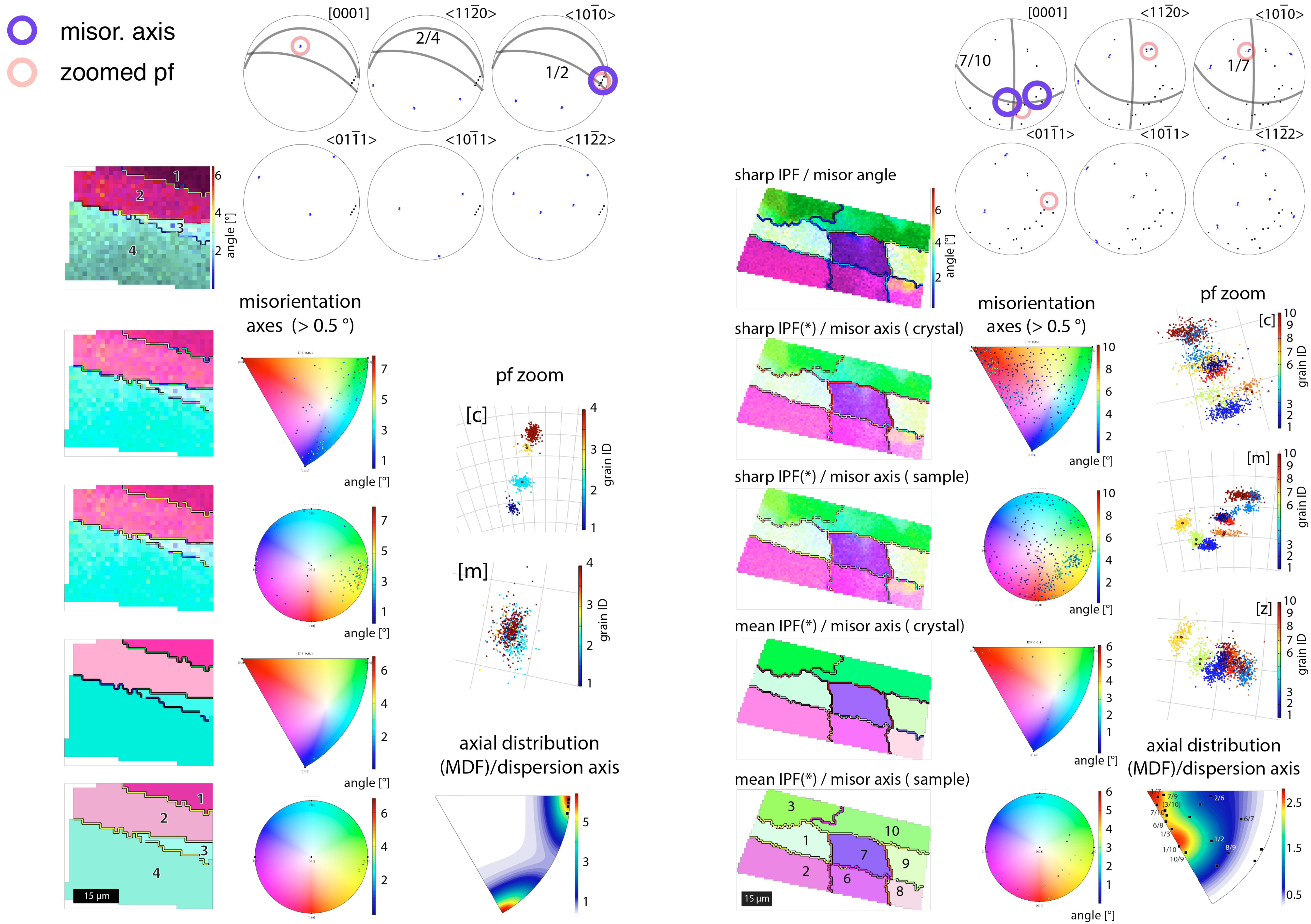
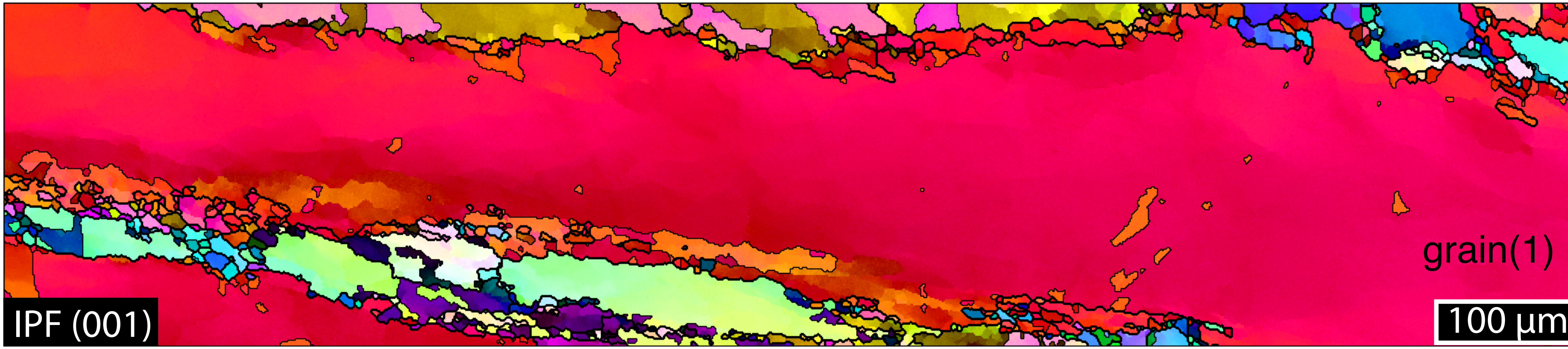
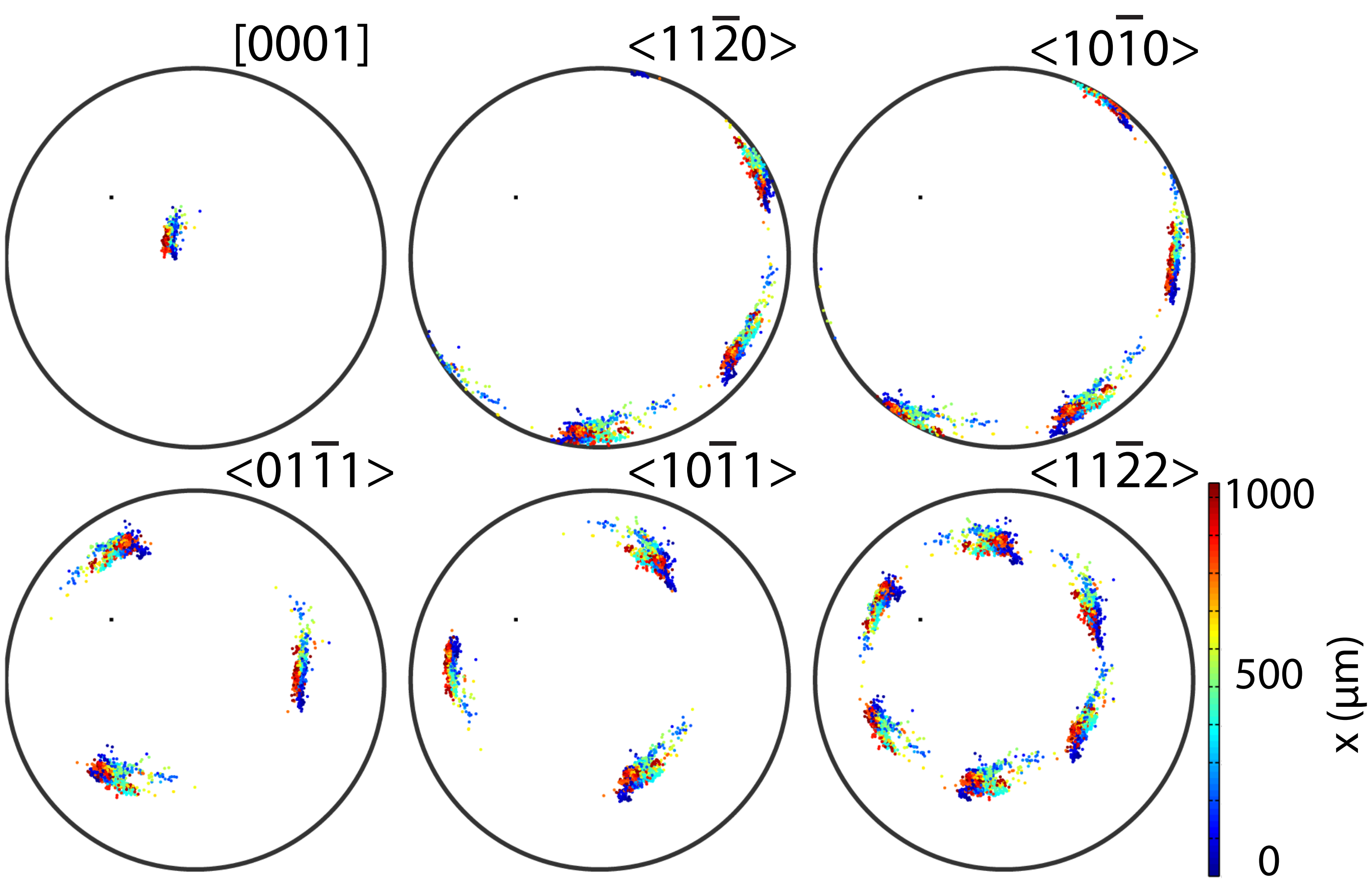
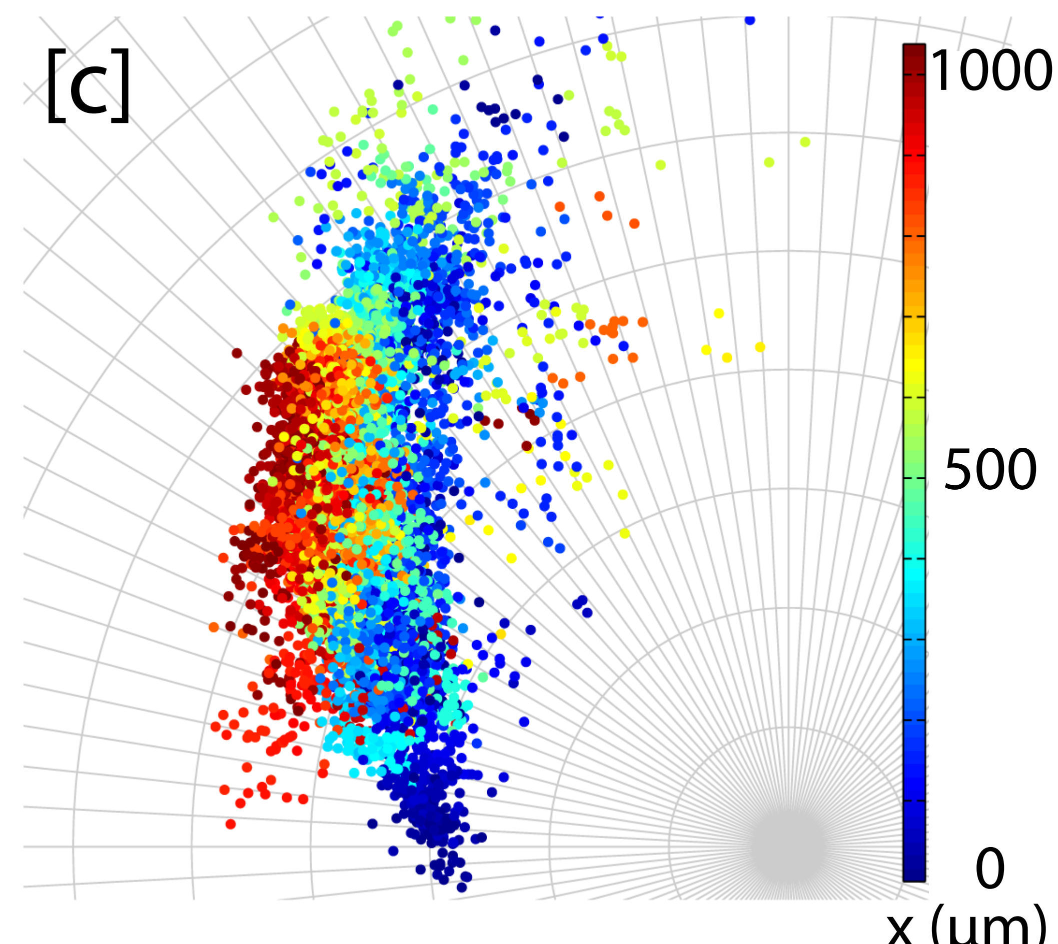


site 1: central c-axis



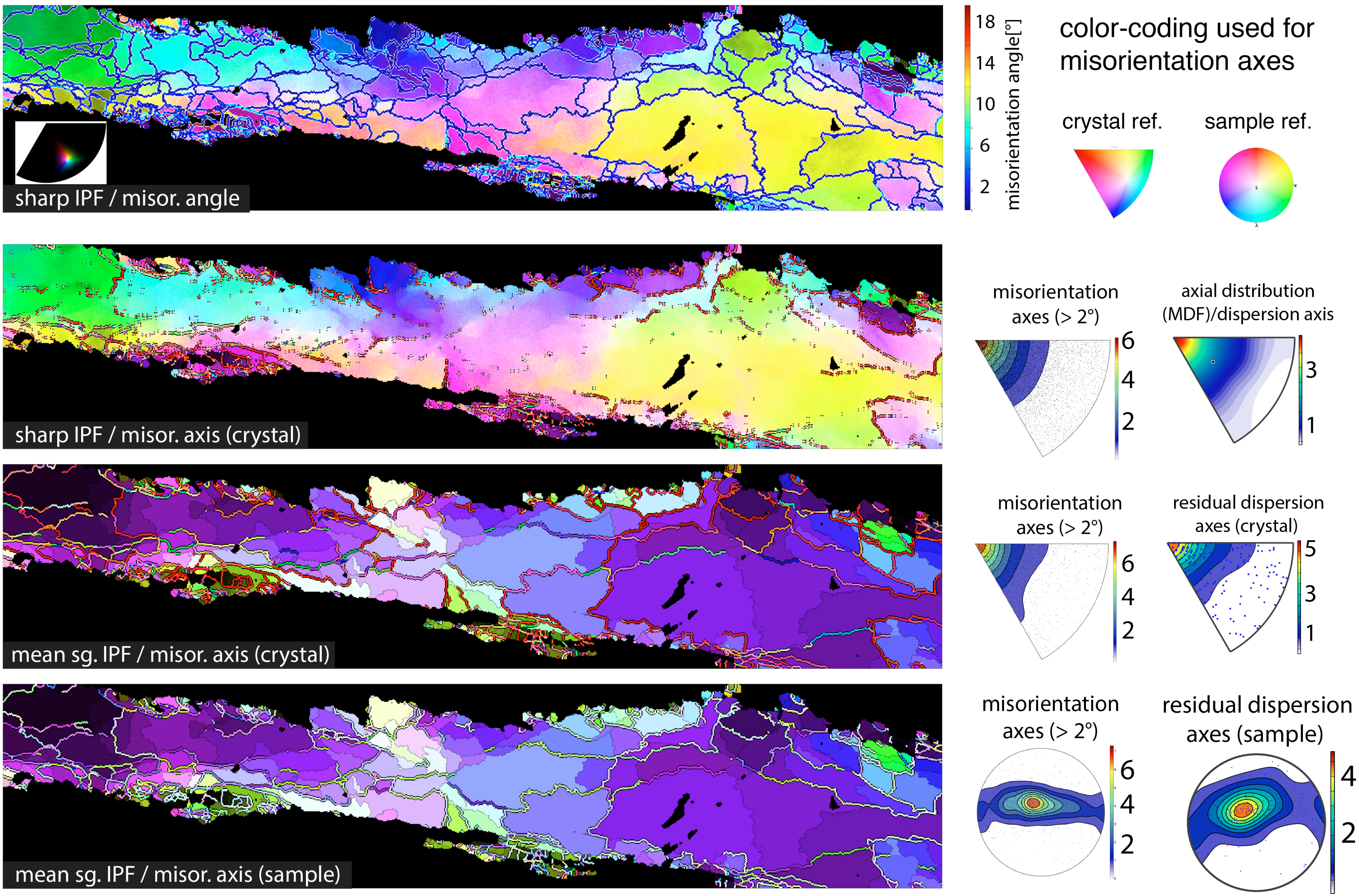


color-coded distance along grain(1) long axis

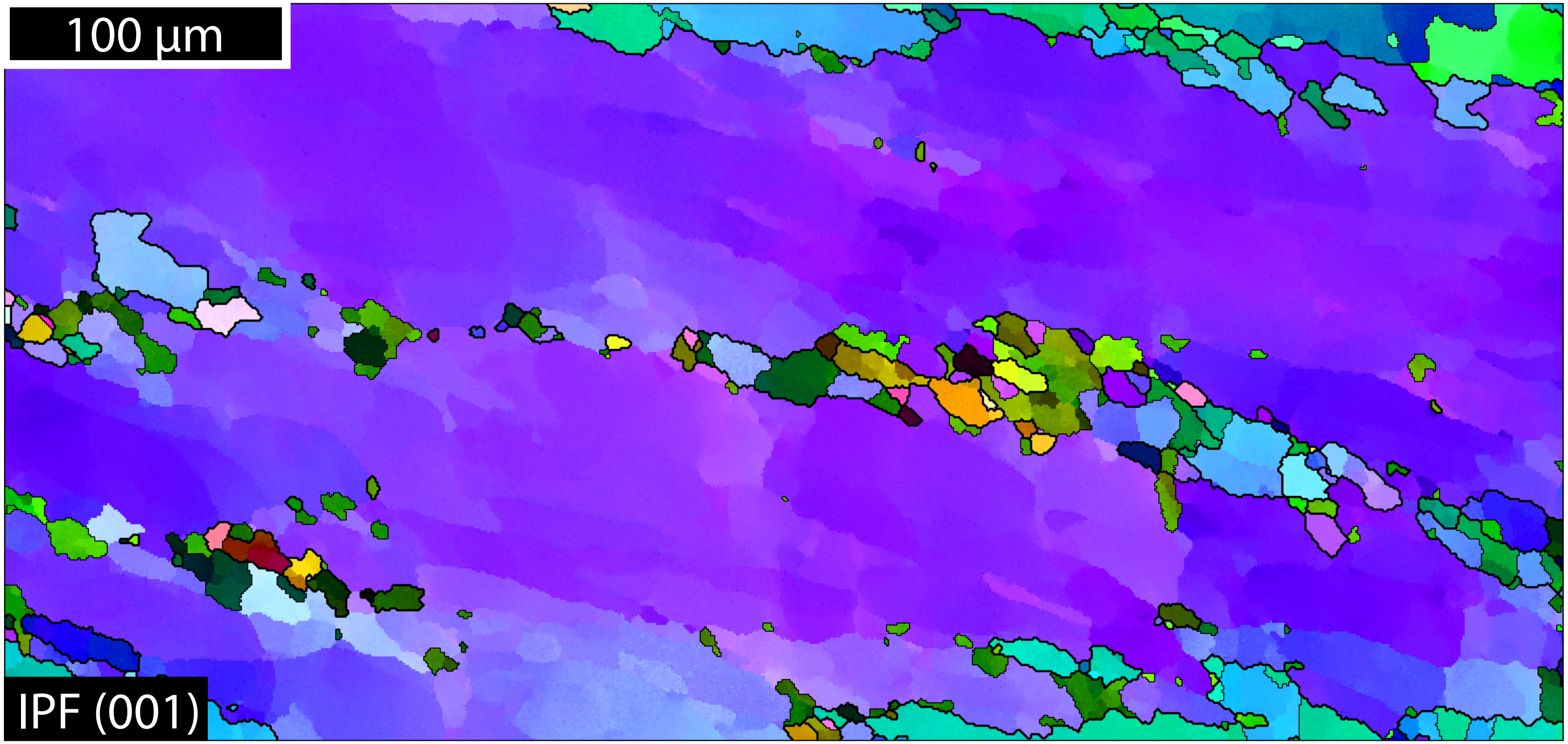


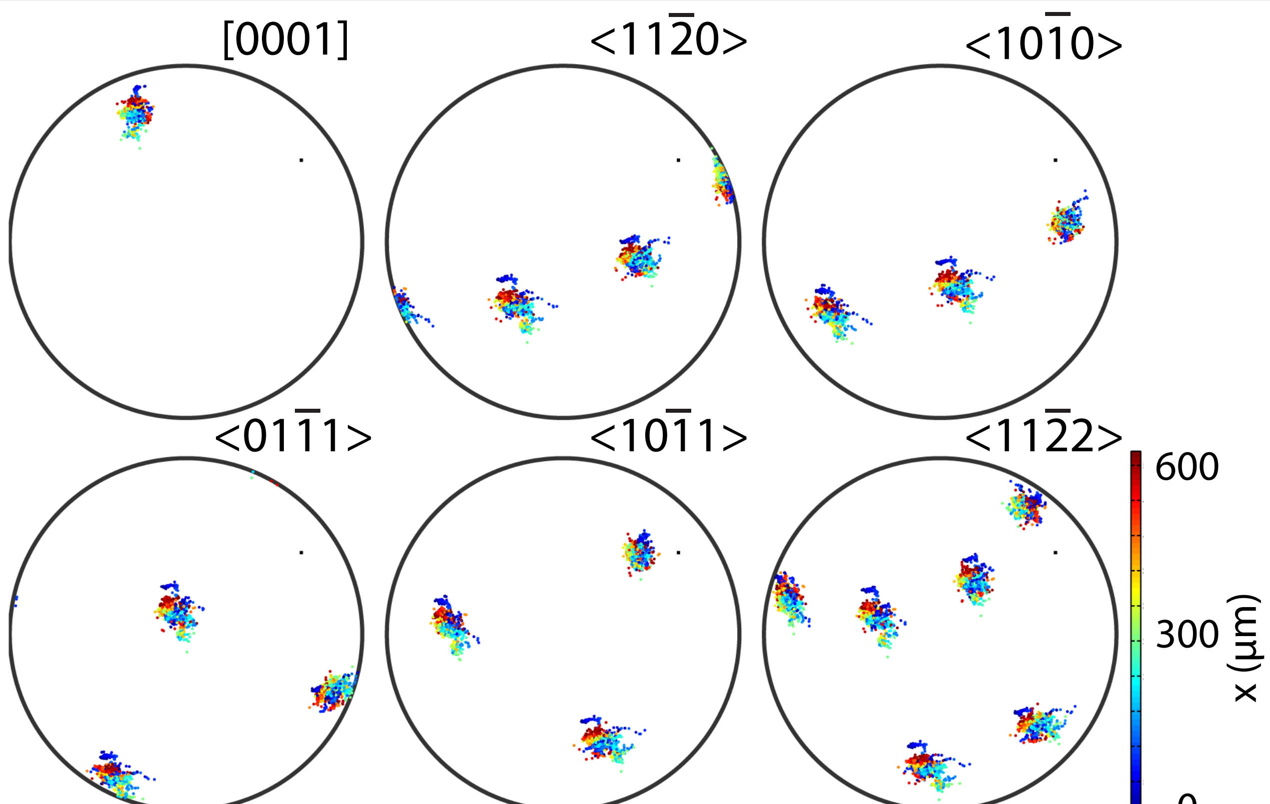
detail of pf for 0001

site 1: central c-axis



site 2: (roughly) peripheral c-axis





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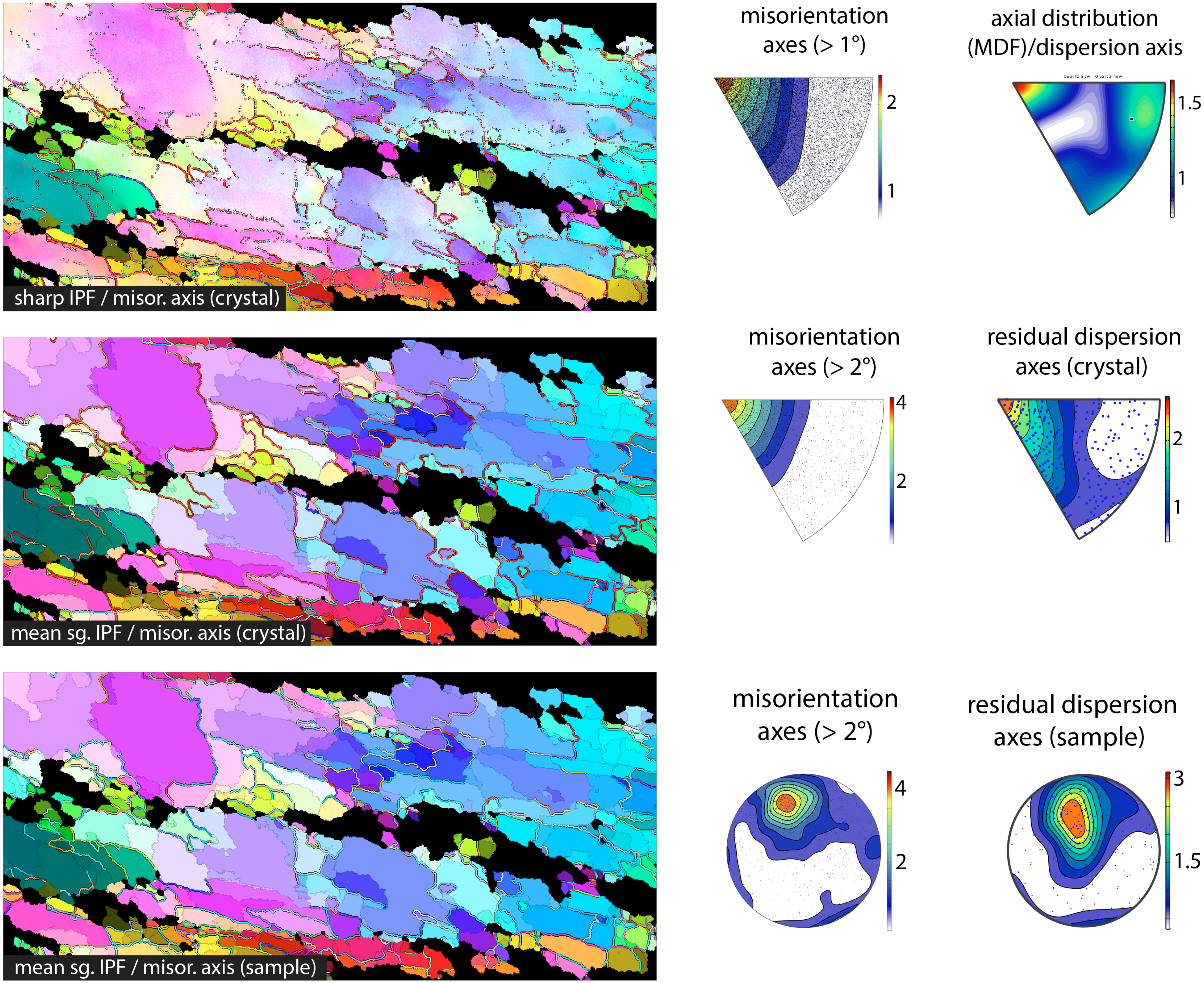
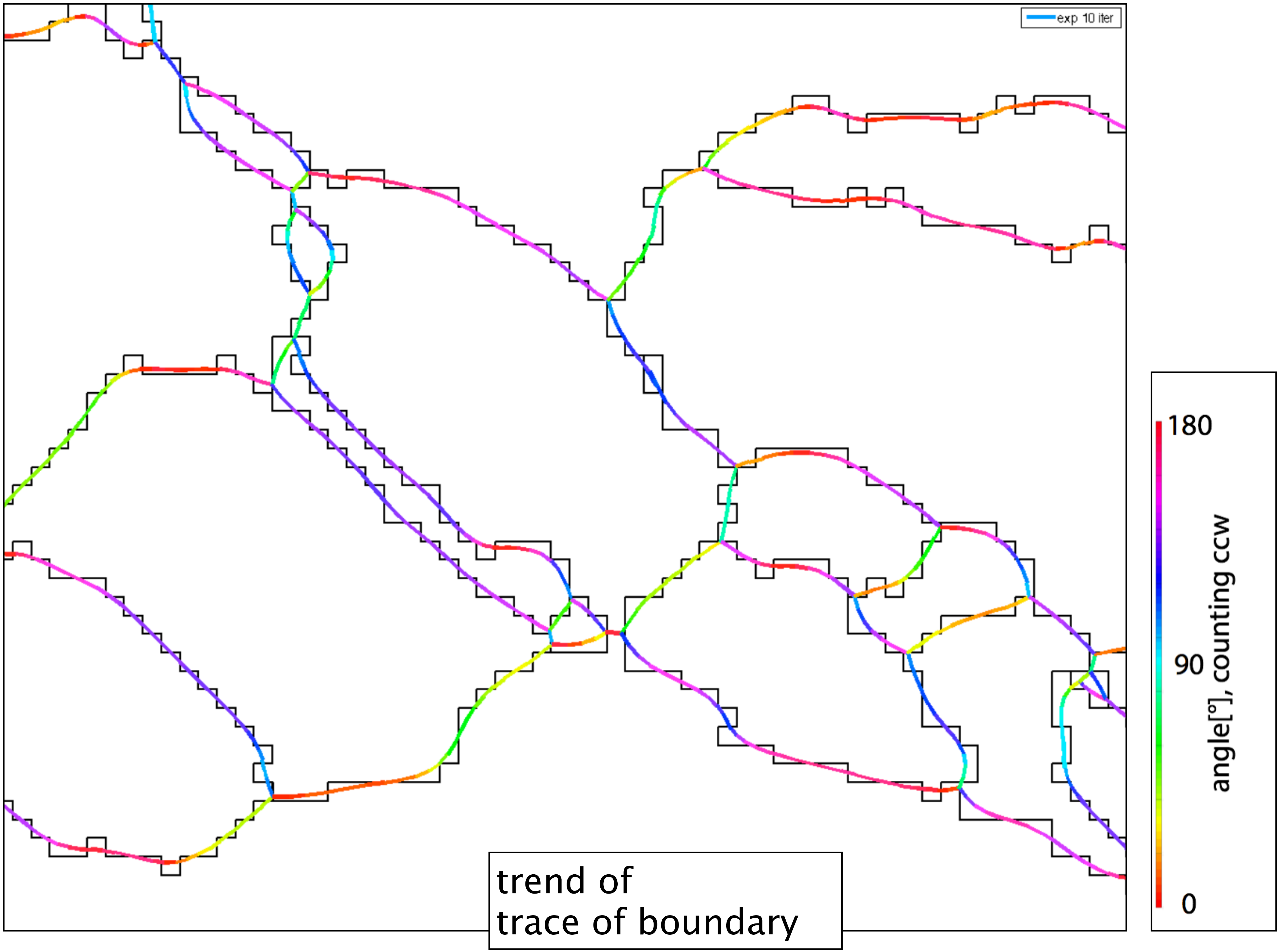
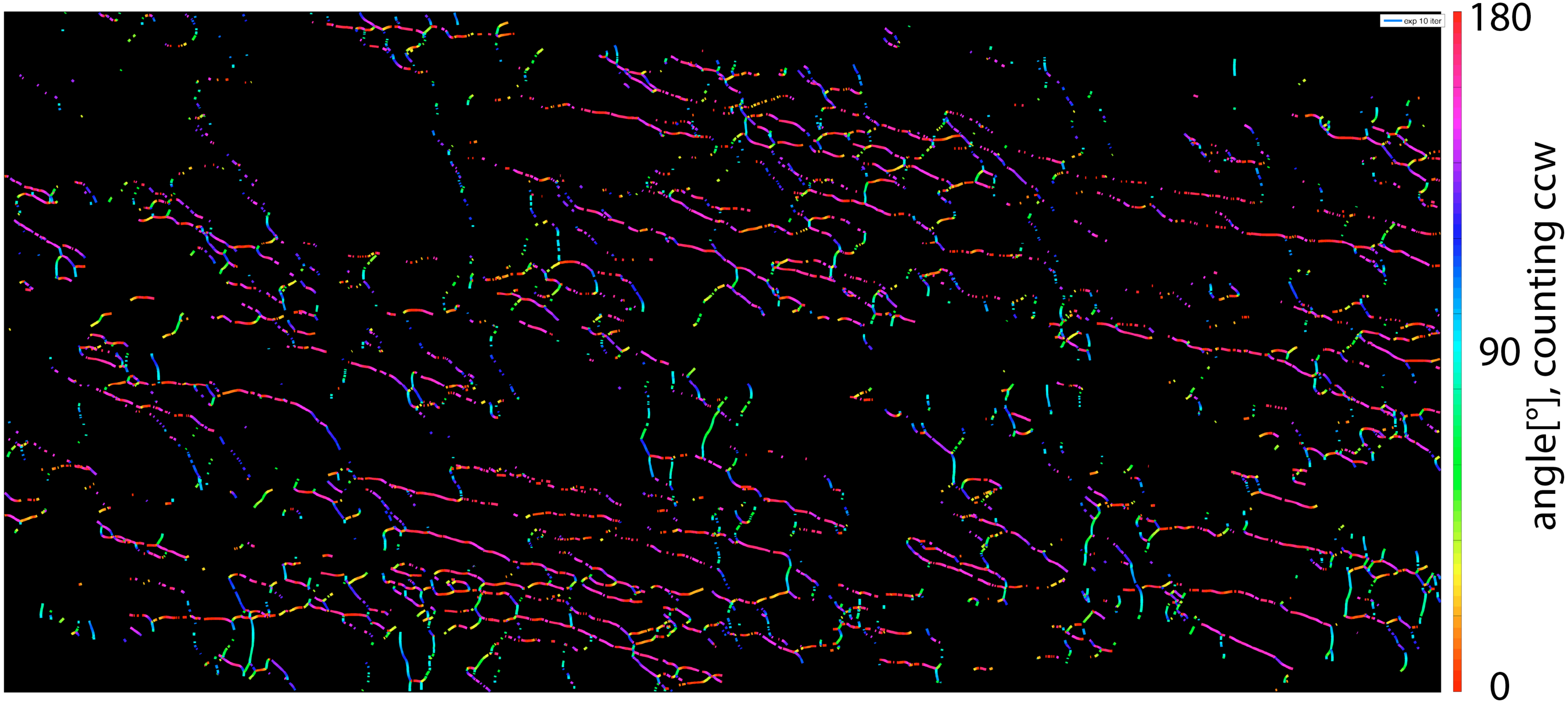


MTEX does very nice boundary smoothing!

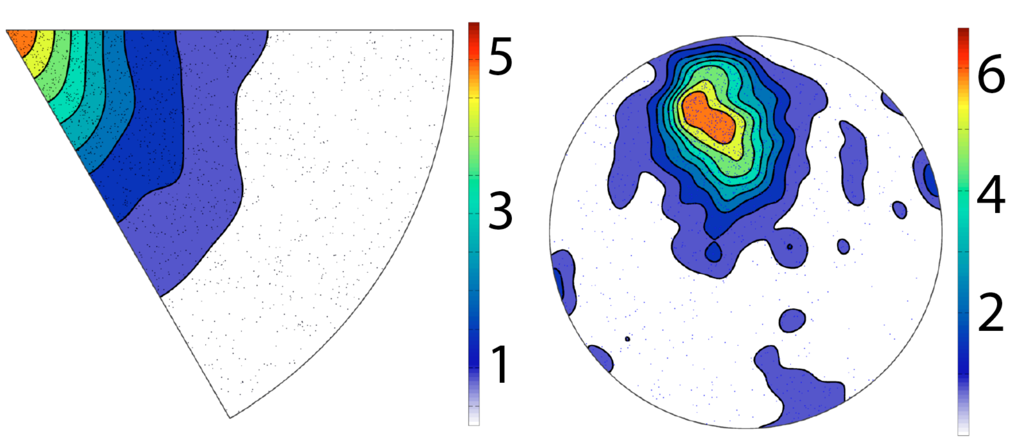


trend of boundary trace:

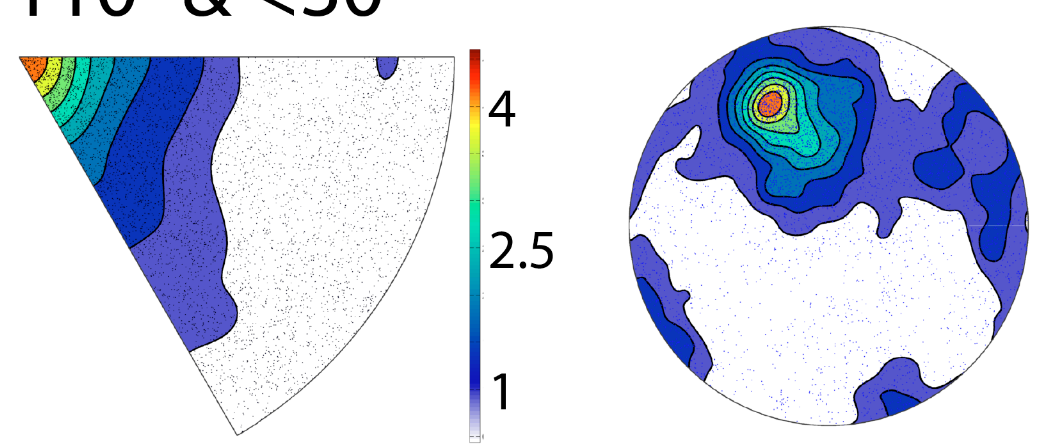


misorientation axes (> 2°)

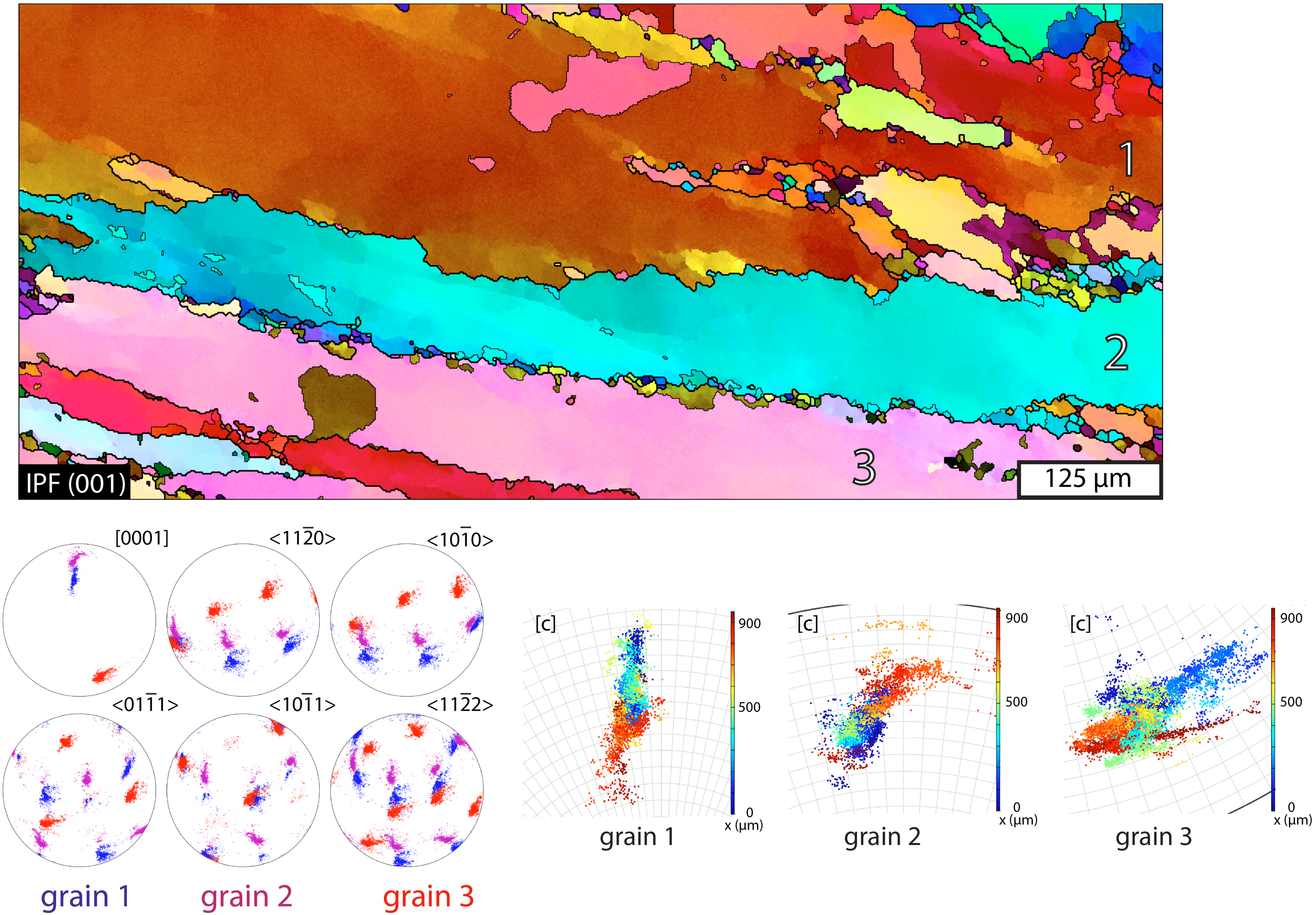
30° -110°



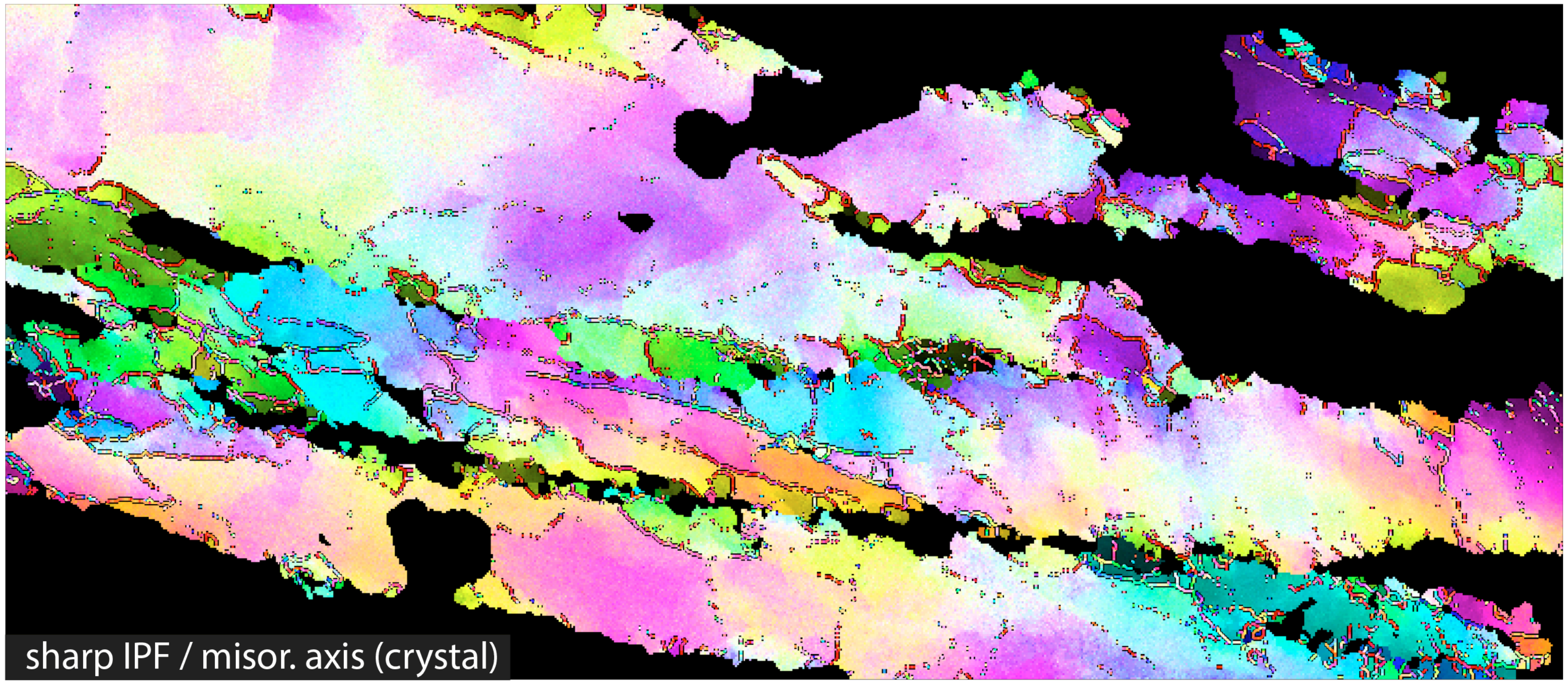
>110° & <30°



site 3: 3 adjacent grains with similar c-axis directions

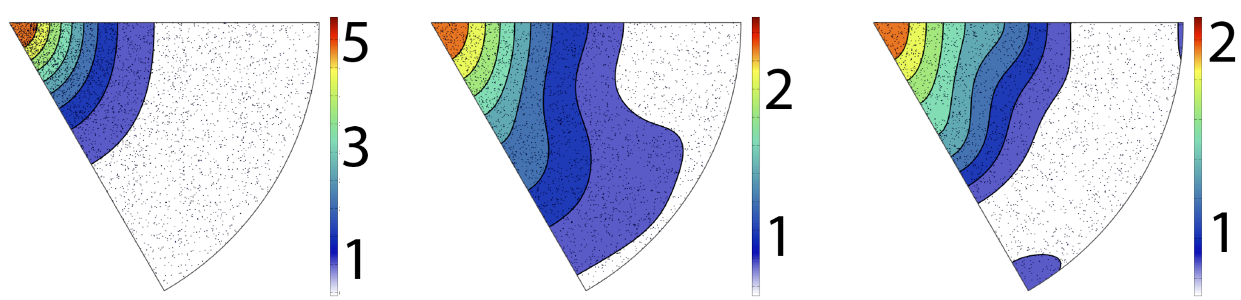


site 3: 3 adjacent grains with similar c-axis directions



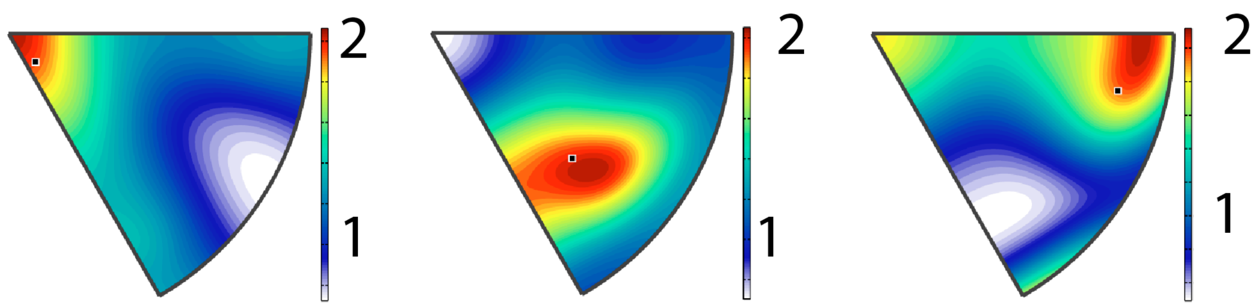
grain1 grain 2 grain 3

misorientation axes (> 1.5°) (crystal ref.)



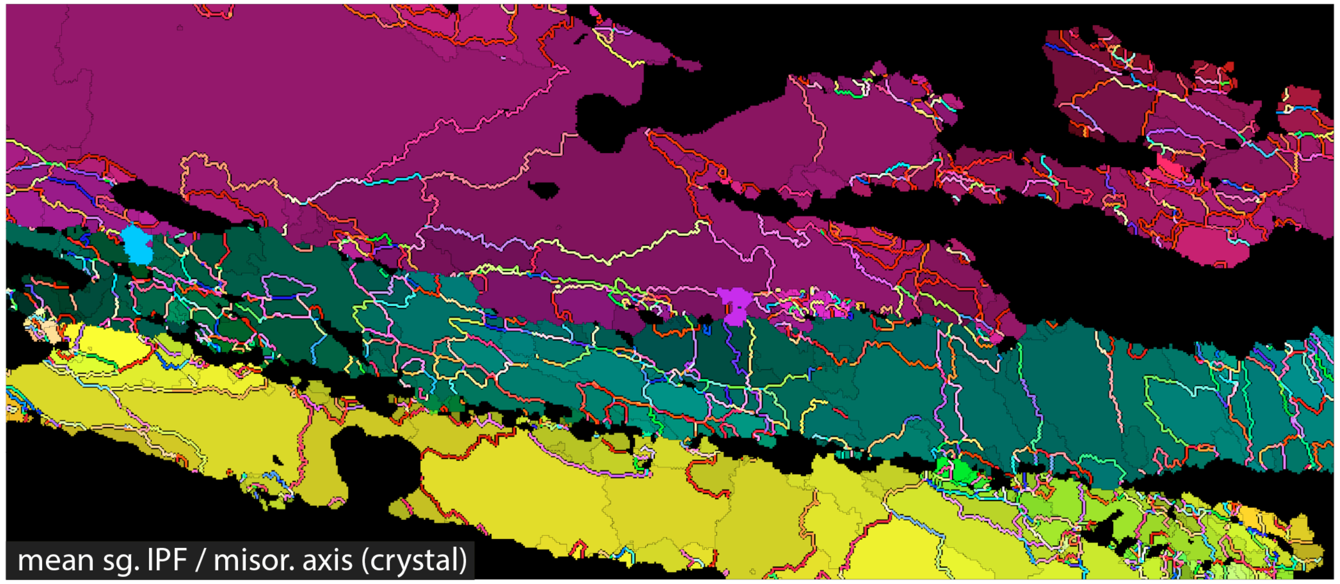
Low angle boundaries show a weak preference for rotation axes around 0001

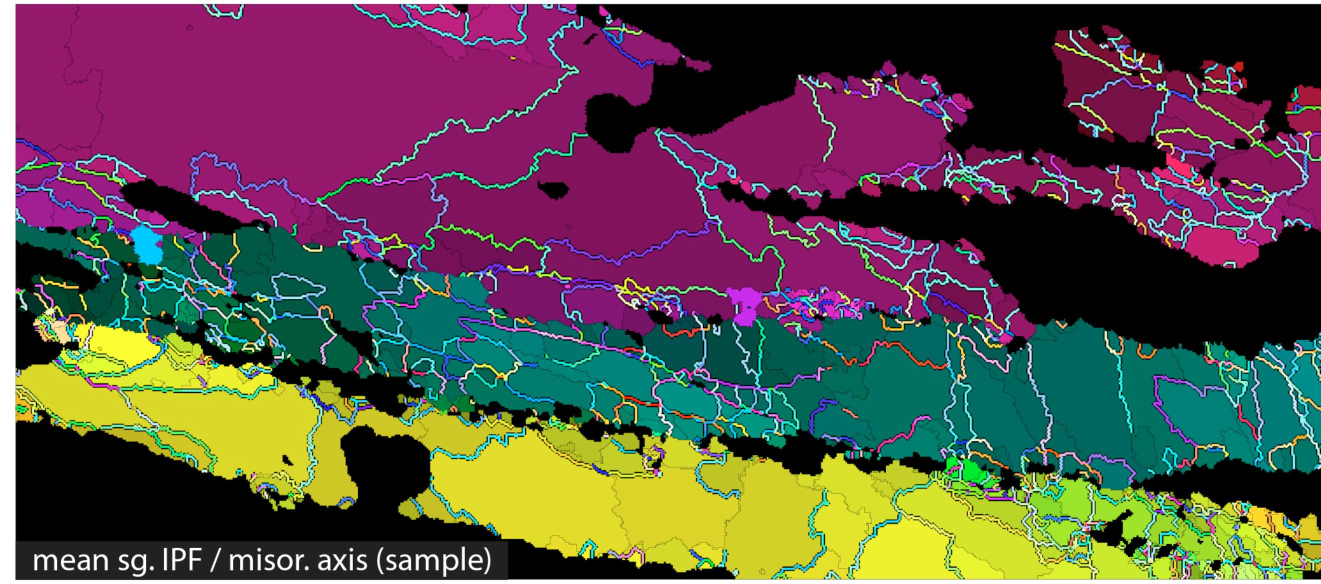
axial distribution (MDF)/dispersion axis



For grain 2 and 3, dispersion and mdf axes of entire grains do not coincide with misorientation axes

site 3: 3 adjacent grains with similar c-axis directions

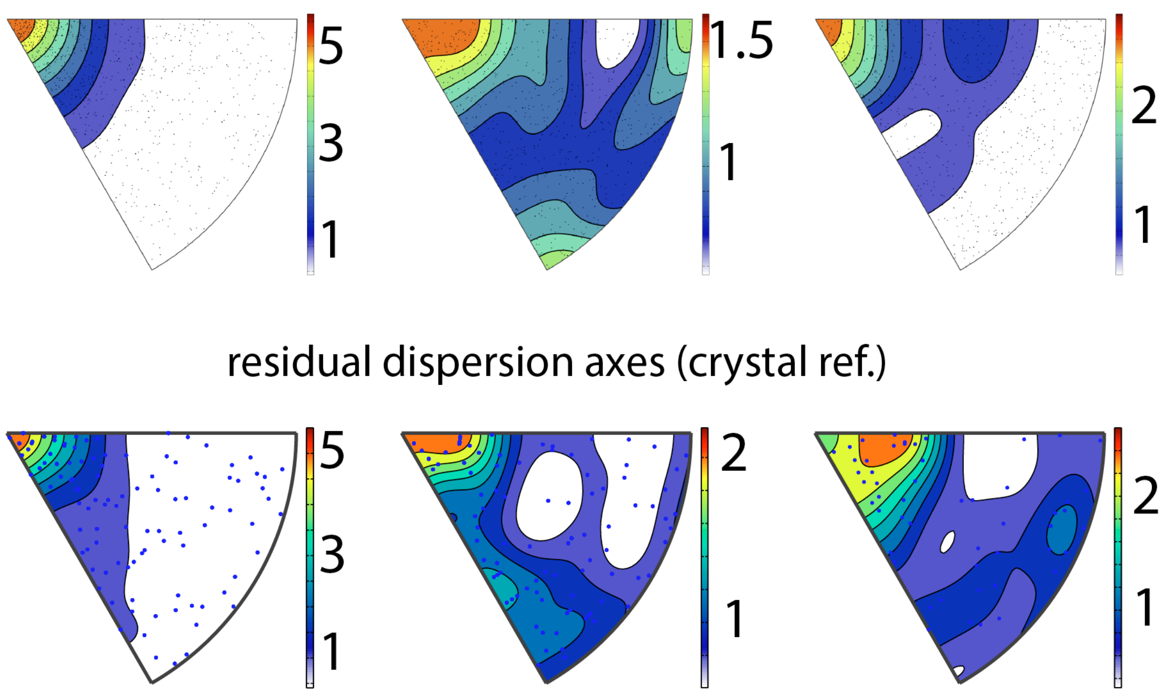




grain1 grain 2 grain 3

misorientation axes (> 2°) (crystal ref.)

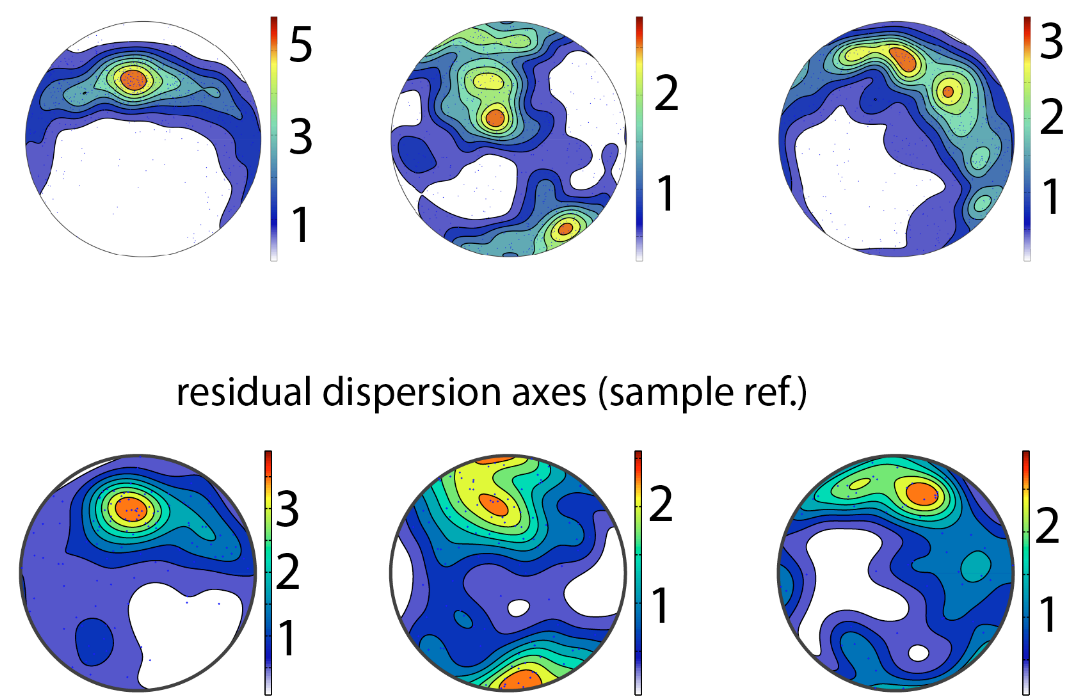
residual dispersion axes (crystal ref.)



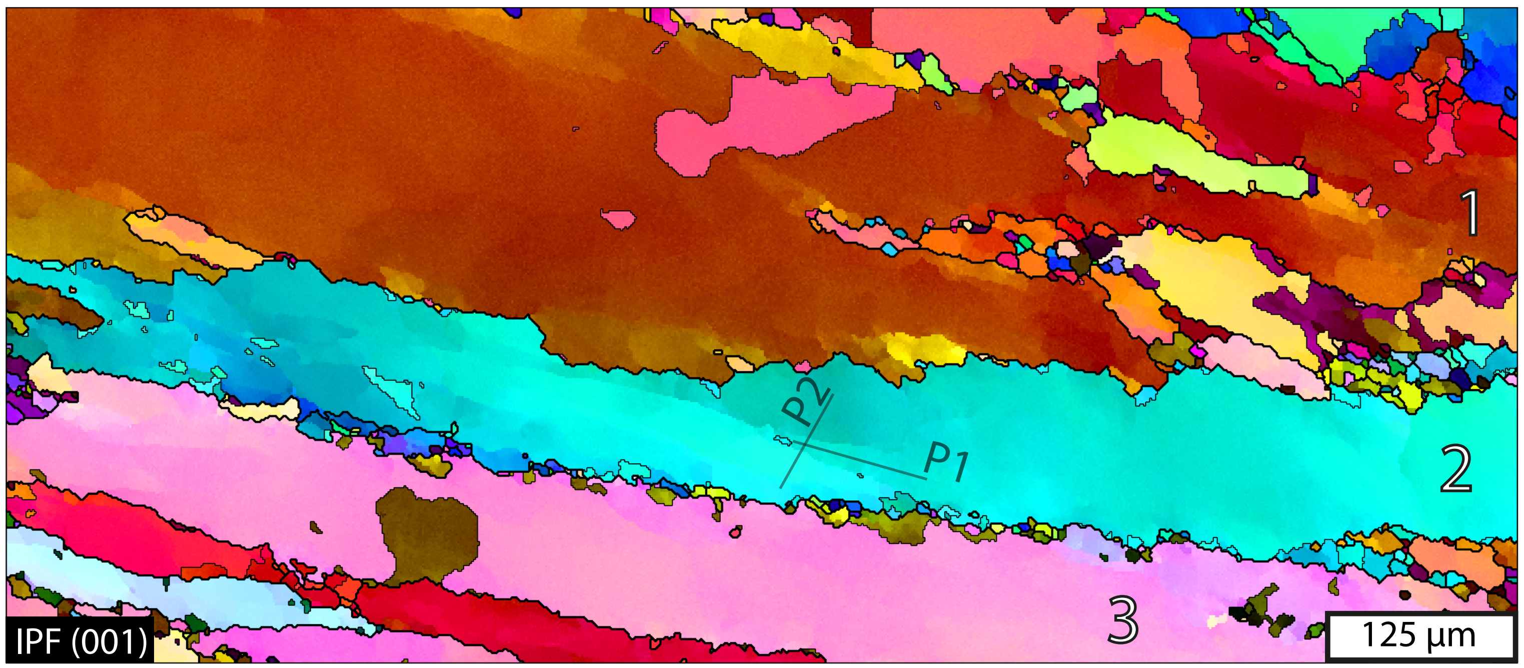
grain1 grain 2 grain 3

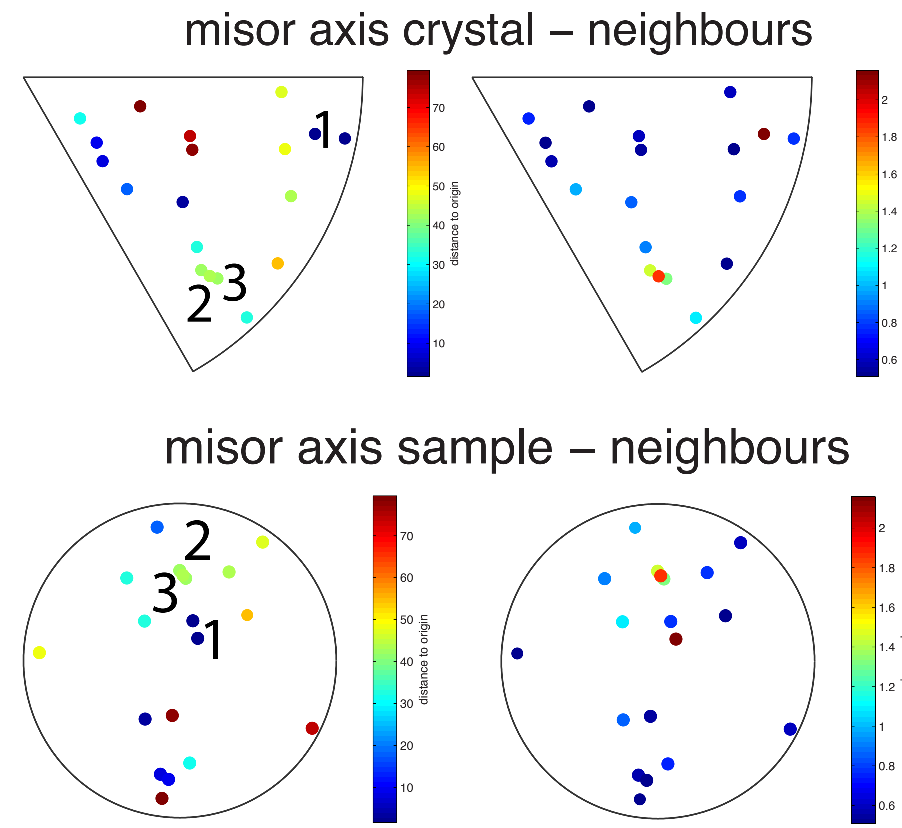
misorientation axes (> 2°) (sample ref.)

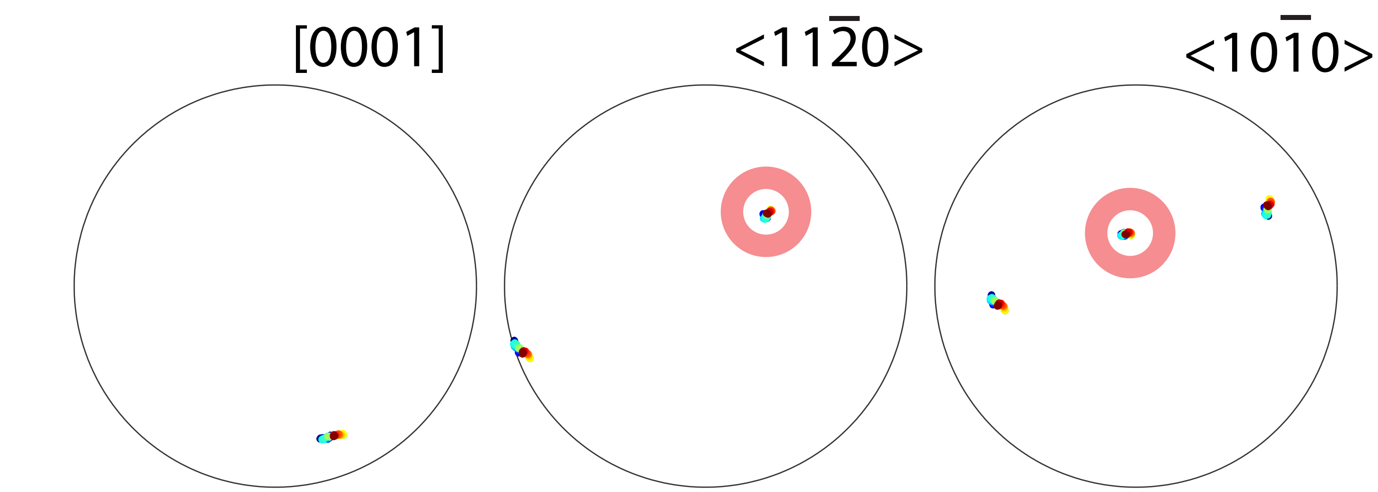
residual dispersion axes (sample ref.)

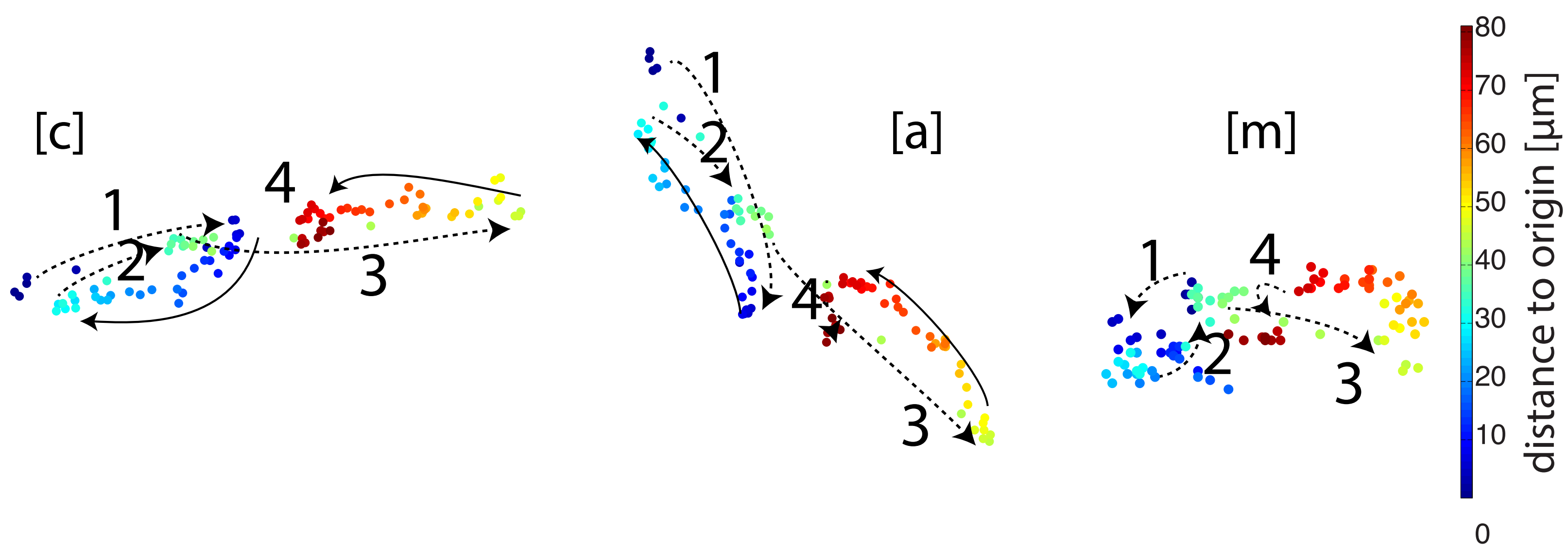


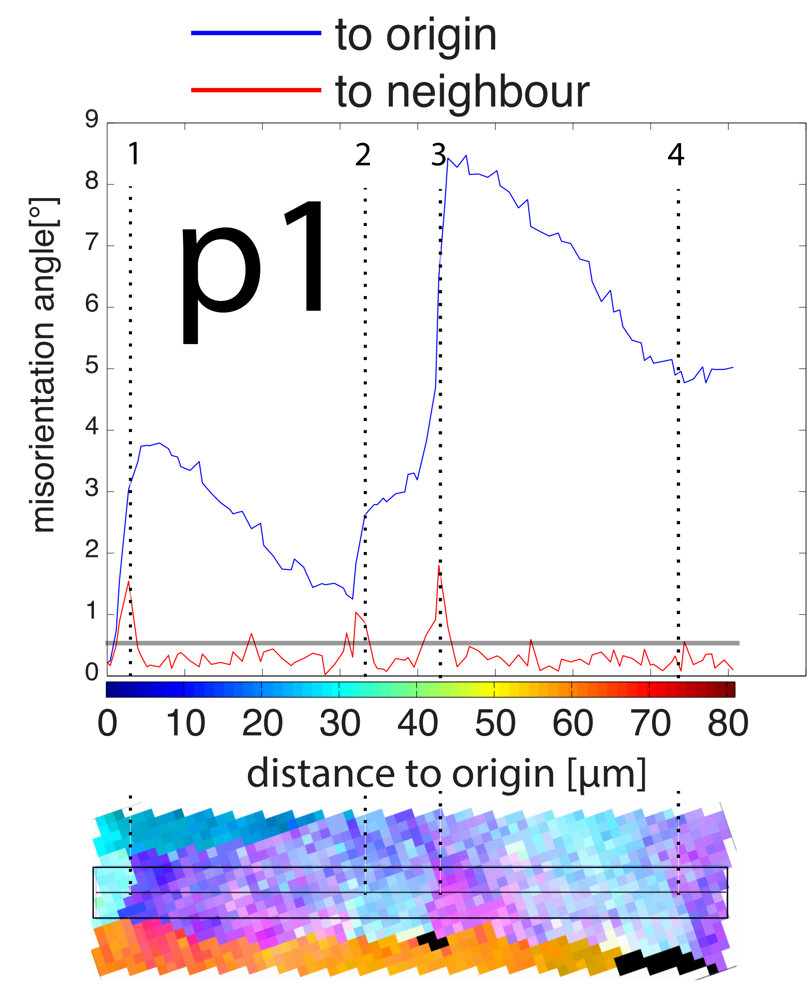
profiles in grain 2:



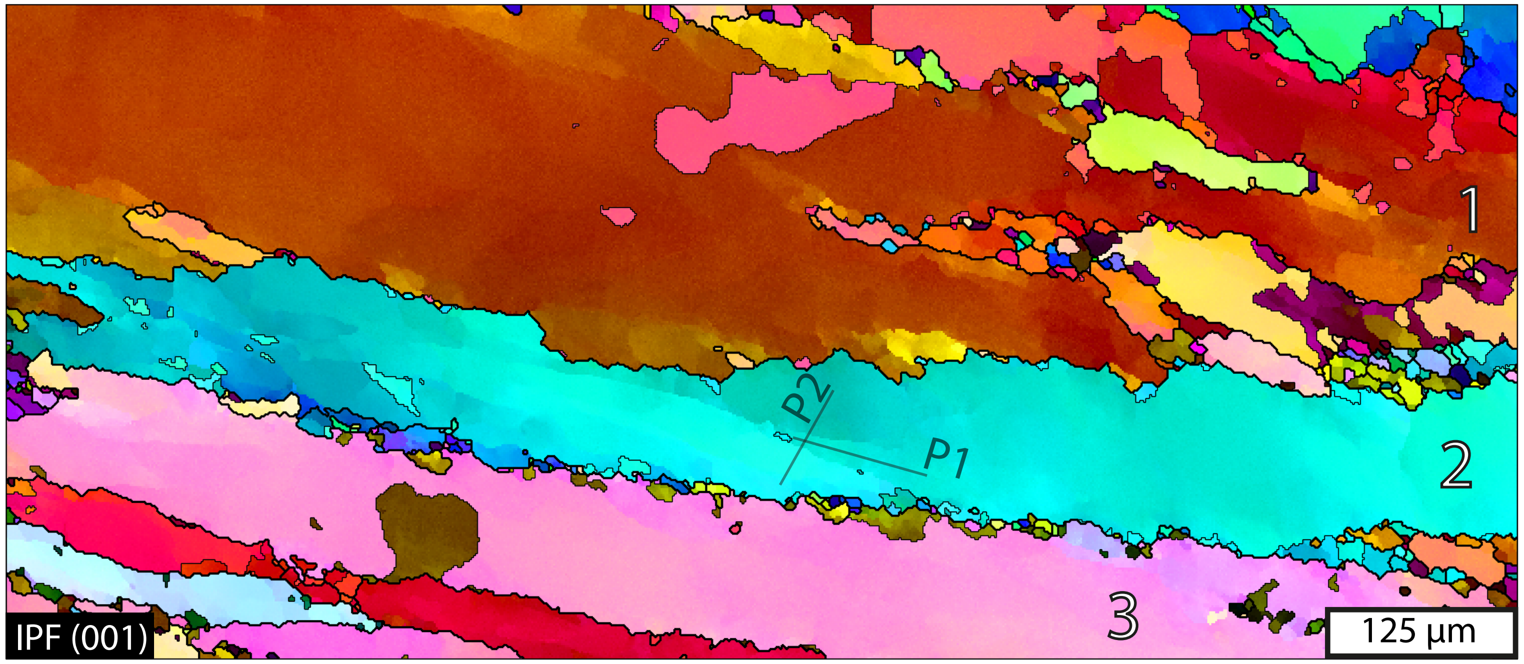


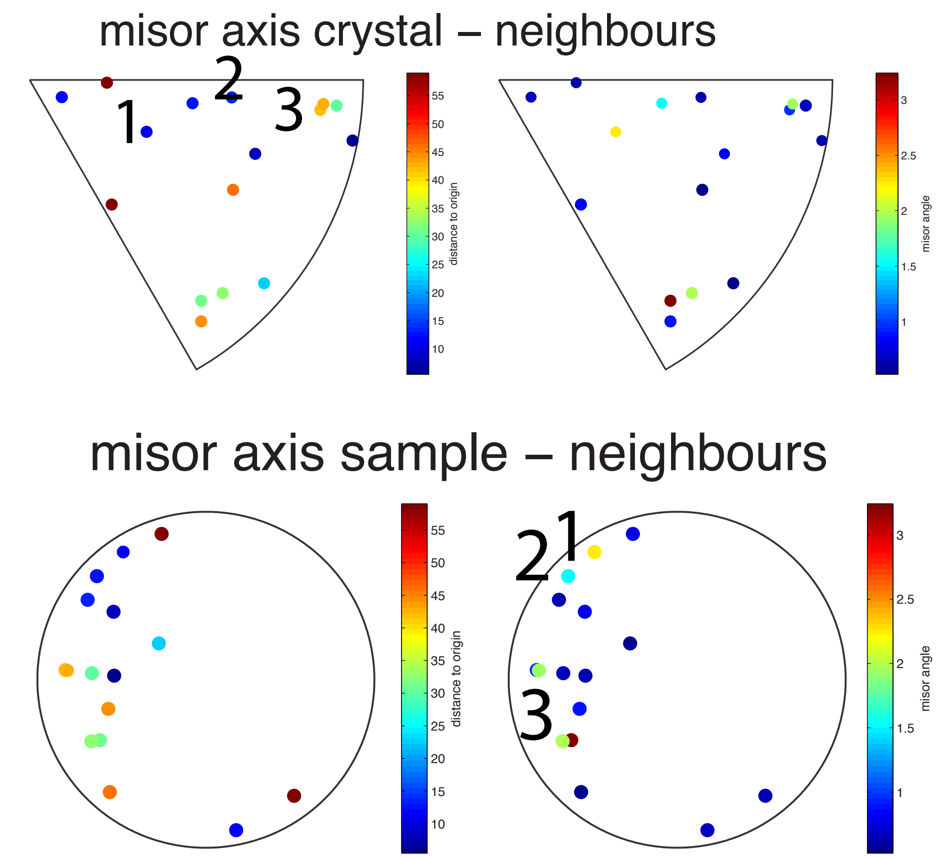


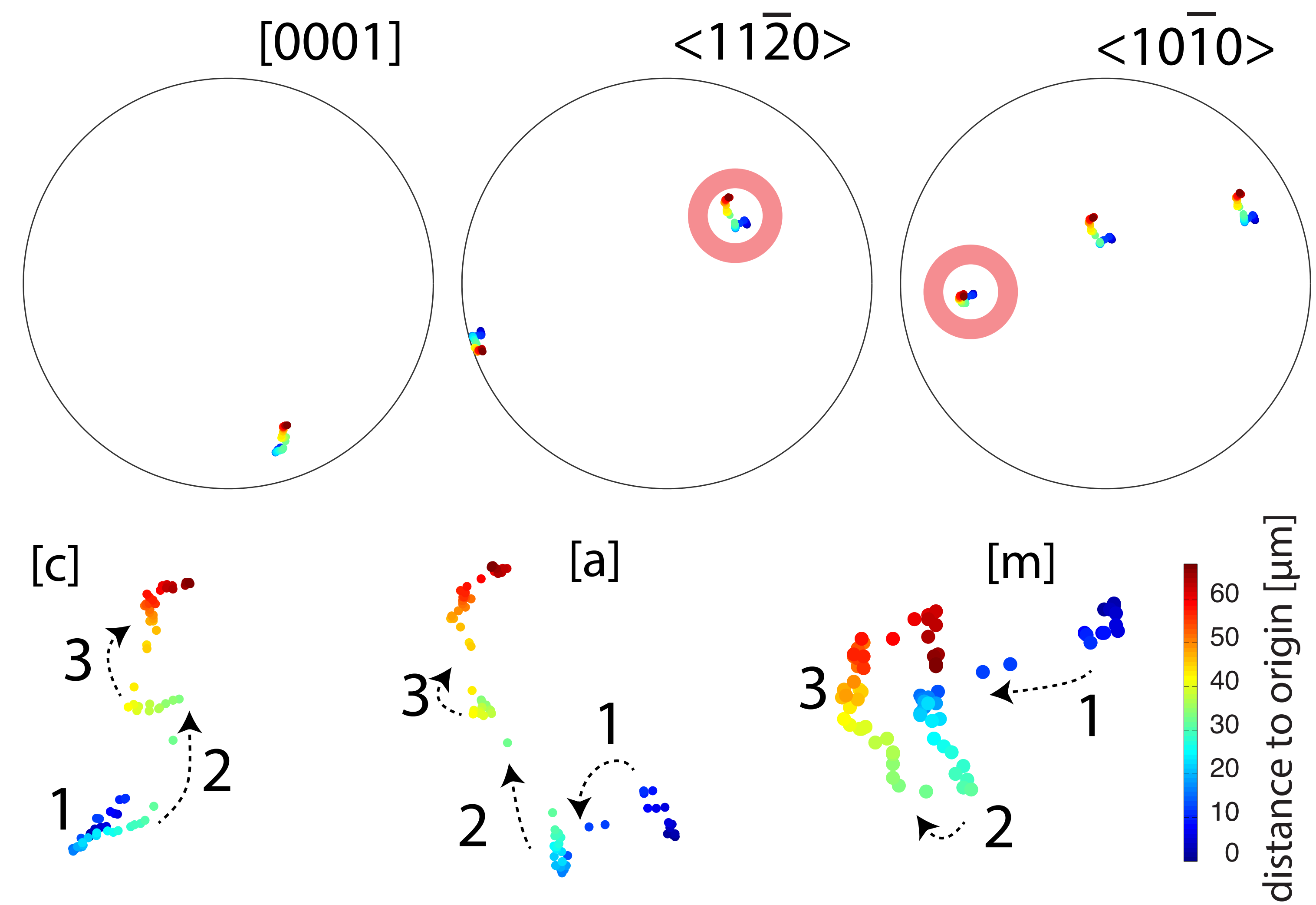


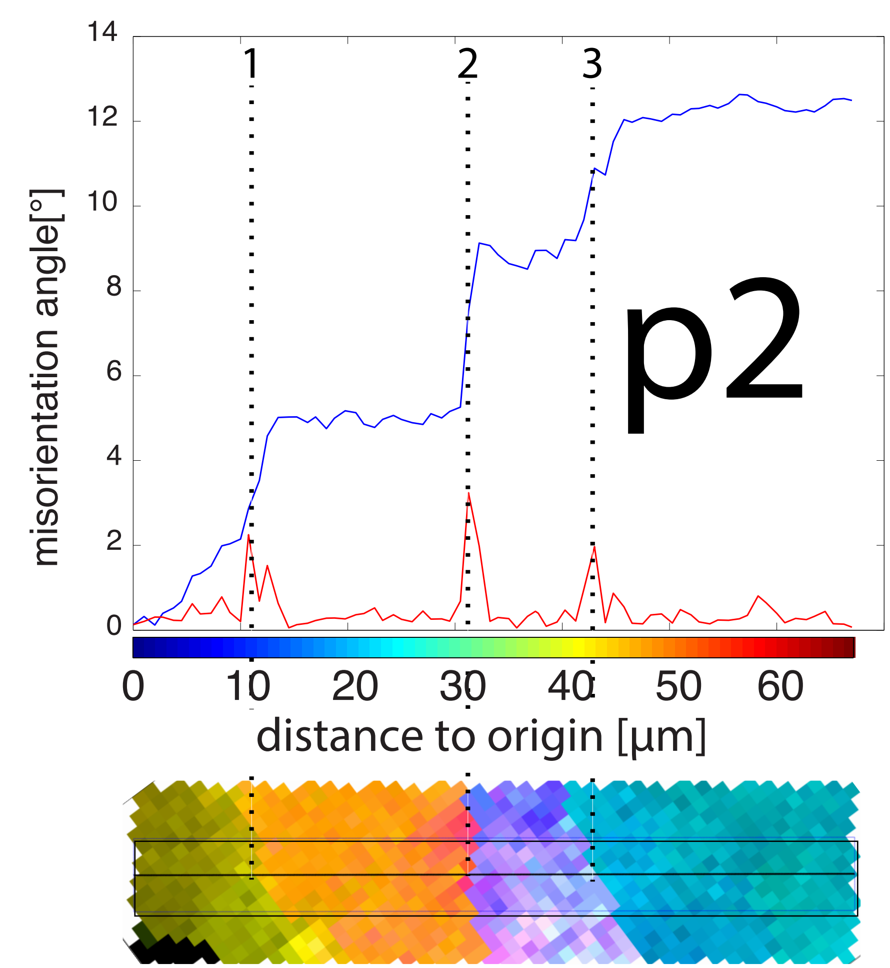


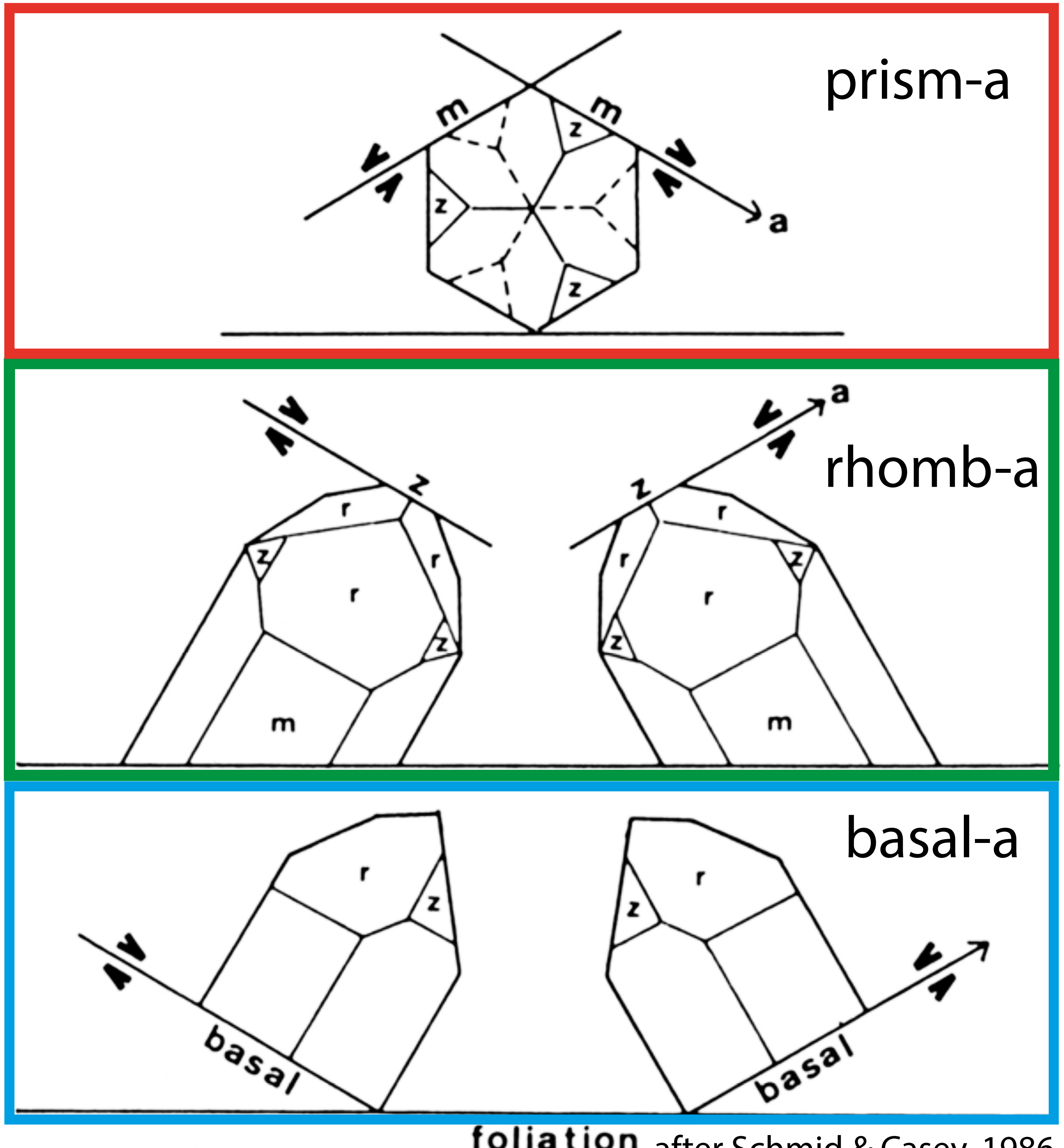
profiles in grain 2:











after Schmid & Casey, 1986

Predicting quartz slip systems from c-axis pole figures? Does that really (always) work?

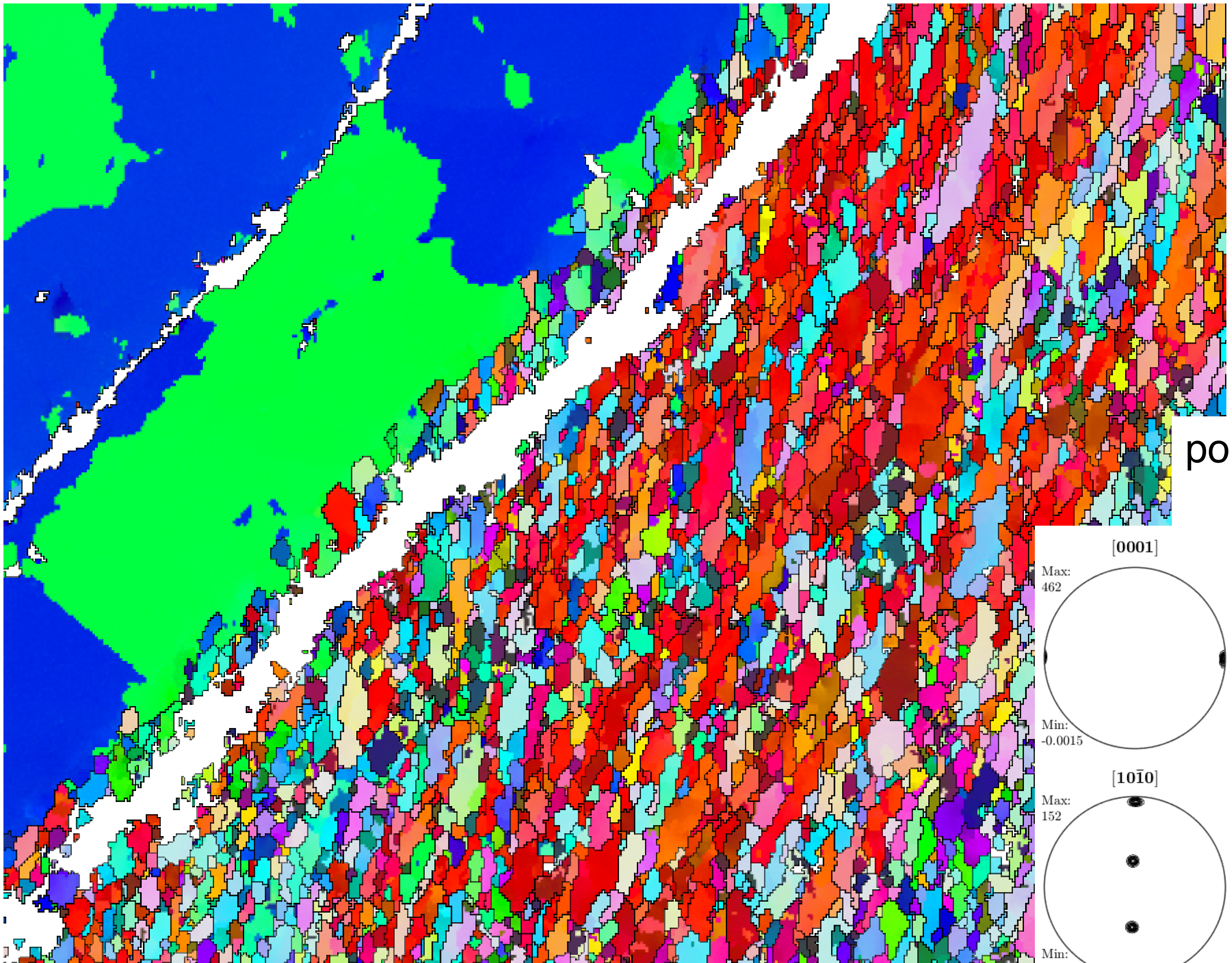
Maybe not always,

especially at low strain and when dynamic recrystallization is restricted. Quartz is plastically anisotropic and hence grains may not "see" only global but rather local strain / kinematics. Additionally, deviations from plane strain might have to be considered as well.

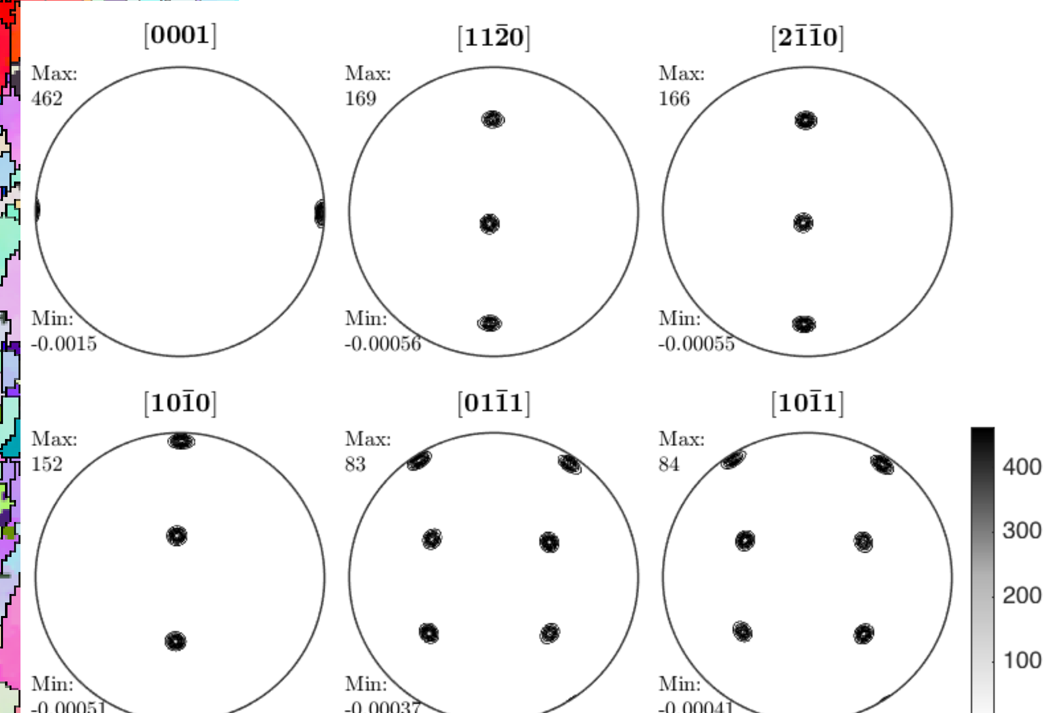
Part 1b:
Are subgrain boundaries necessarily deformation induced?
(rather a question)

Experimentally deformed BHQ:

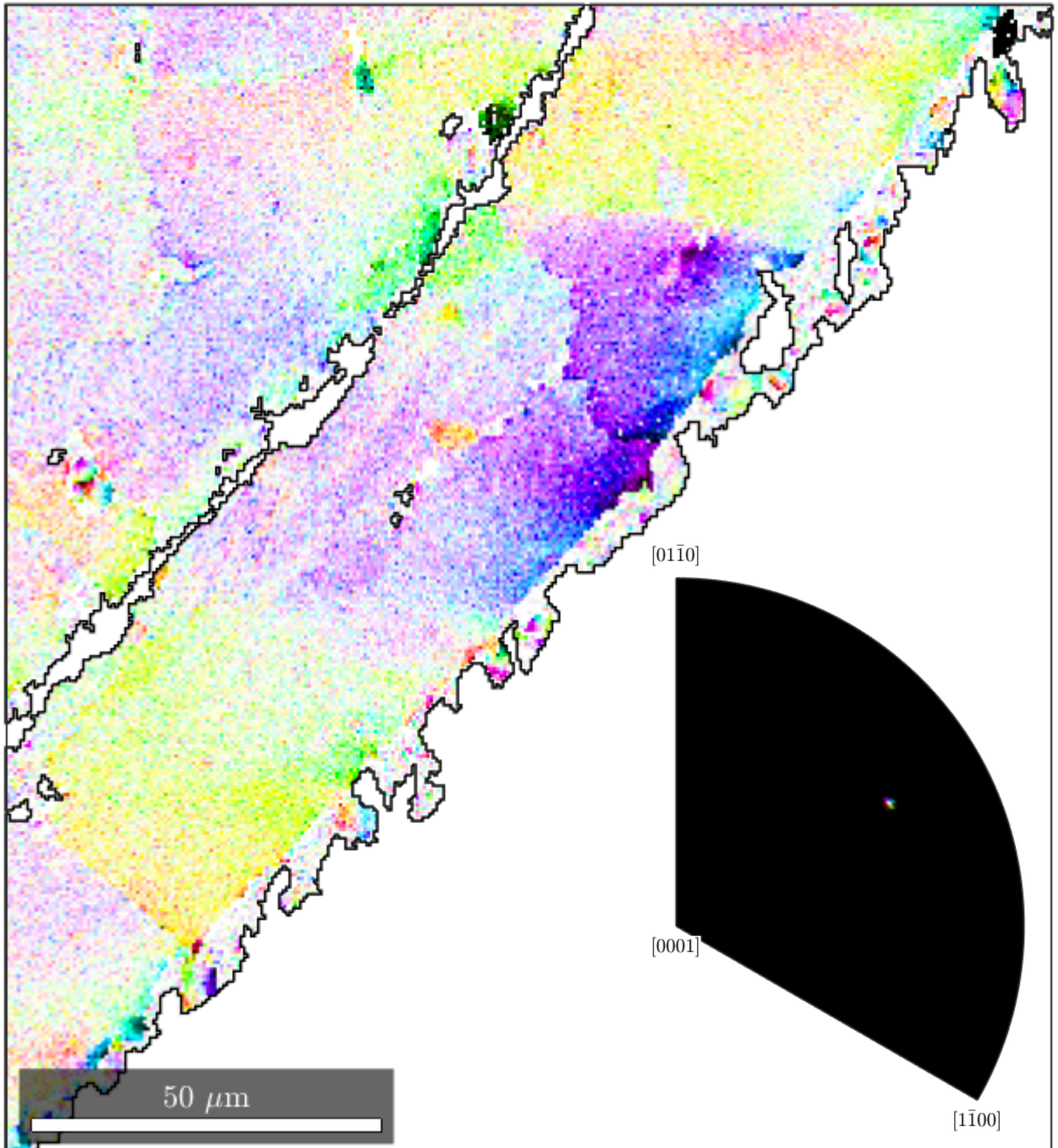
915°C/3*10^{-5}/s, shortening direction horizontal, 45° precut quartz forcing blocks
[sample of Heilbronner & Tullis, 2002]



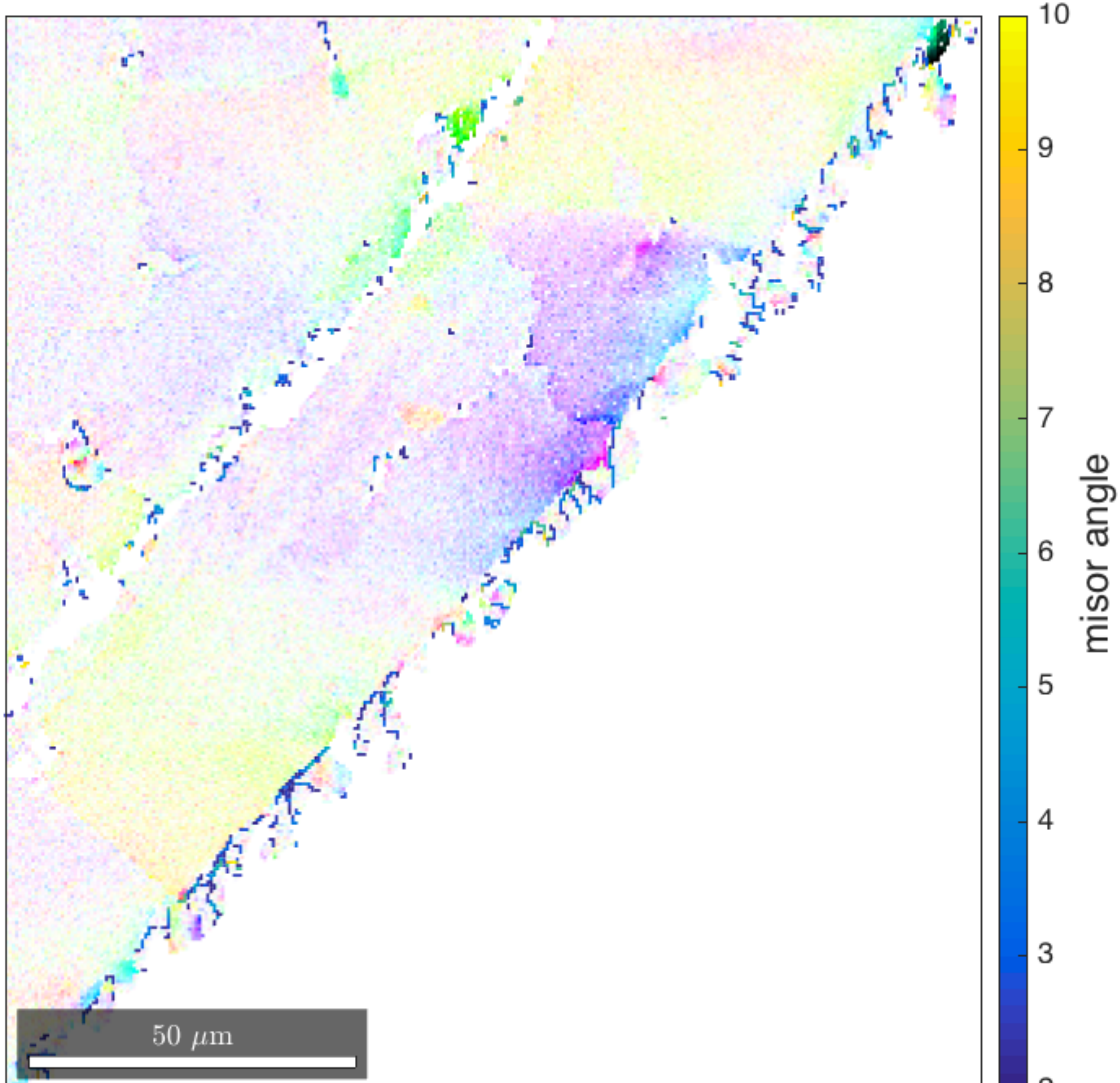
pole figure of quartz forcing blocks



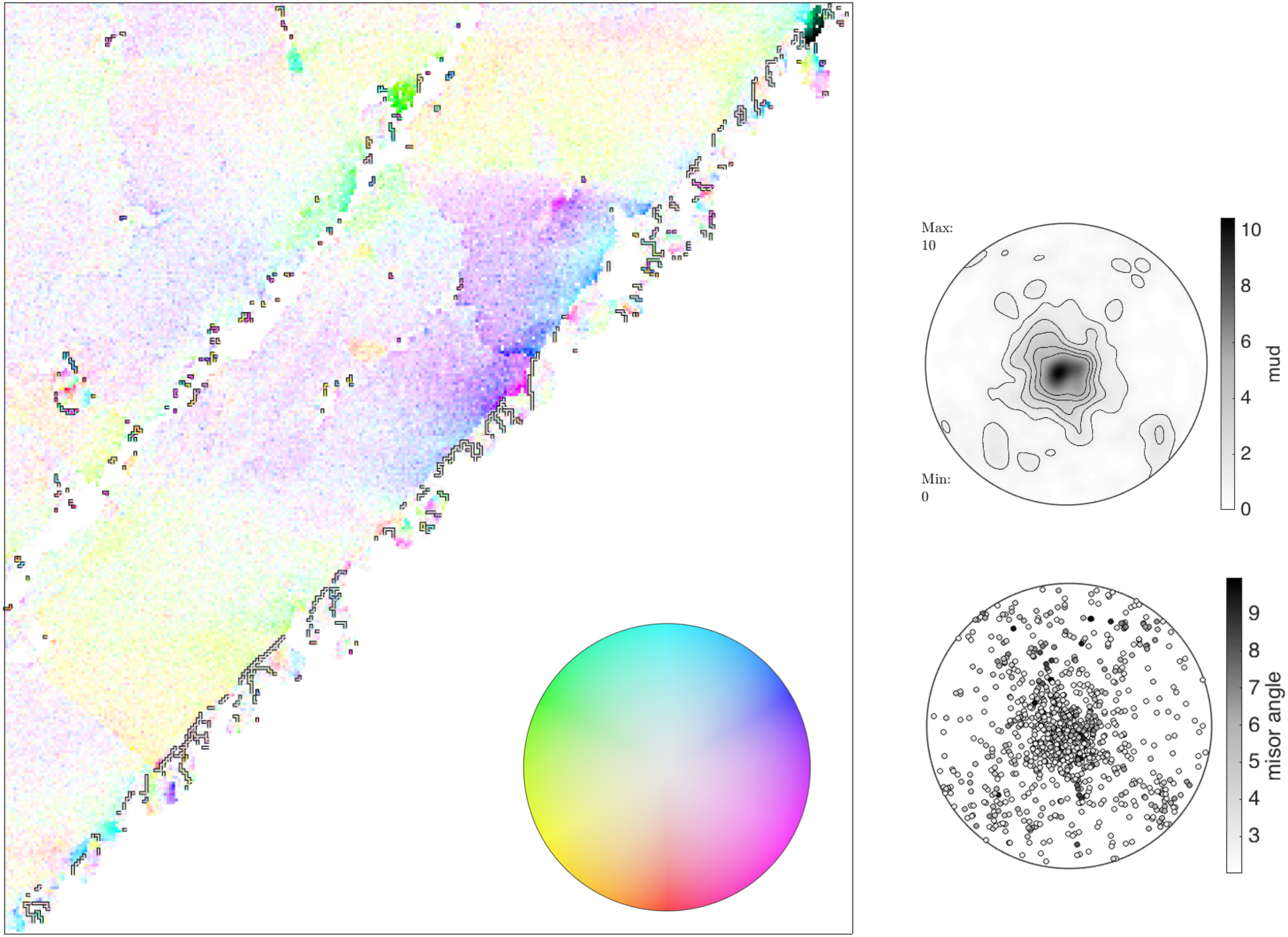
forcing block with very sharp color-coding



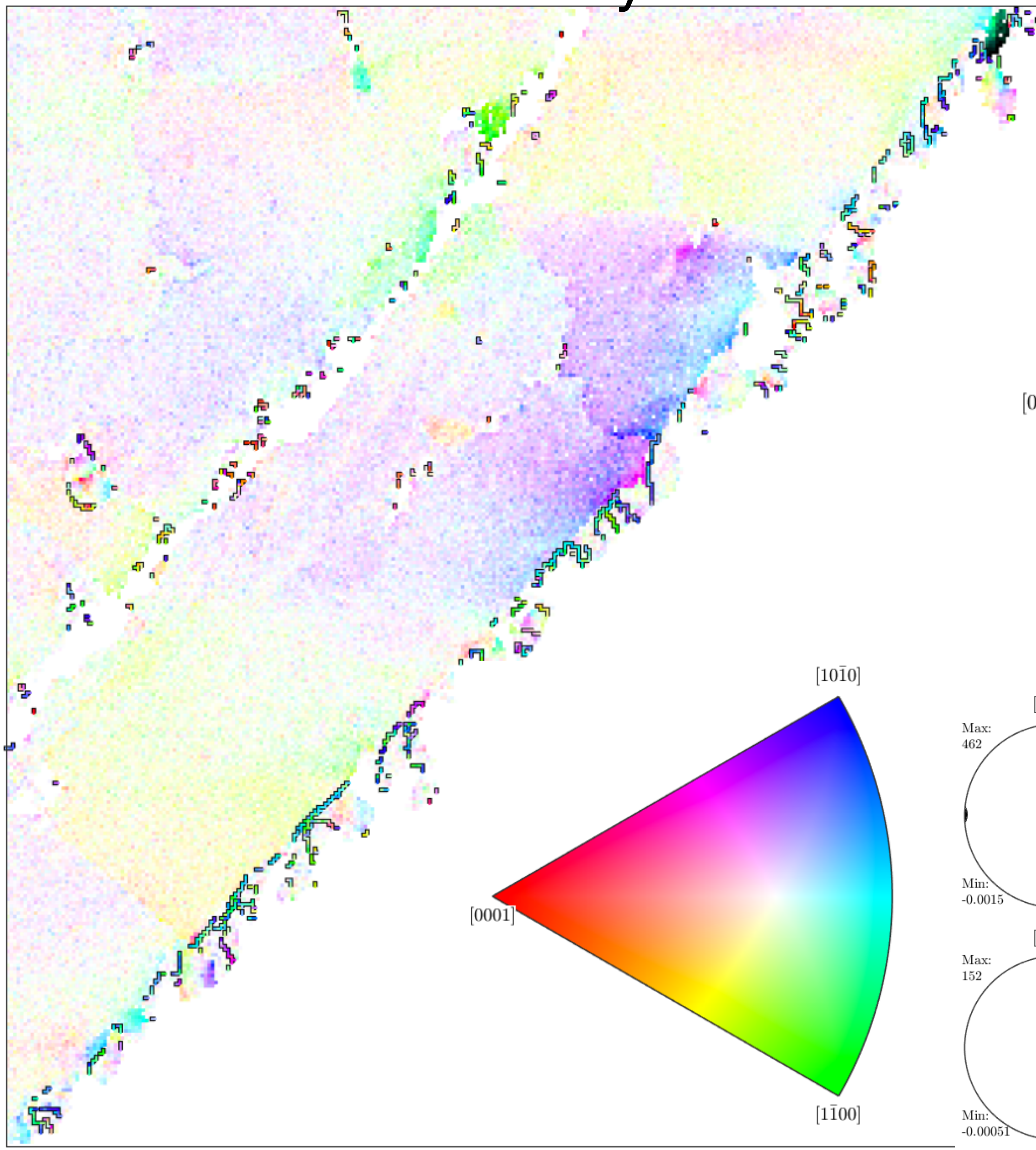
low angle boundaries (> 2°) in the forcing block

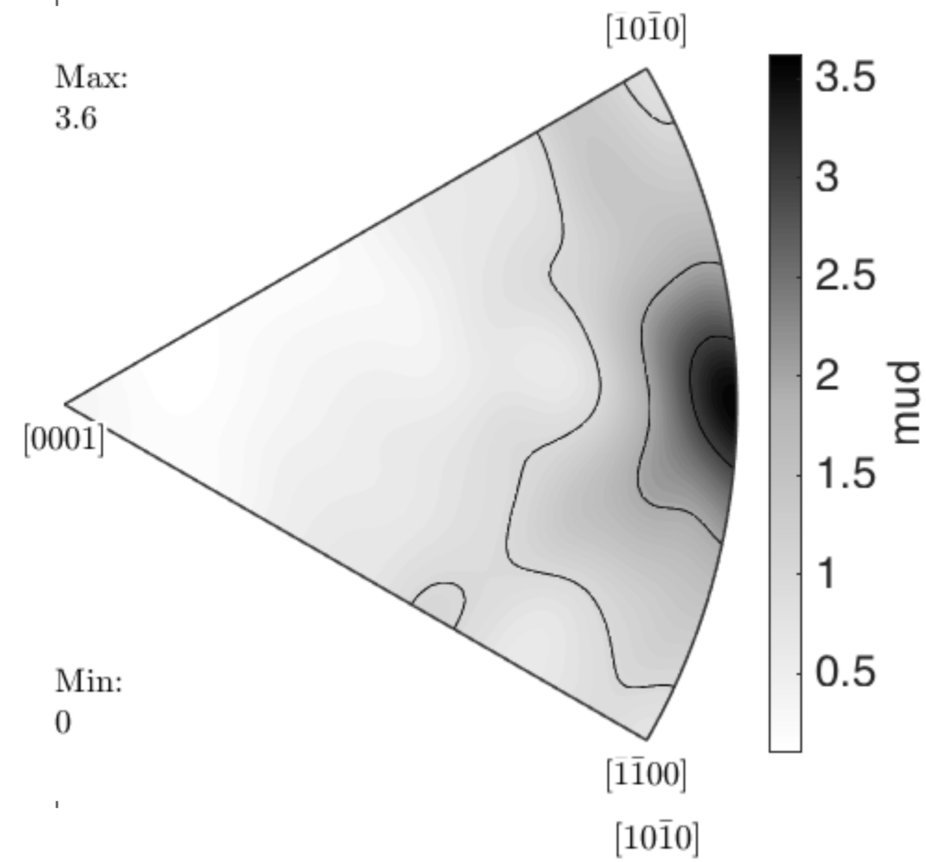


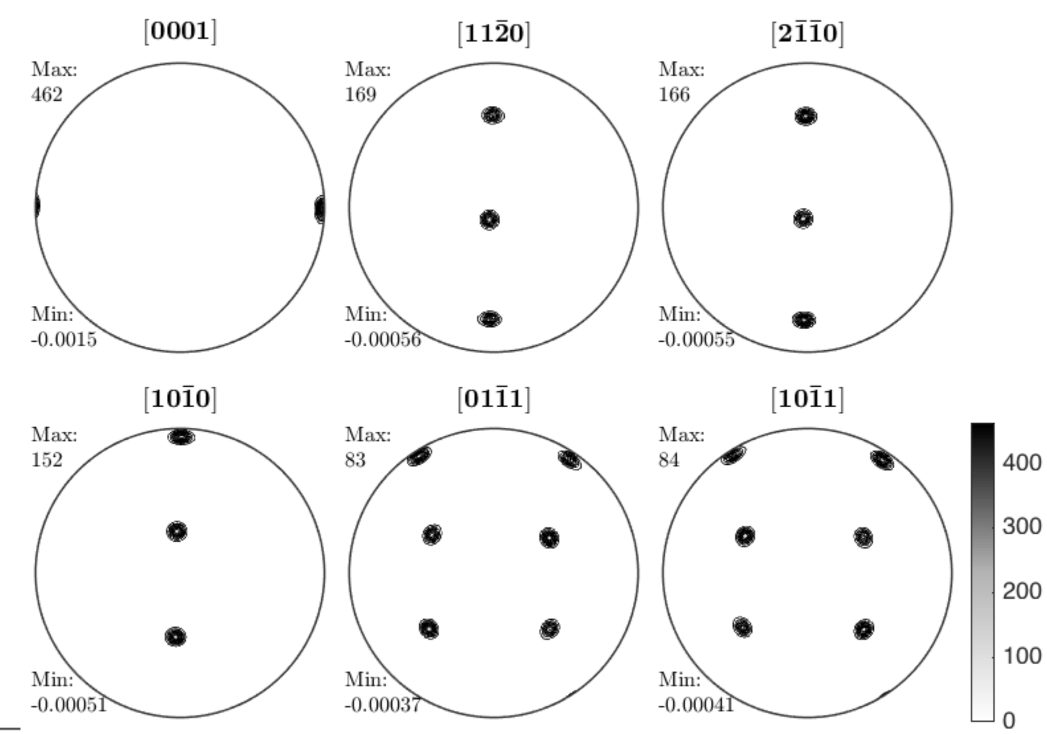
misorientation axes: sample reference frame



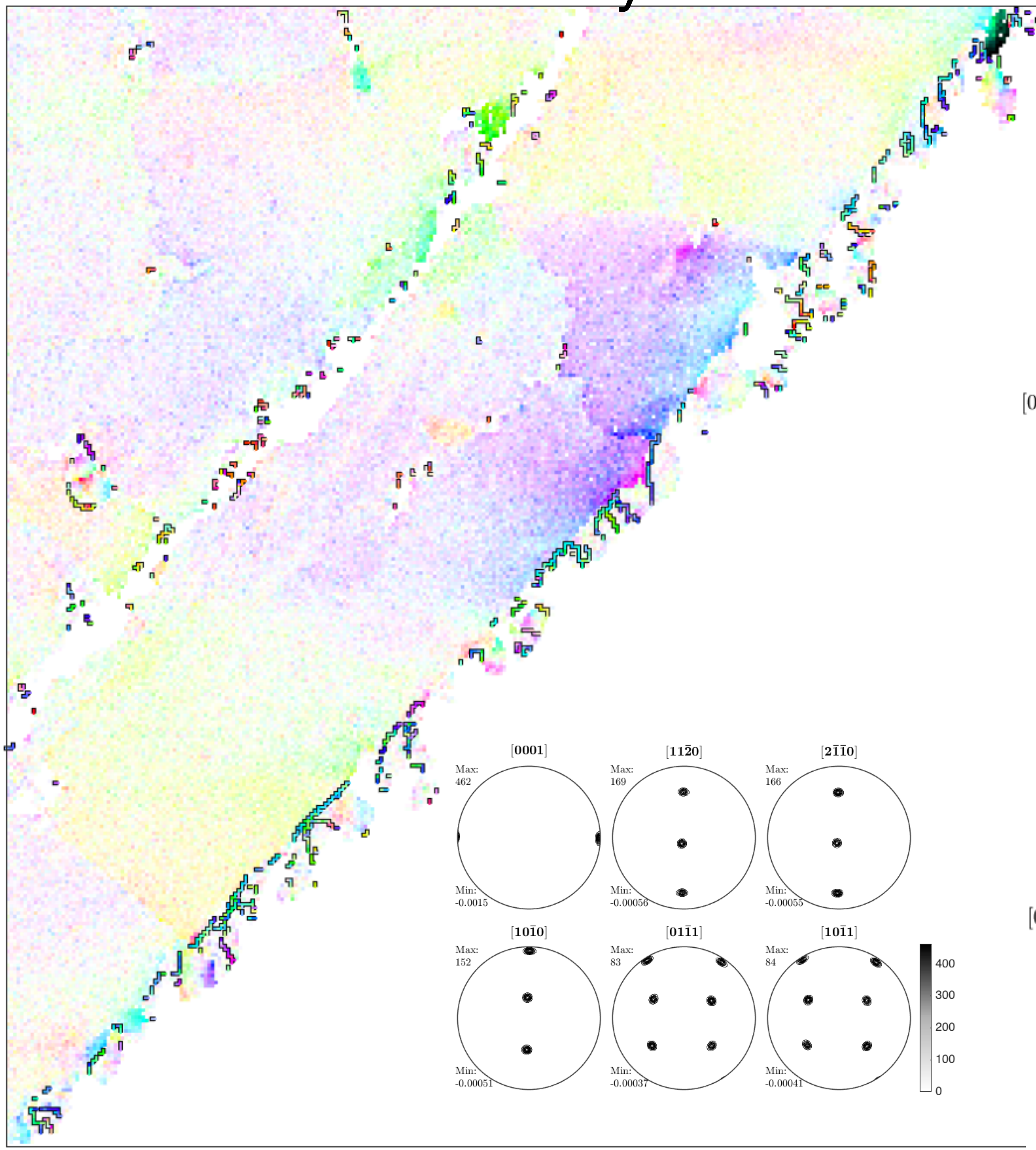
misorientation axes: crystal reference frame

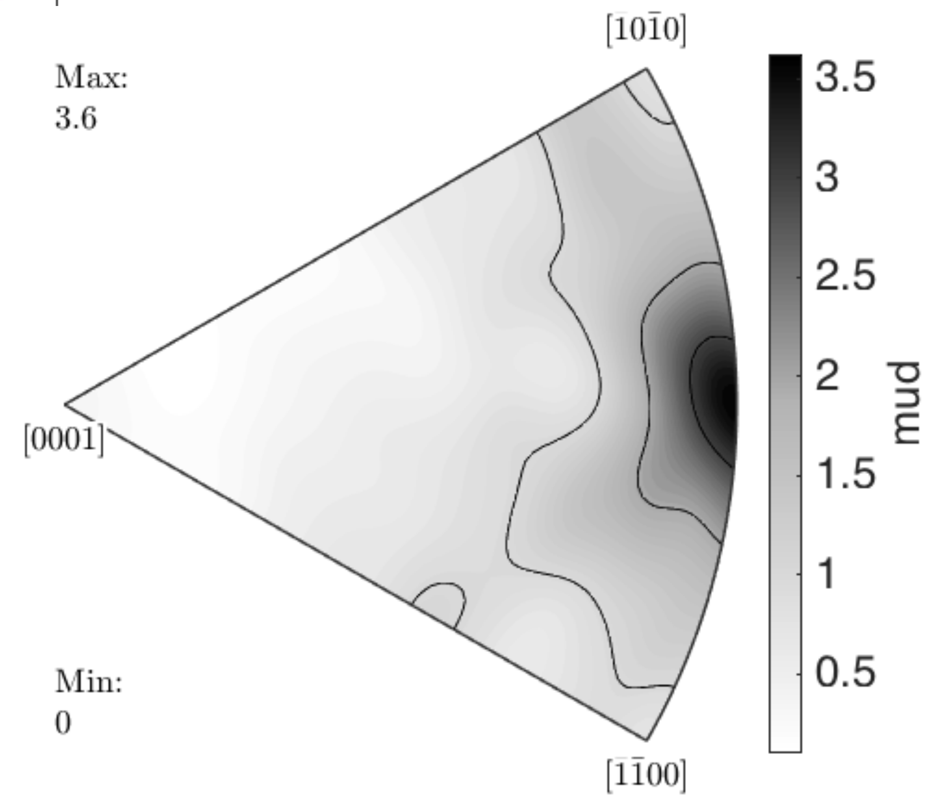


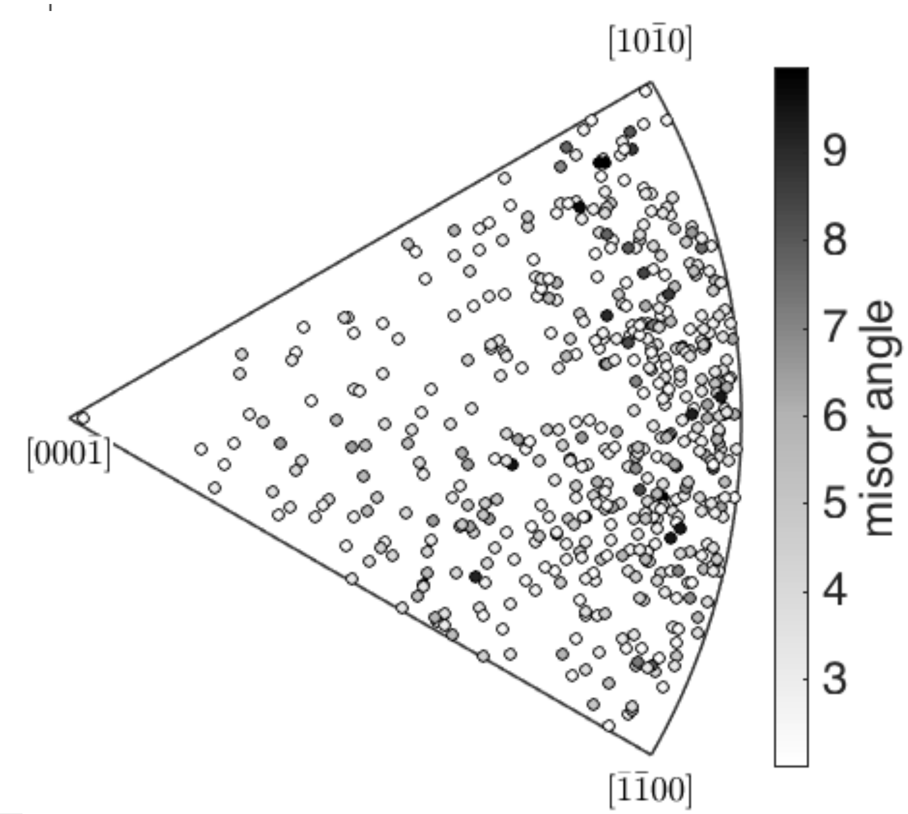




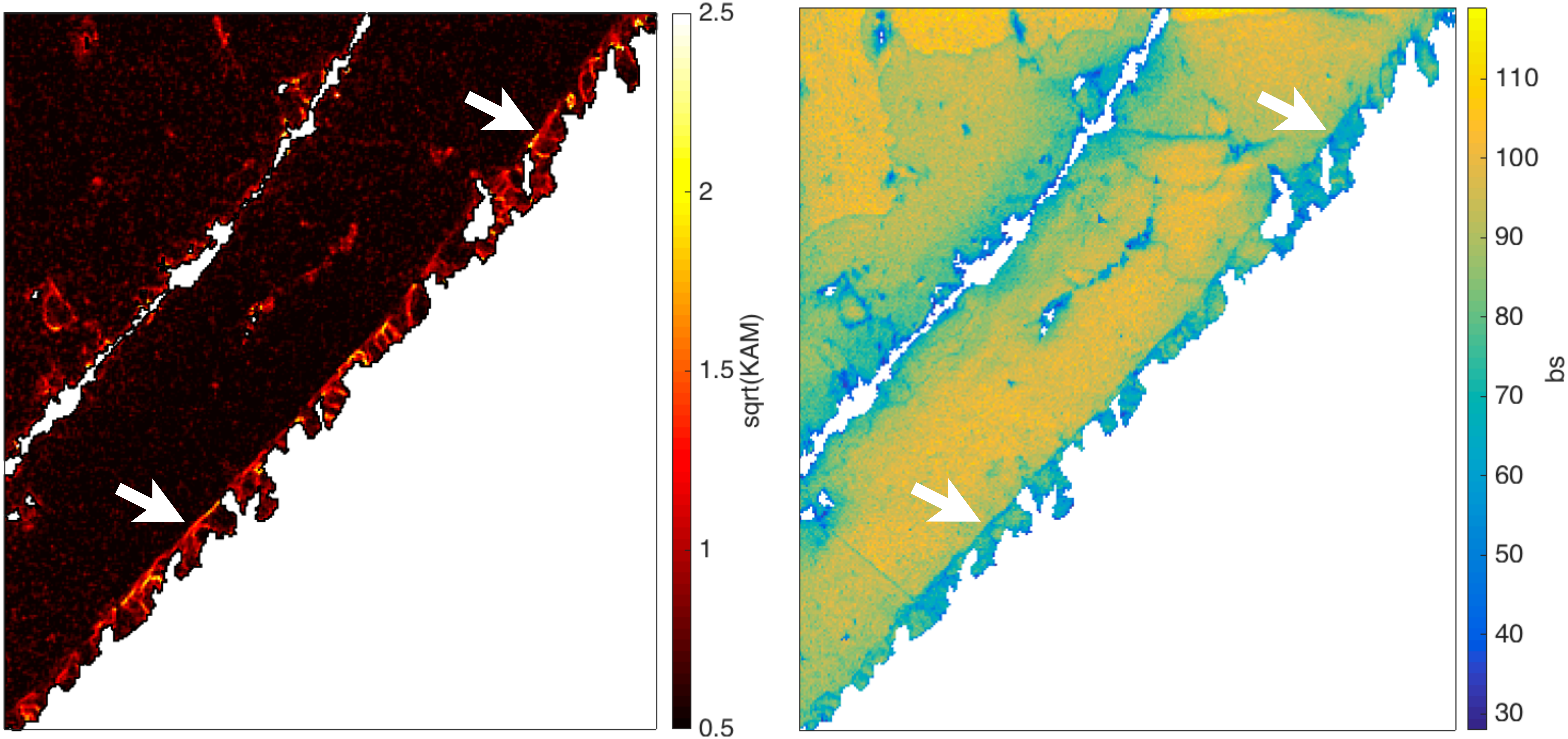
misorientation axes: crystal reference frame







KAM or bs reveal original, saw cut crystal interface: growth during experiments

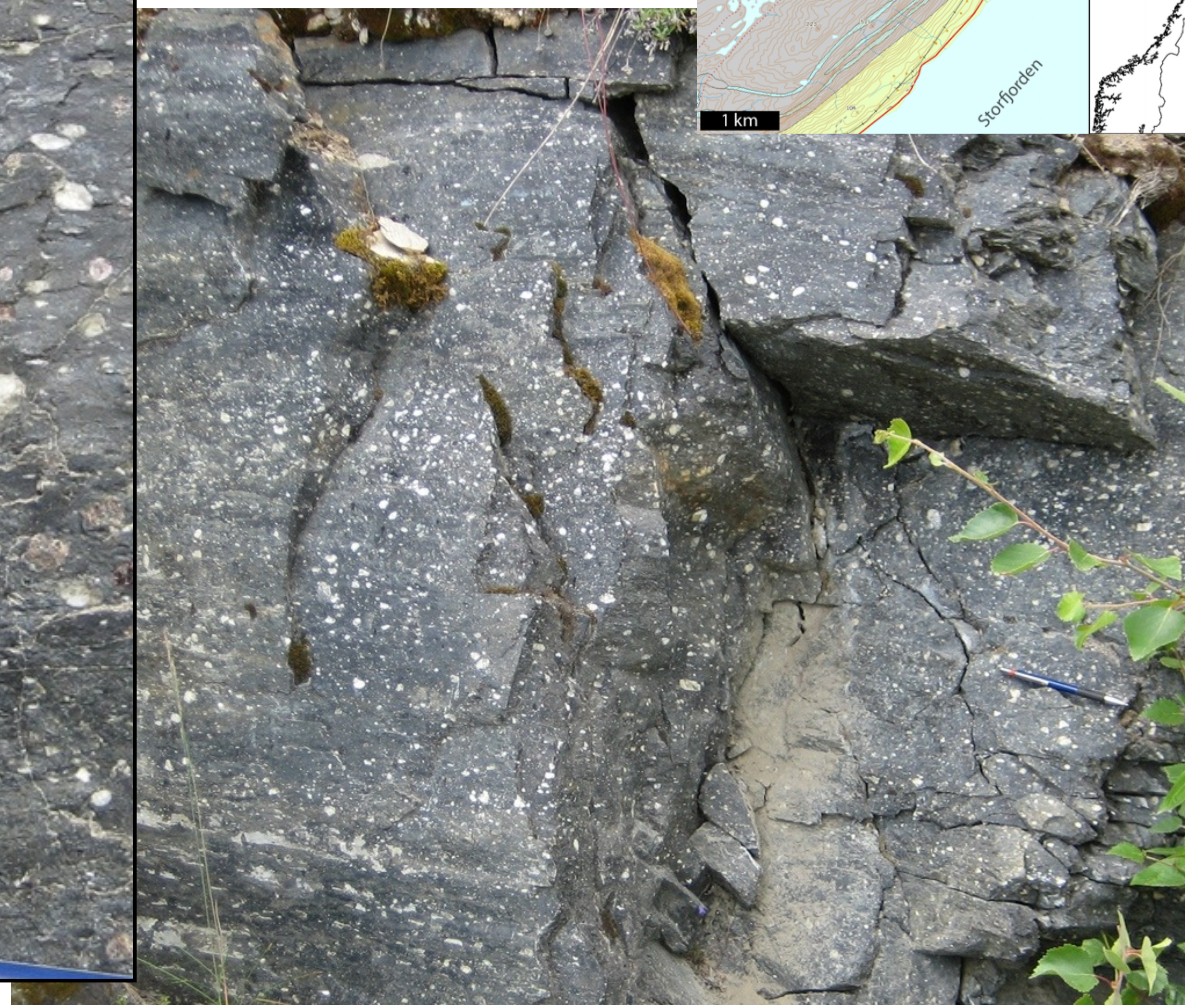


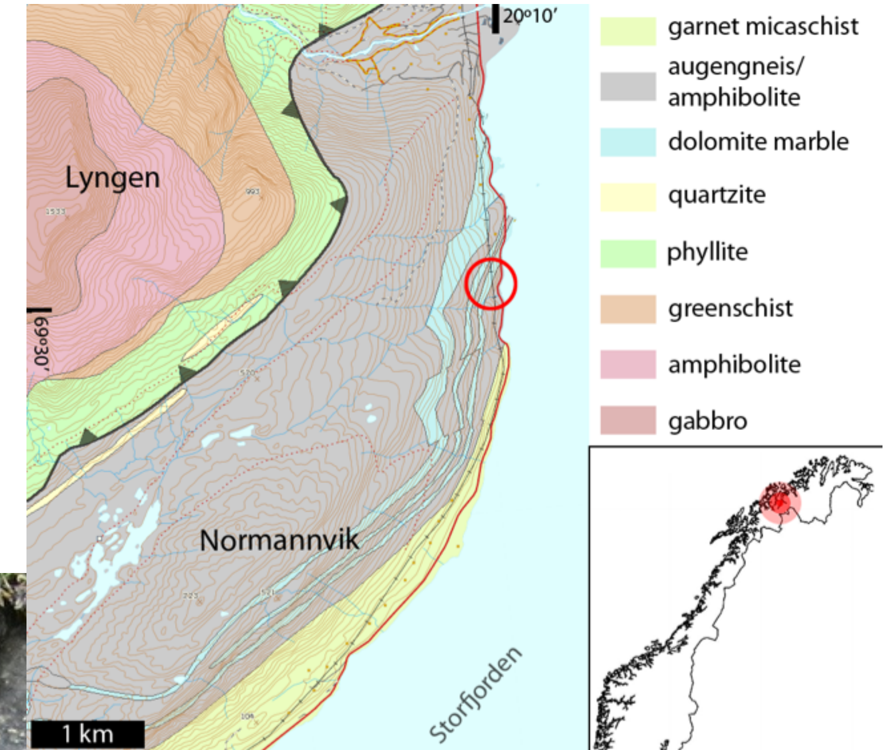
...so may some of the subgrain boundaries we look at actually be relict growth features?

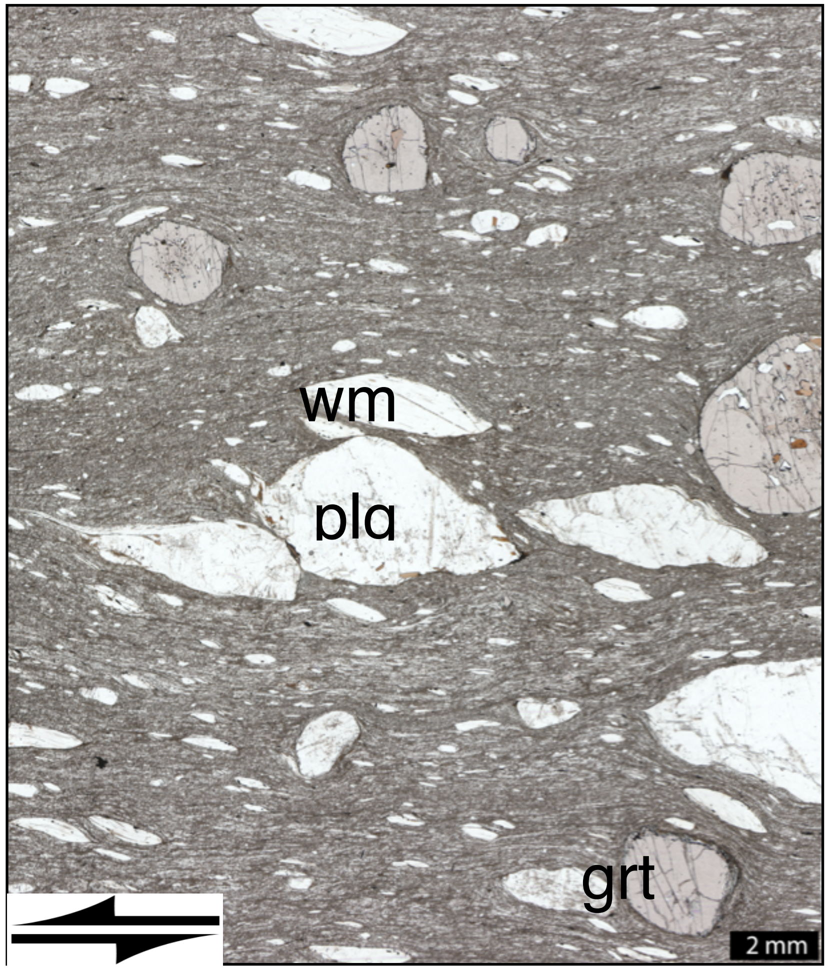
Part 2:
Weak textures in ultramylonites (highly deformed rocks)

Intra-nappe shear zone from the Normannvik nappe, Norwegian Caledonides

deformation at ~600-650°C/0.9 GPa

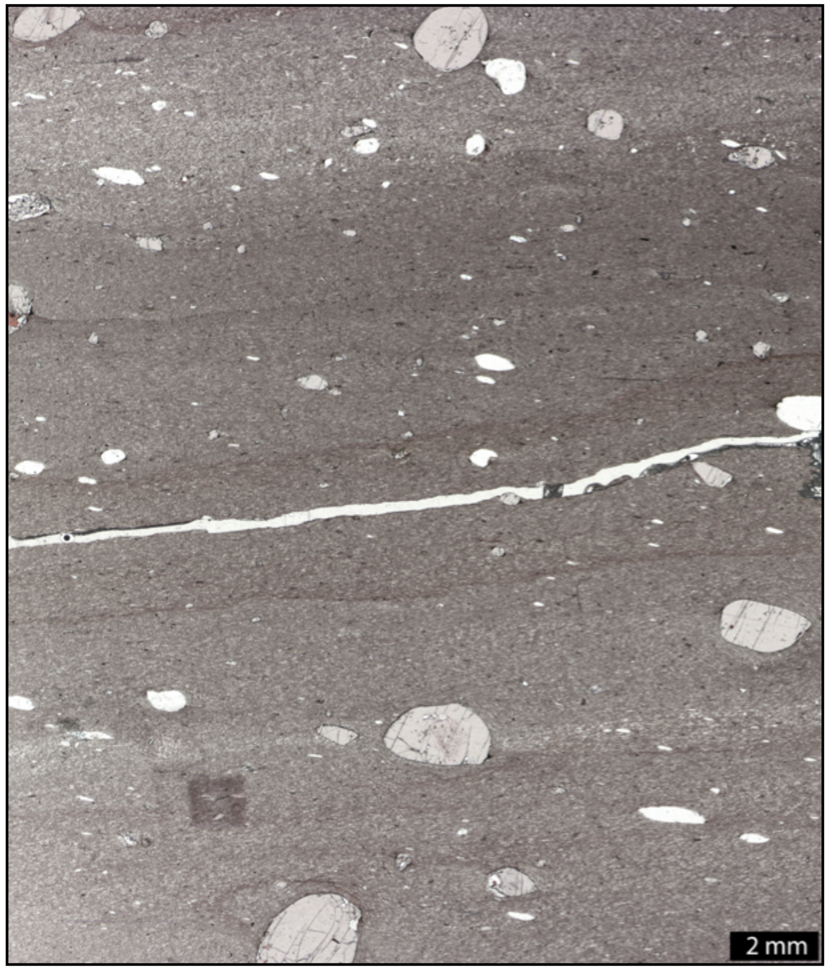






80 %

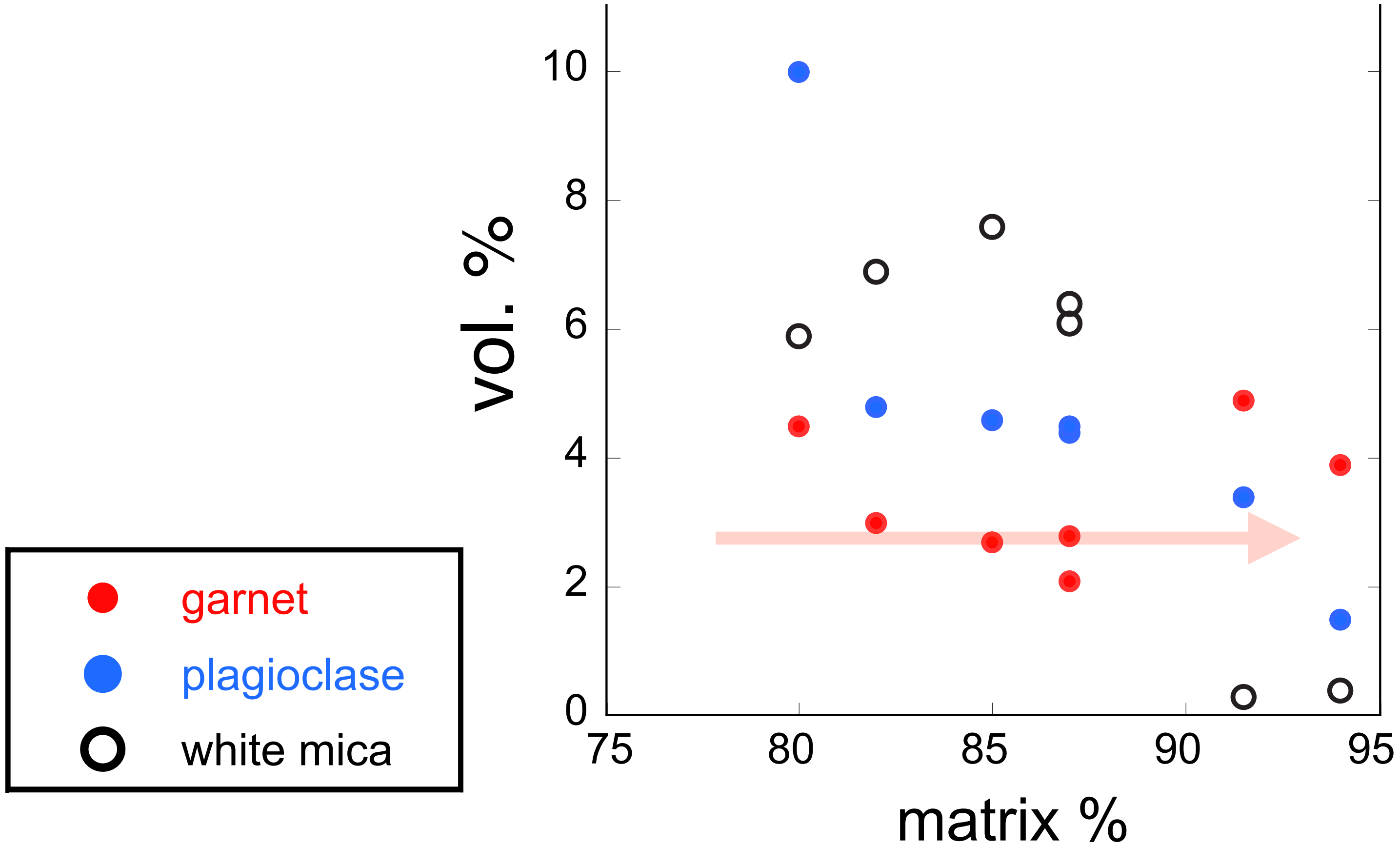
87 %



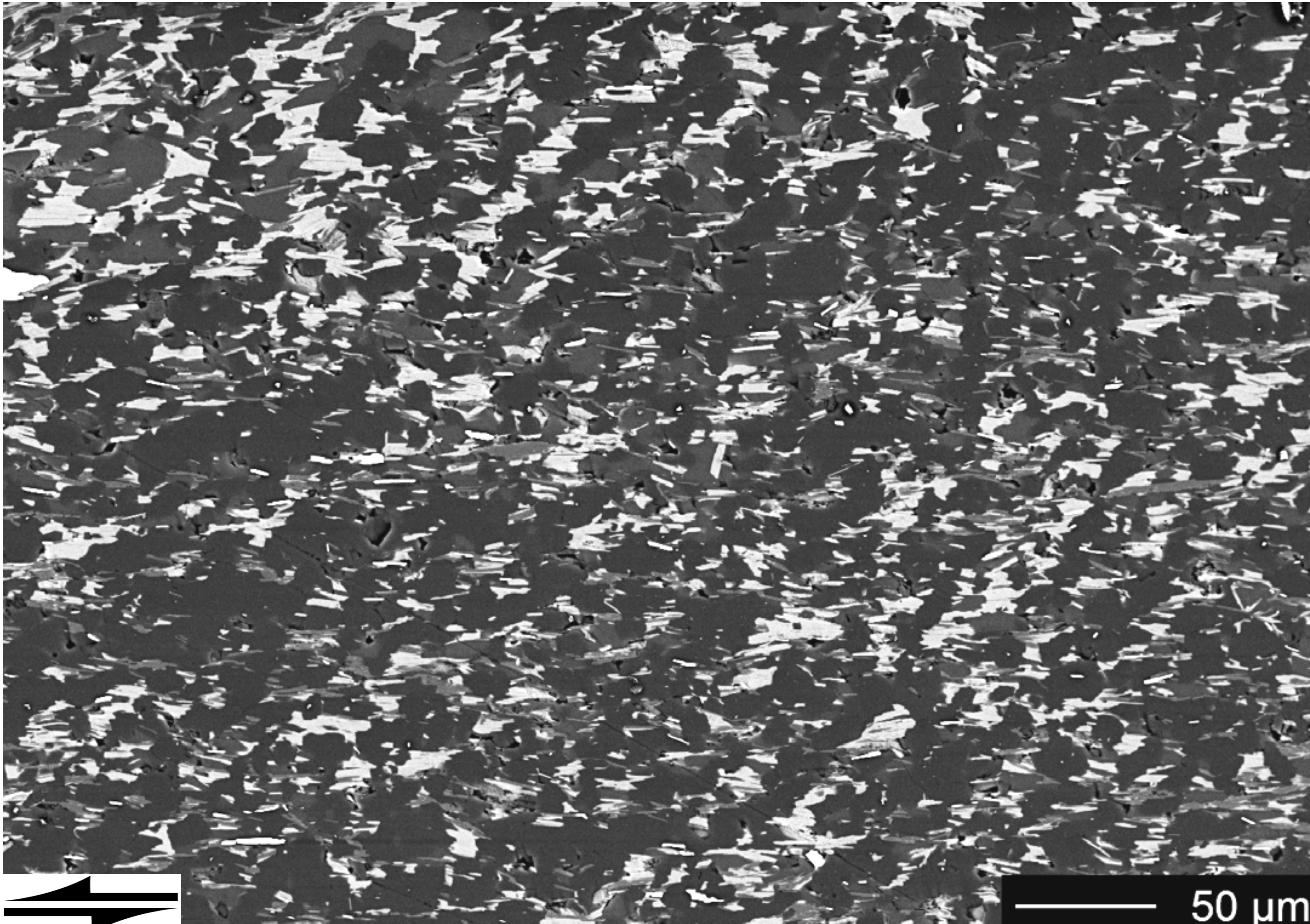
94 %

With increasing matrix fraction:

- increase of matrix homogeneity
- vol. % of garnet porphyroclasts remains constant at ~3 %
- white mica and plagioclase porphyroclasts disappear

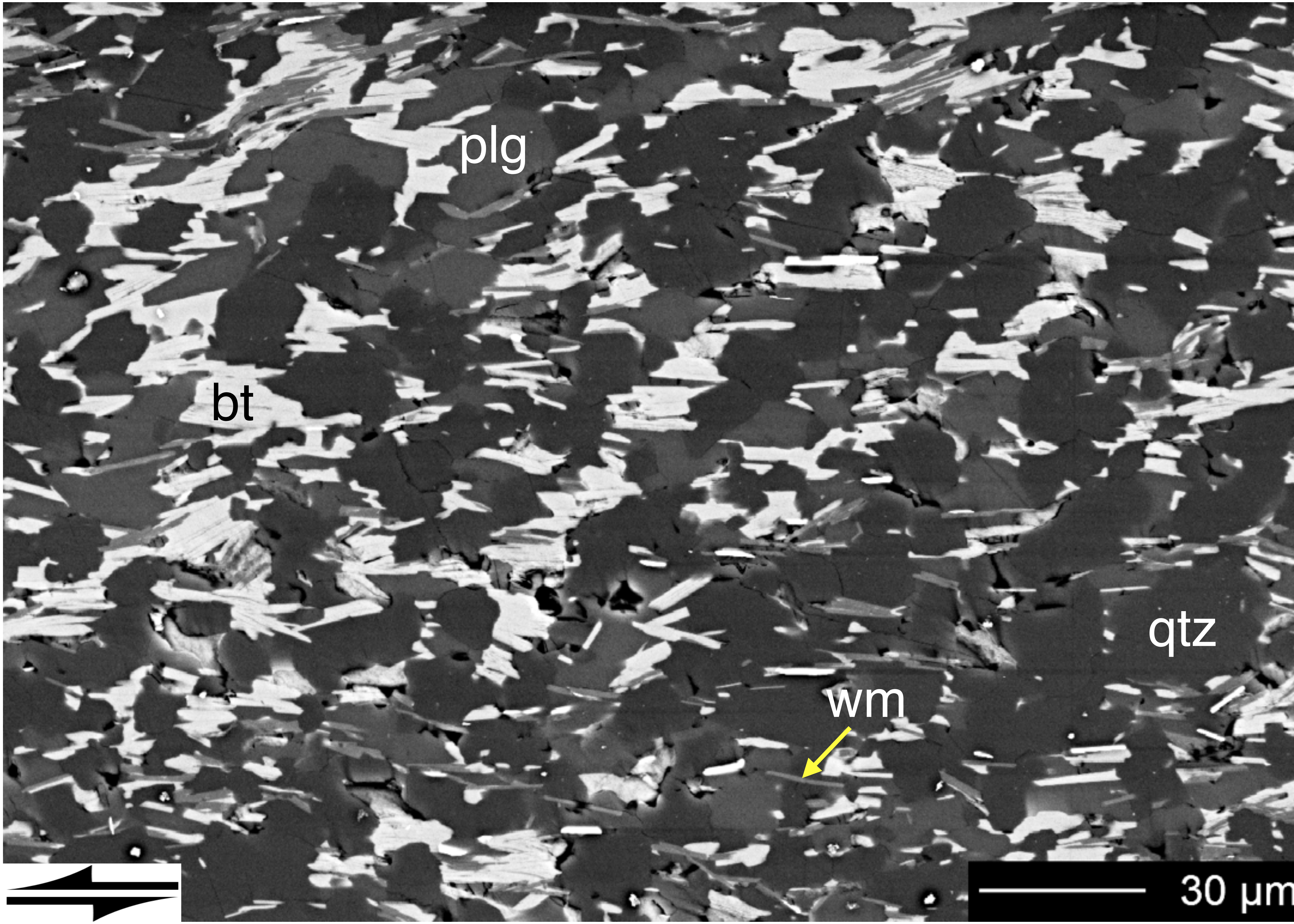


matrix with a highly homogenous, oblique fabric



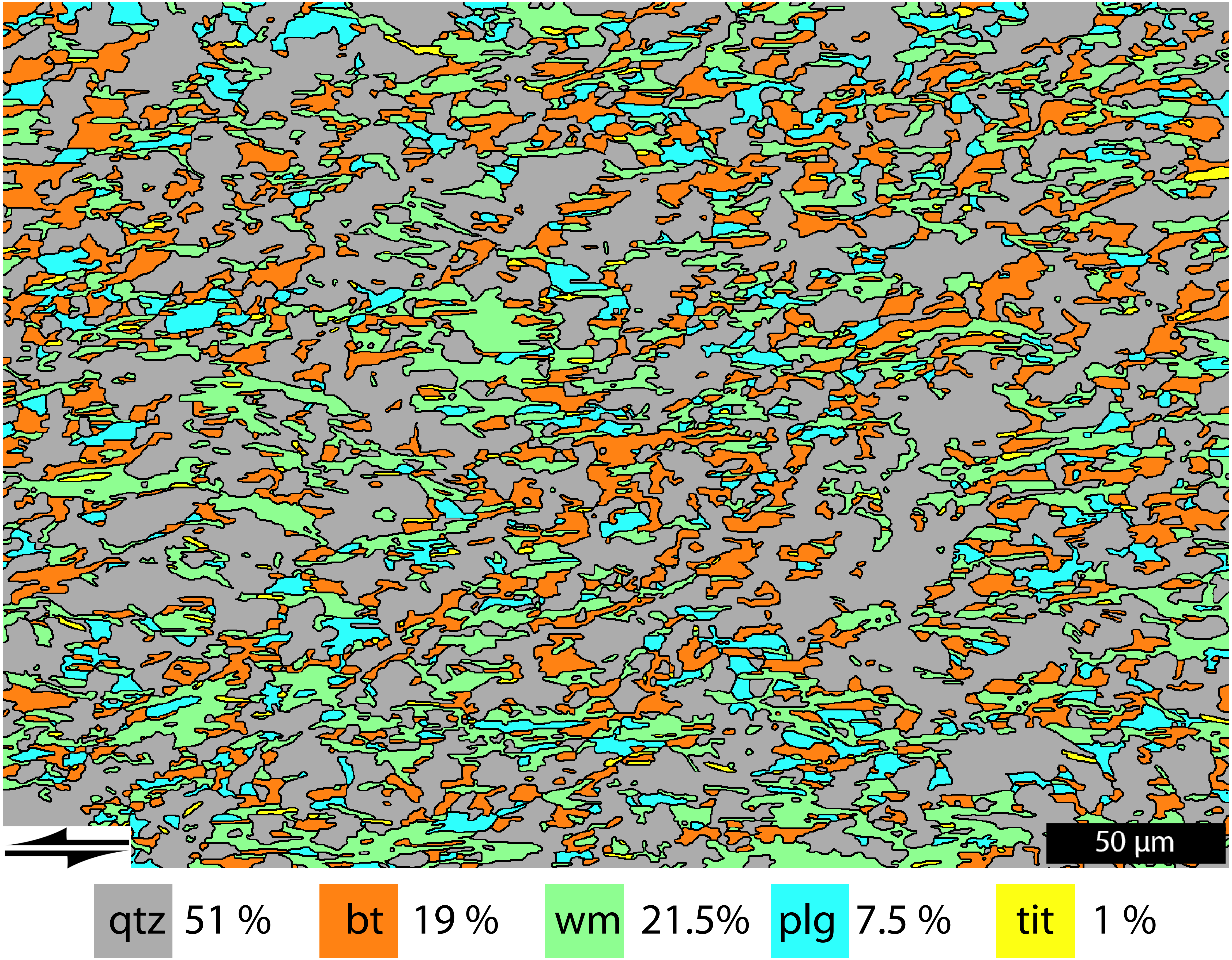
SEM/BSE

fine grained qtz, plg, bt, wm ,ilm/tit



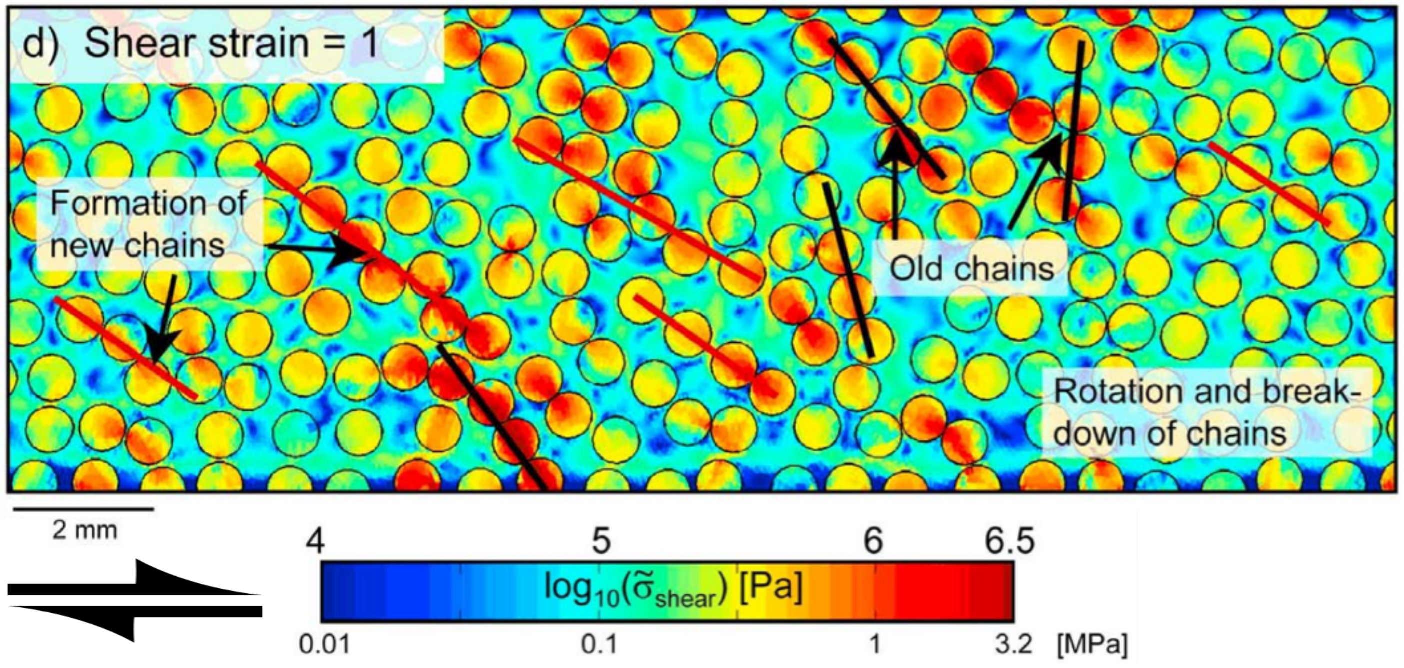
SEM/BSE

Phase map: qtz forms columnar structures (from ACF)

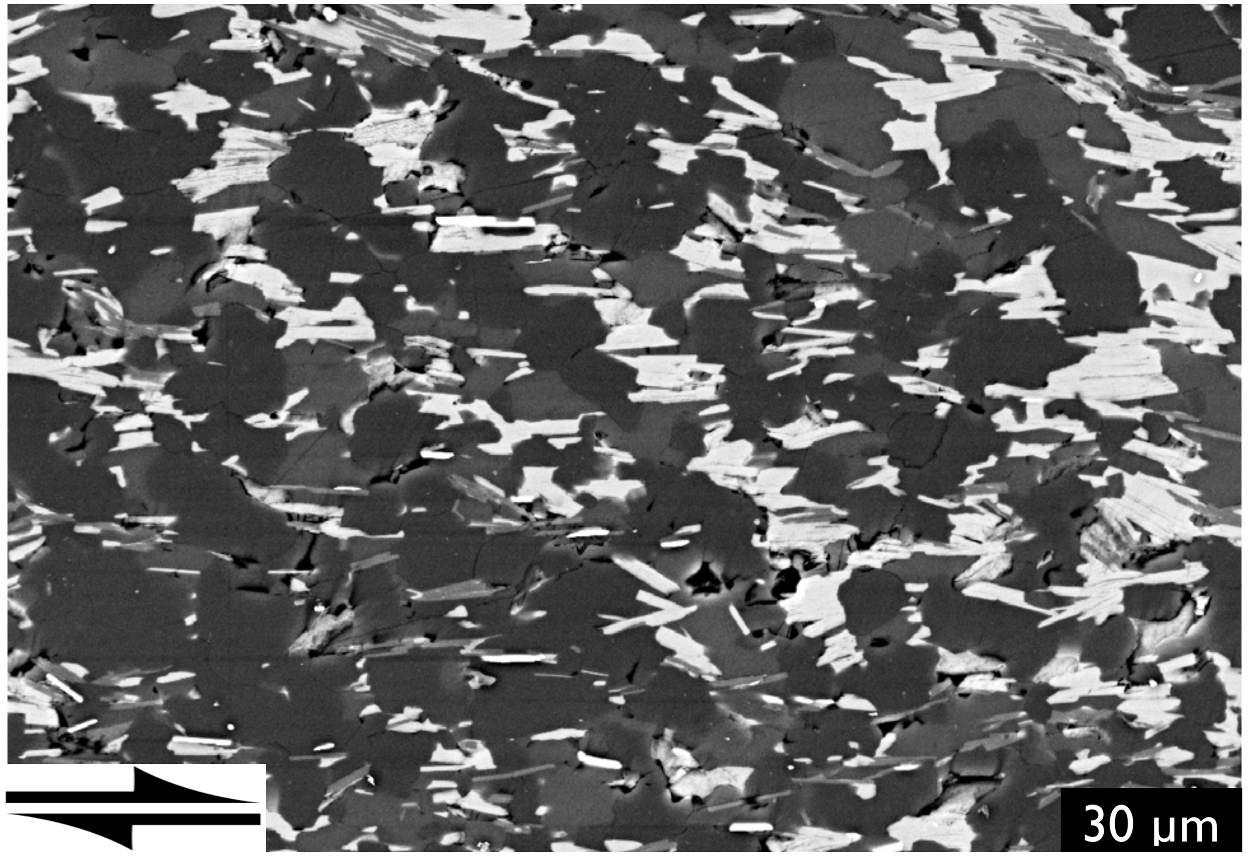


Model of granular flow

Deubelbeiss et al., 2011



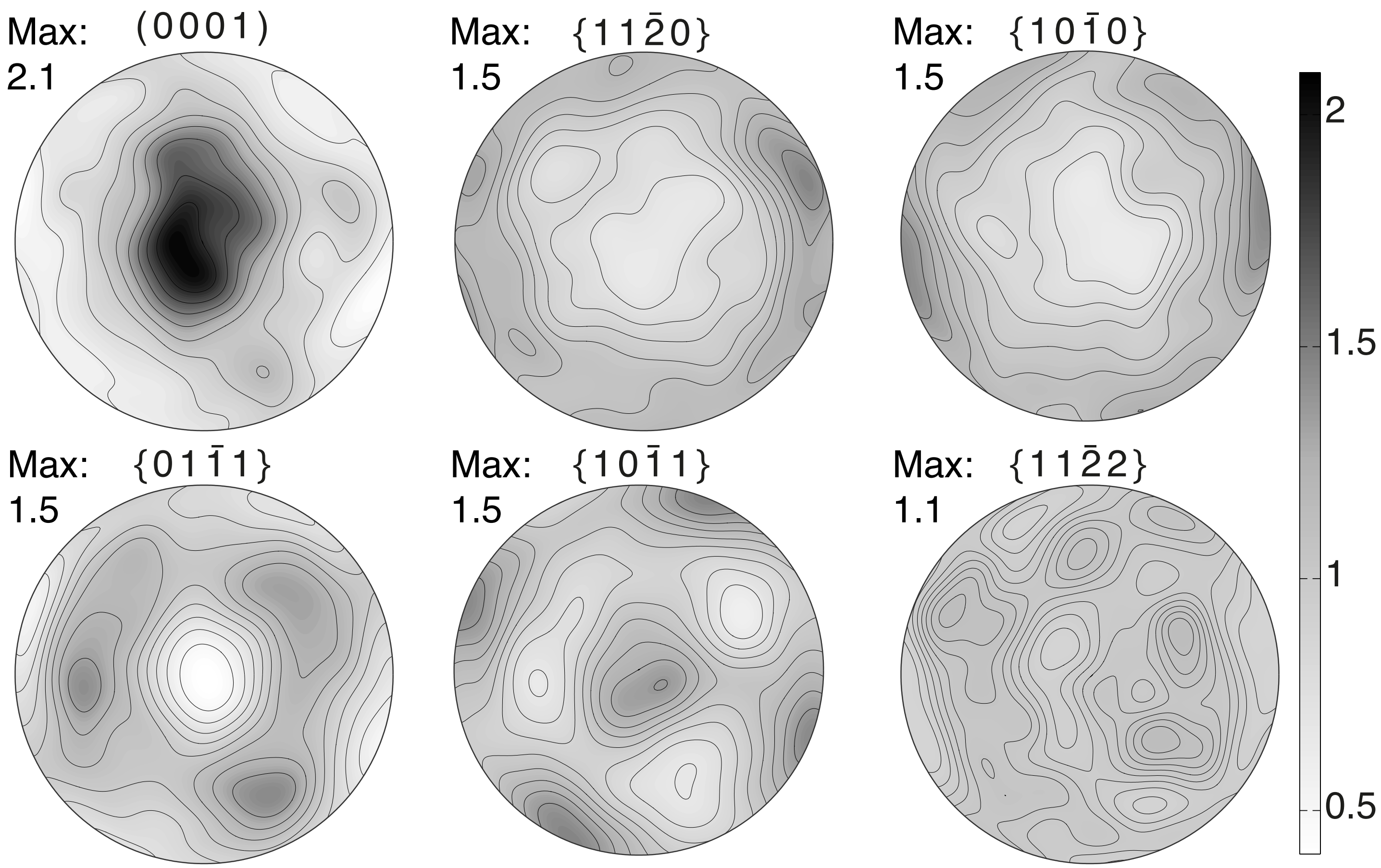
this study



- high stress and low stress bands ≈ positions of qtz and bt
- qtz in aggregates needs to deform (flat contacts, no dilatancy?)

How does quartz accommodate deformation in jammed clusters?

Quartz crystallographic preferred orientation: EBSD

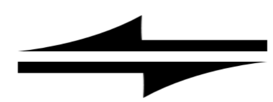


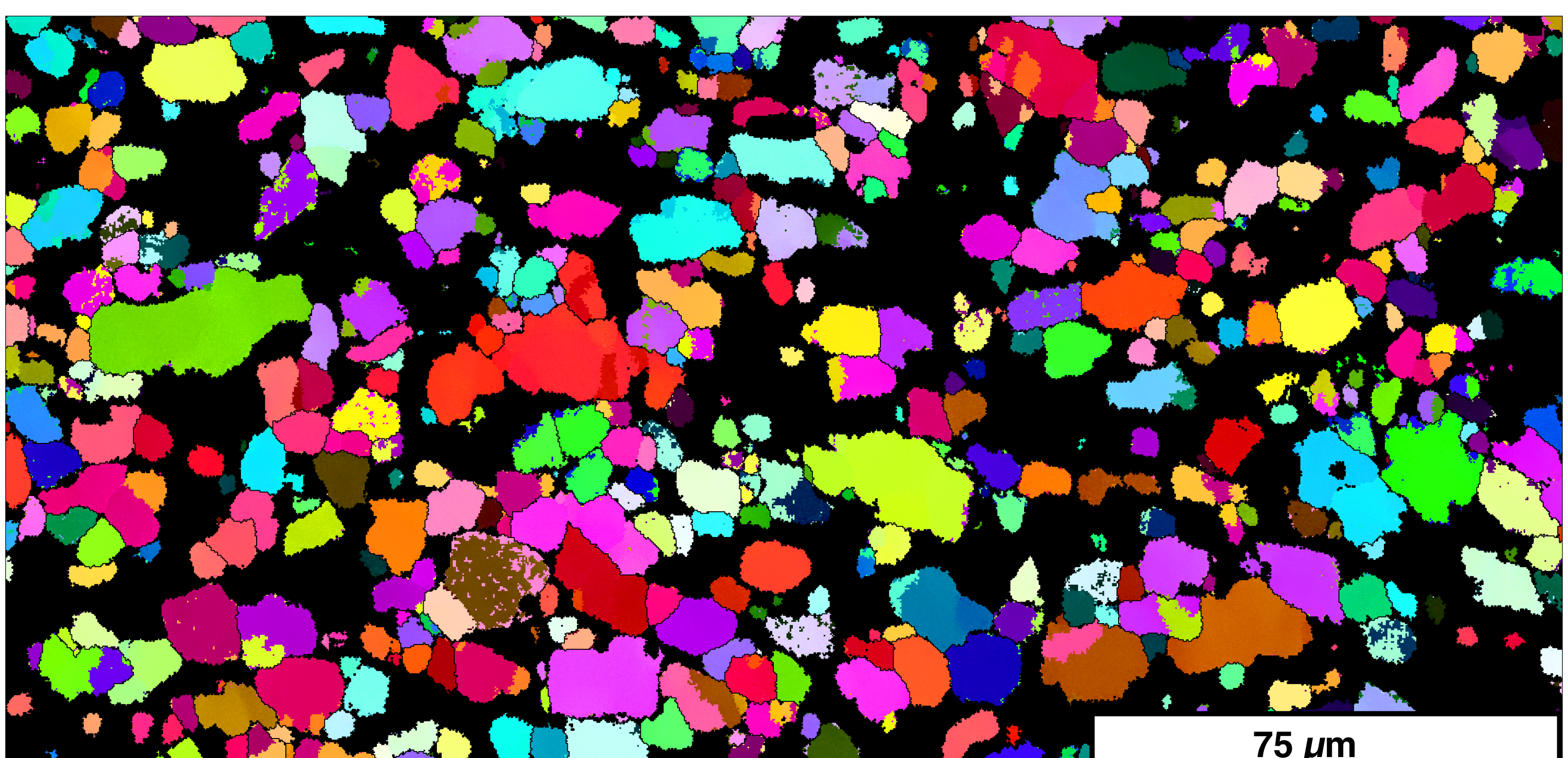
Pole figure of mean grain orientations of 14 individual maps:

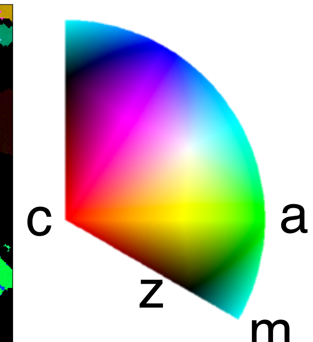
- weak preferred orientation
- central maximum of 0001
- orthogonal maxima of 10-11

Significant and distinct from random?

m-index: 0.13 - 0.01 texture index (@10°/5°): 1.3/1.6 pole figure index: 1.2
51% qtz n=12890 (> 10 px)

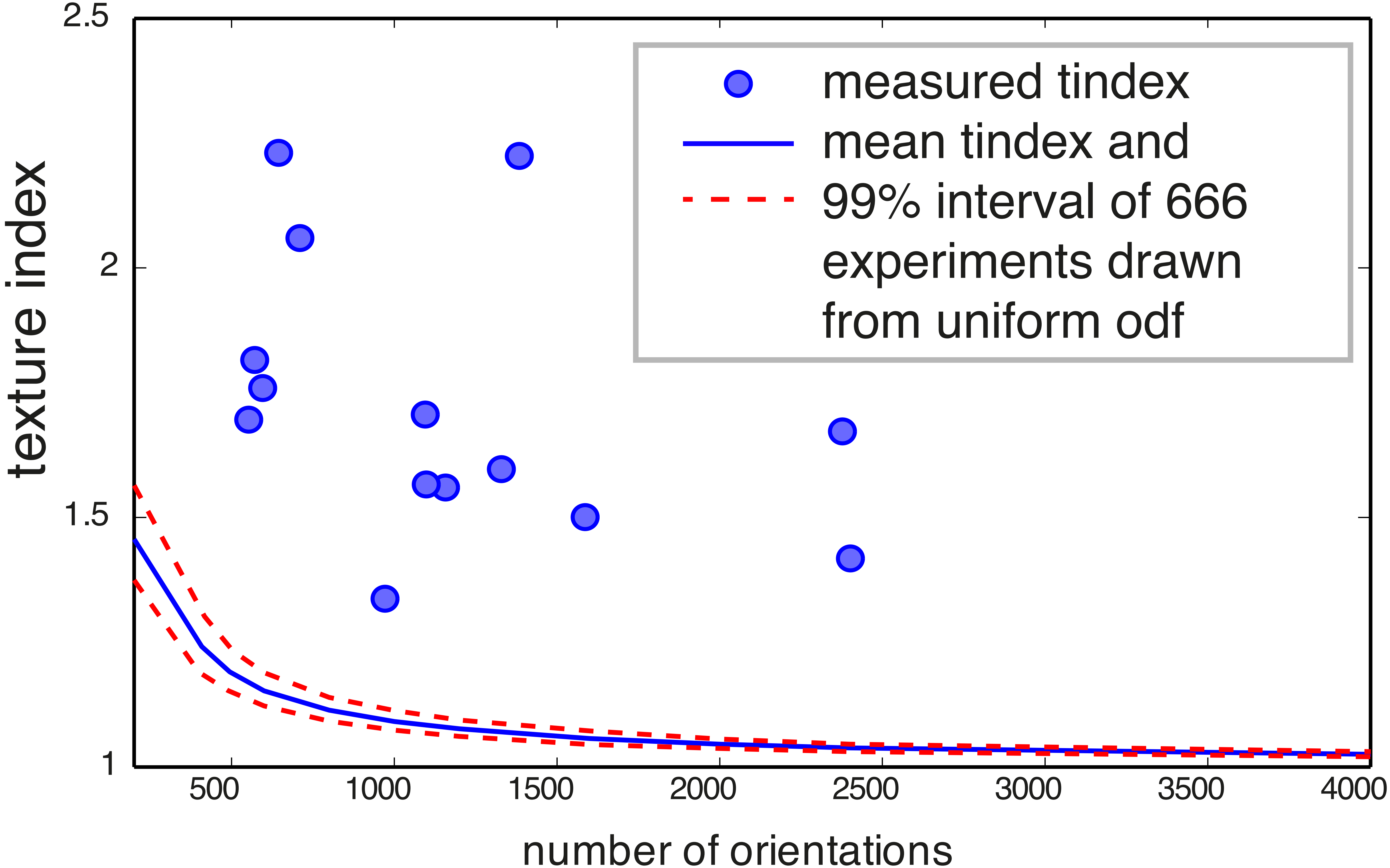






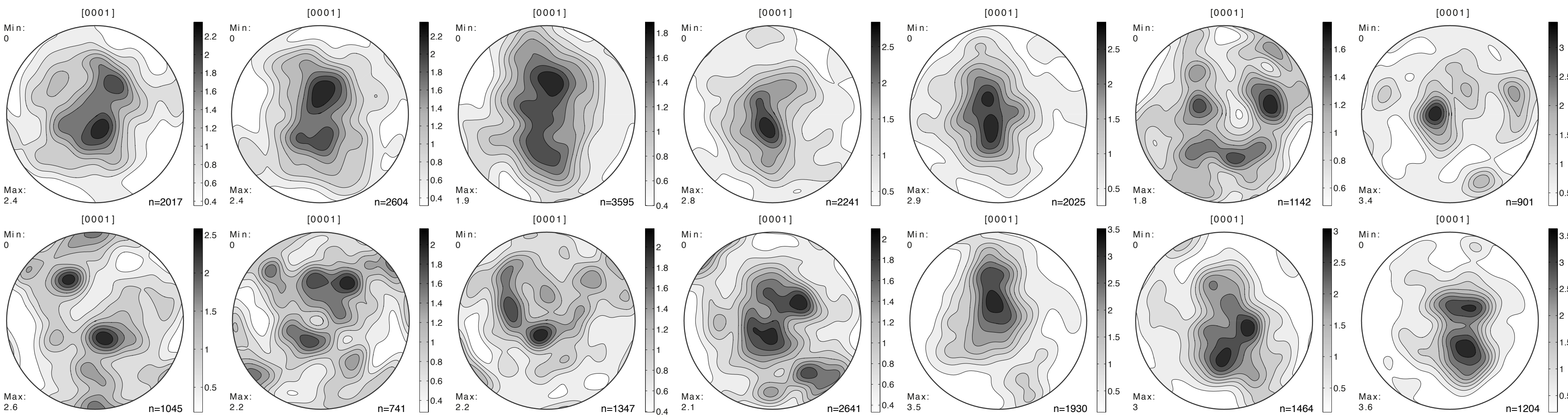
ipf colorcoding wrt. 001

texture indices of independent datasets:
measured compared to random

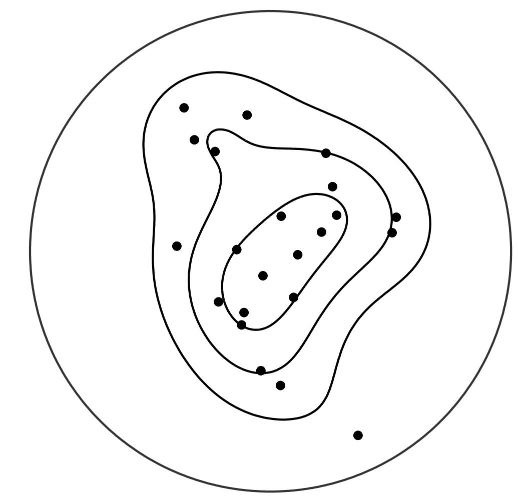


CPO geometry of independent datasets:

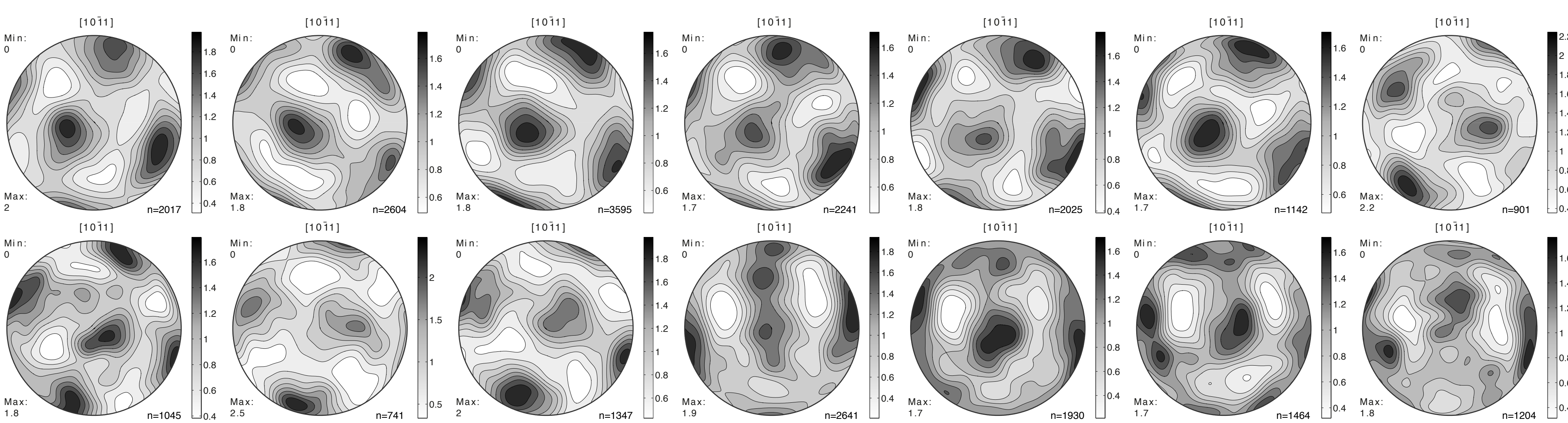
[0001]: central maximum



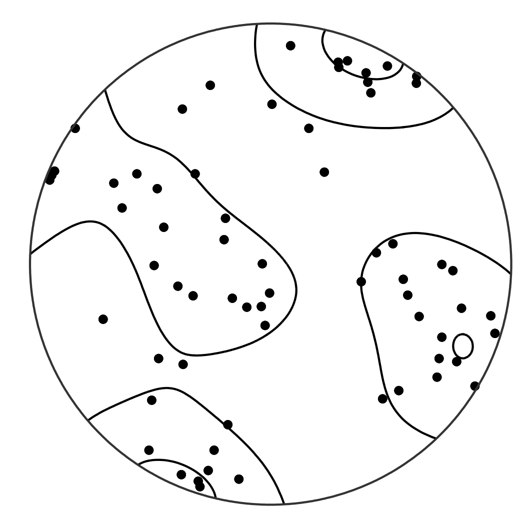
[0001]
first 2 local modes



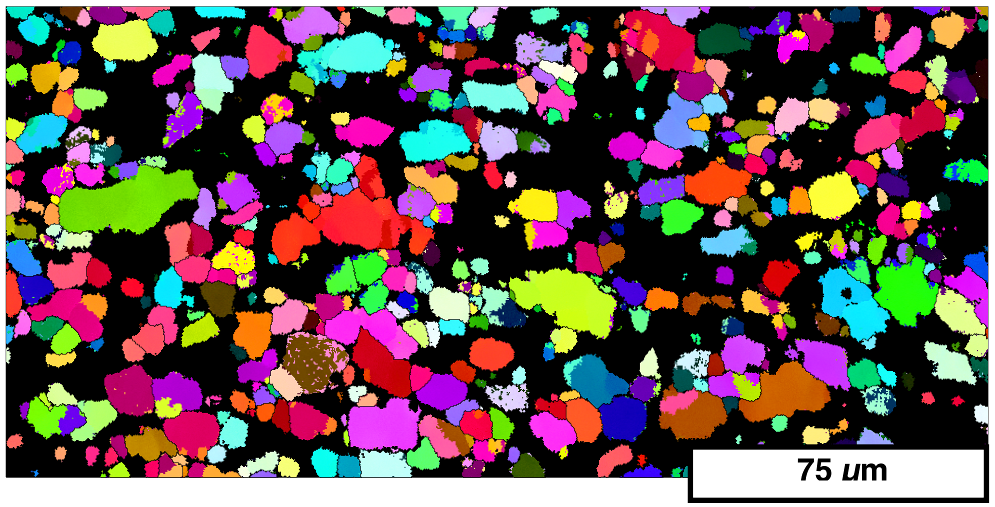
[10-11]: 4 orthogonal maxima

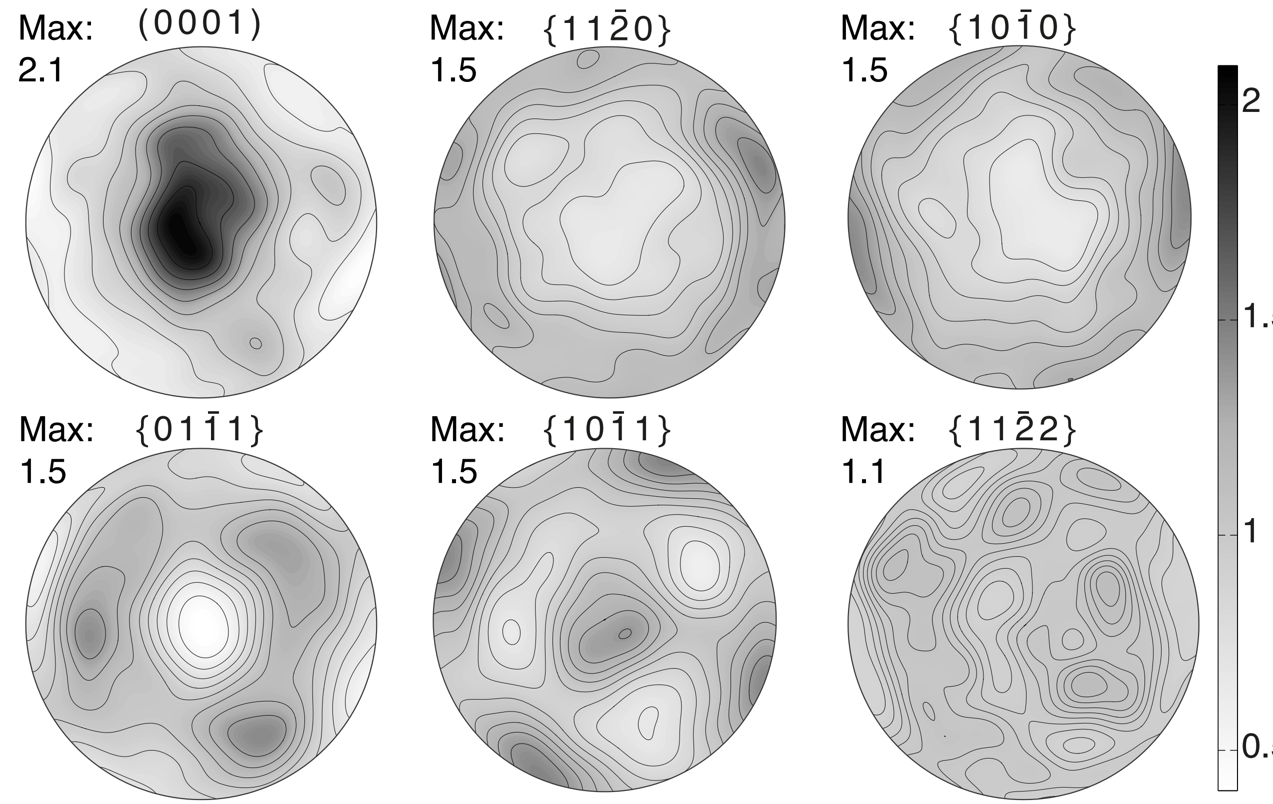


{10-11}
first 2 local modes

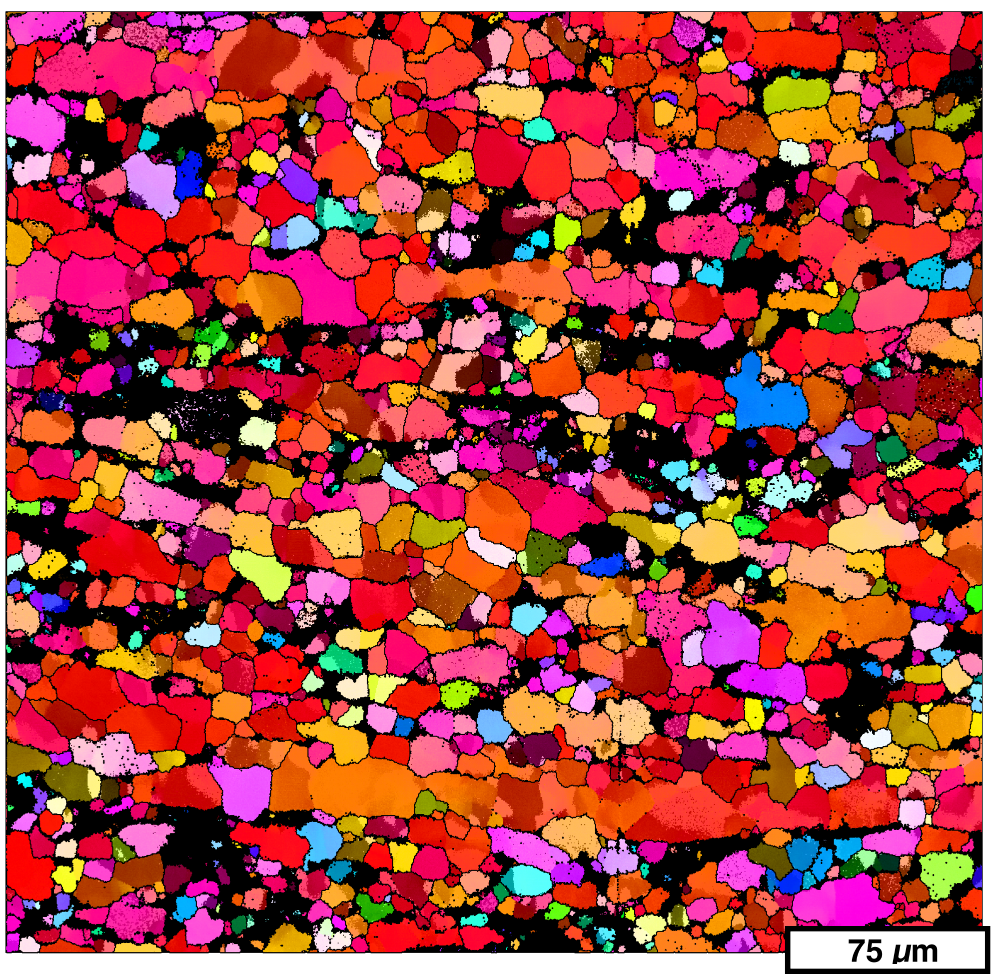


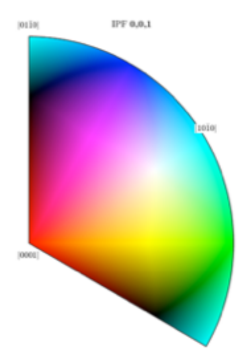
comparison with quartz-rich parts of the shear zone

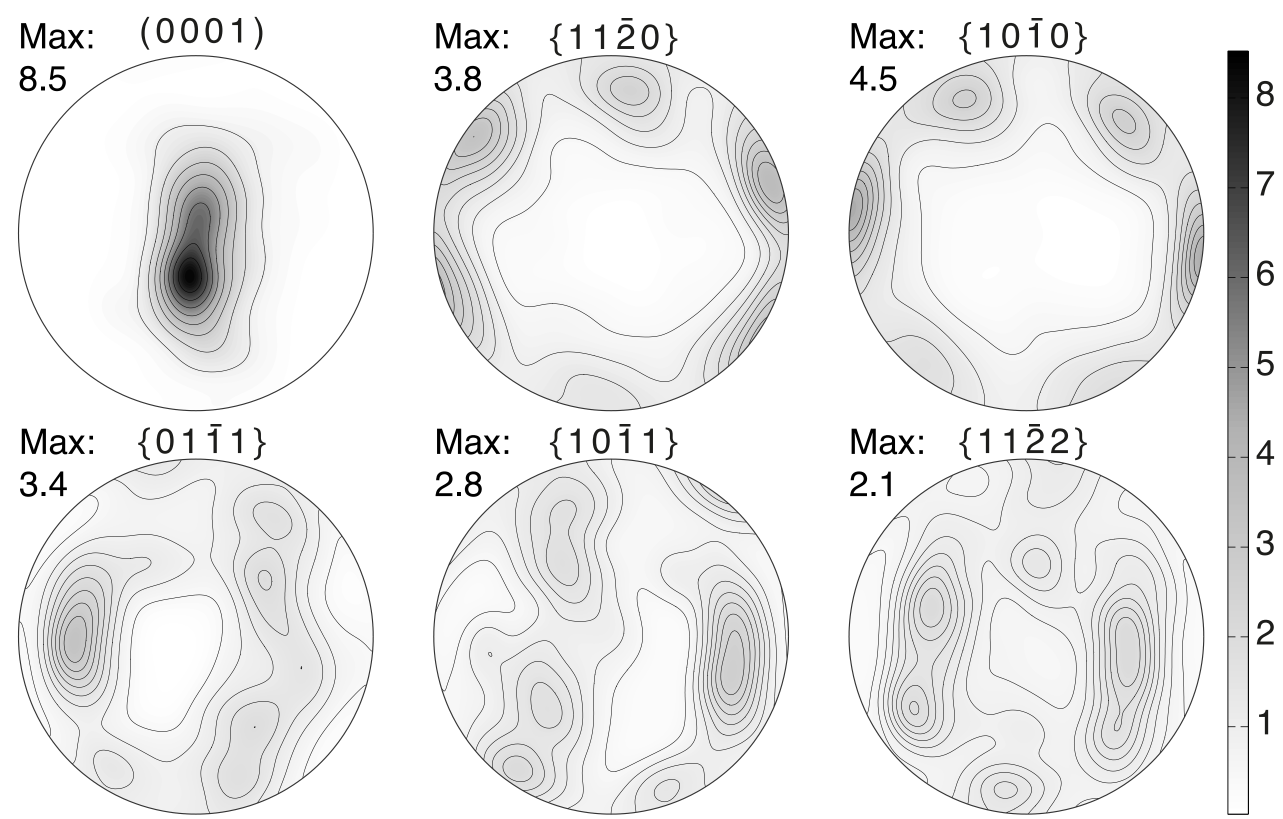




m-index: 0.13 - 0.01 texture index (@10°/5°): 1.3/1.6 pole figure index: 1.2
51% qtz n=12890 (> 10 px)







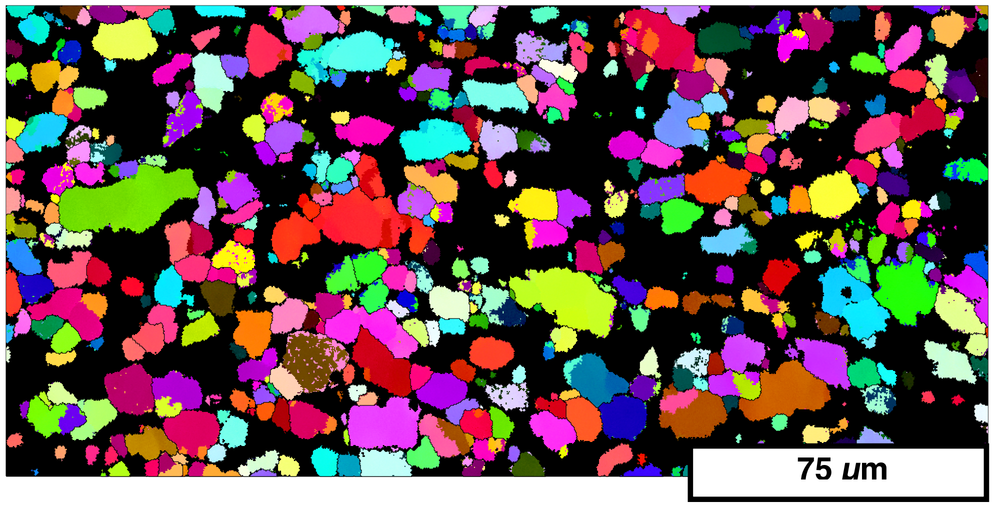
ipf (001)

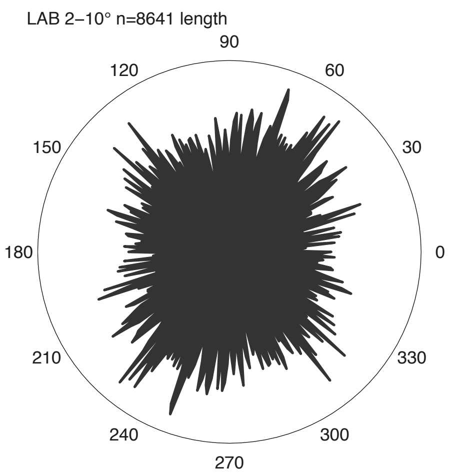
m-index: 0.39-0.12 texture index (@10°/5°): 4.9/8.7 pole figure index (0001): 3.4
83% qtz n=1368

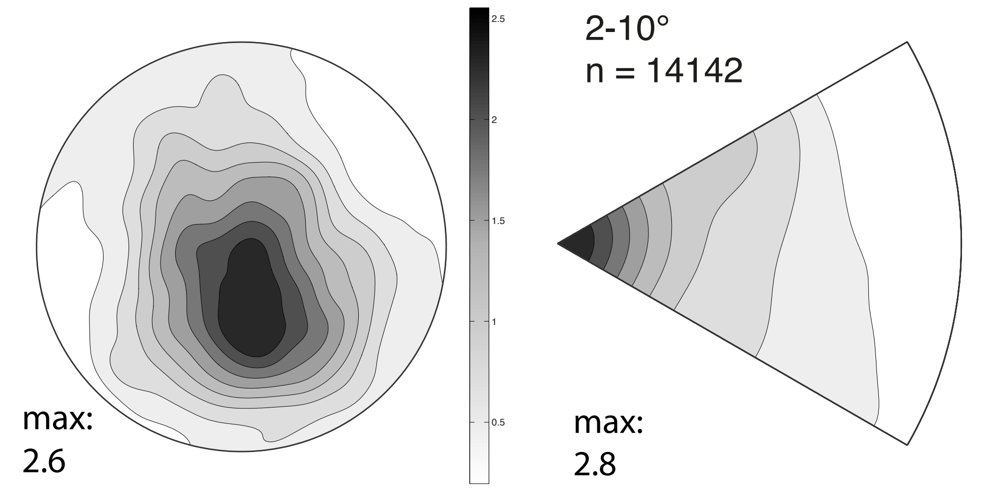
comparison with quartz-rich parts of the shear zone

rose diagram
for trend of LAB

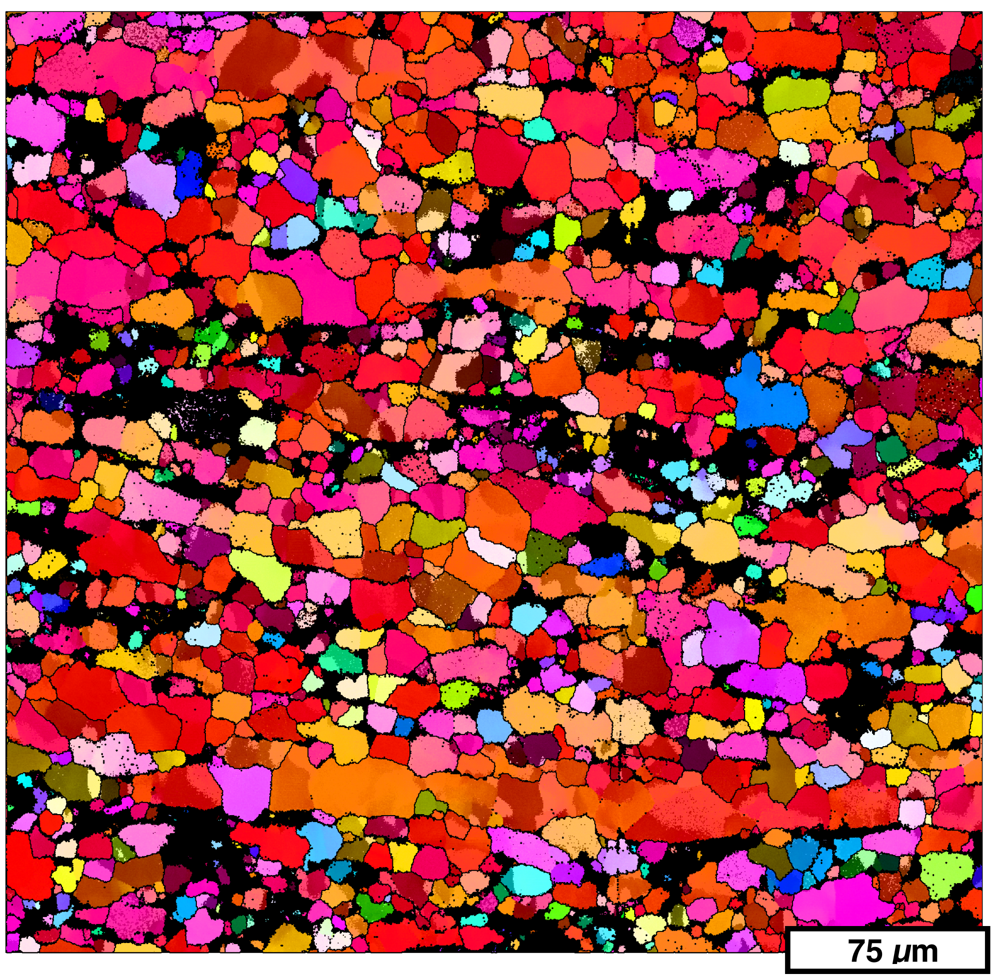
misorientation axes

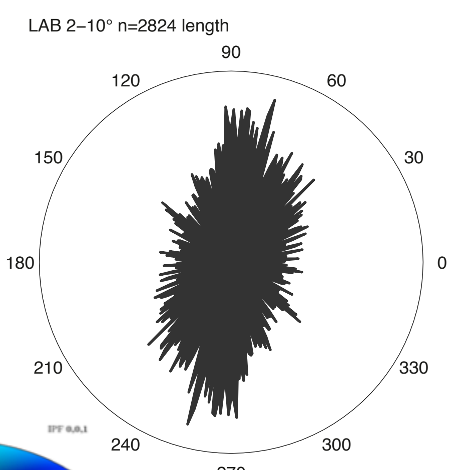


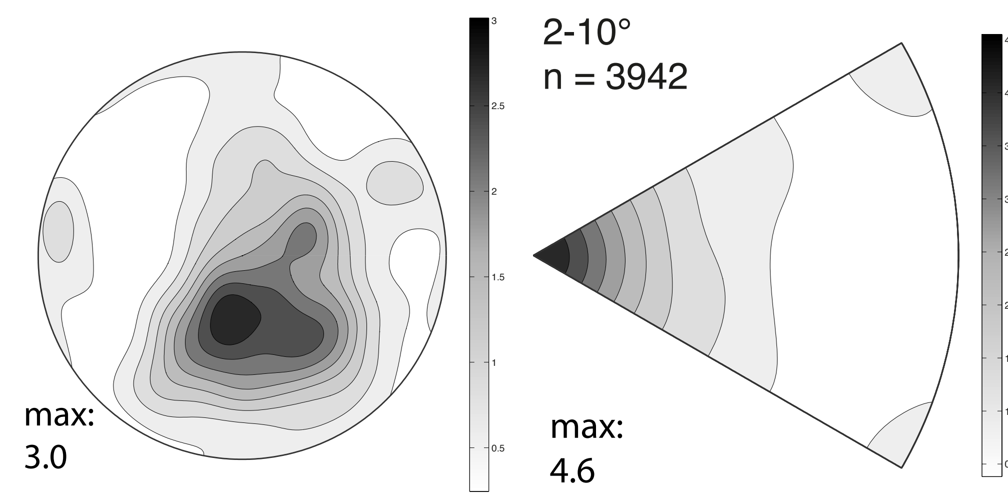


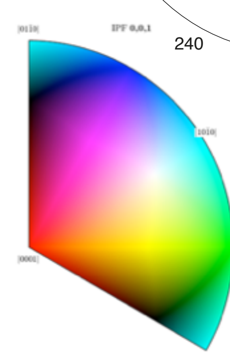


texture is most likely not inherited





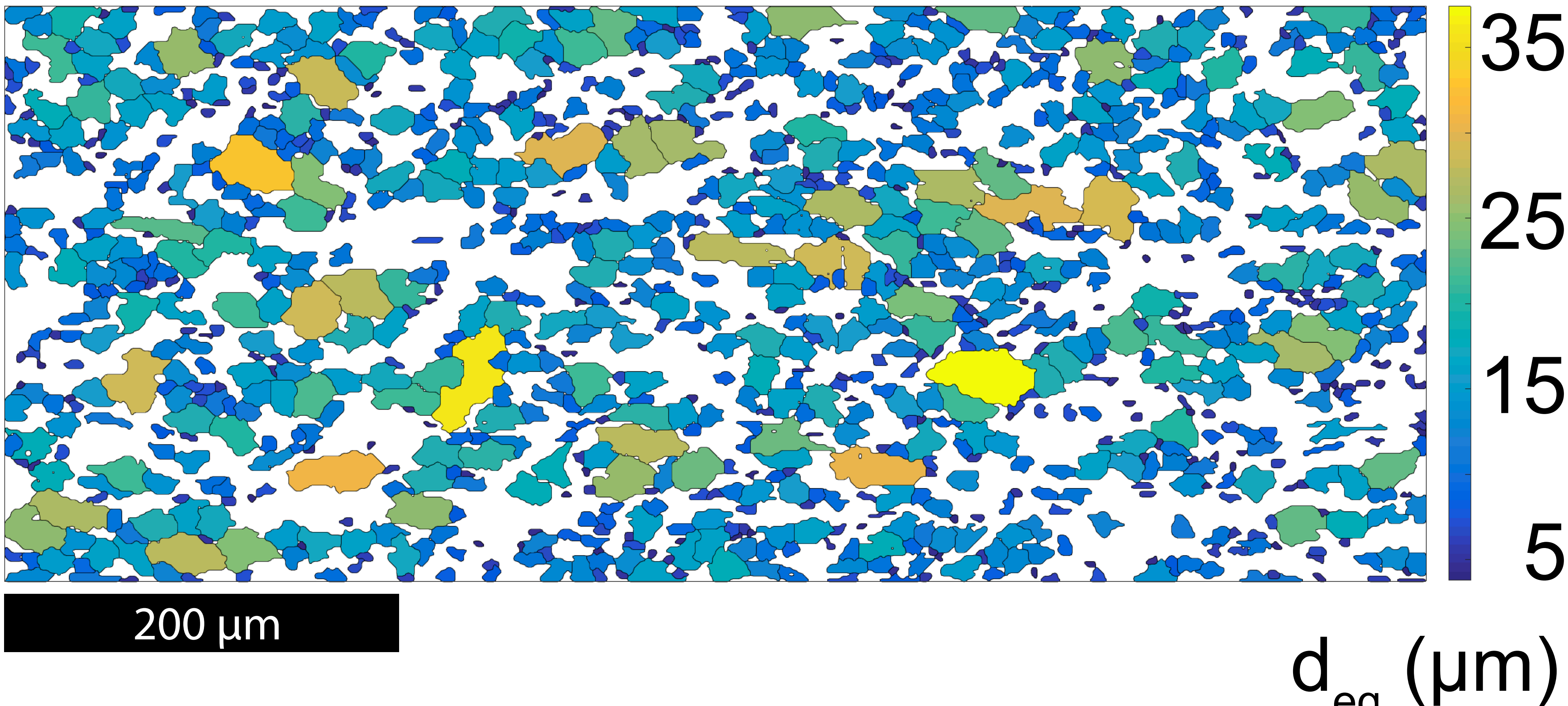




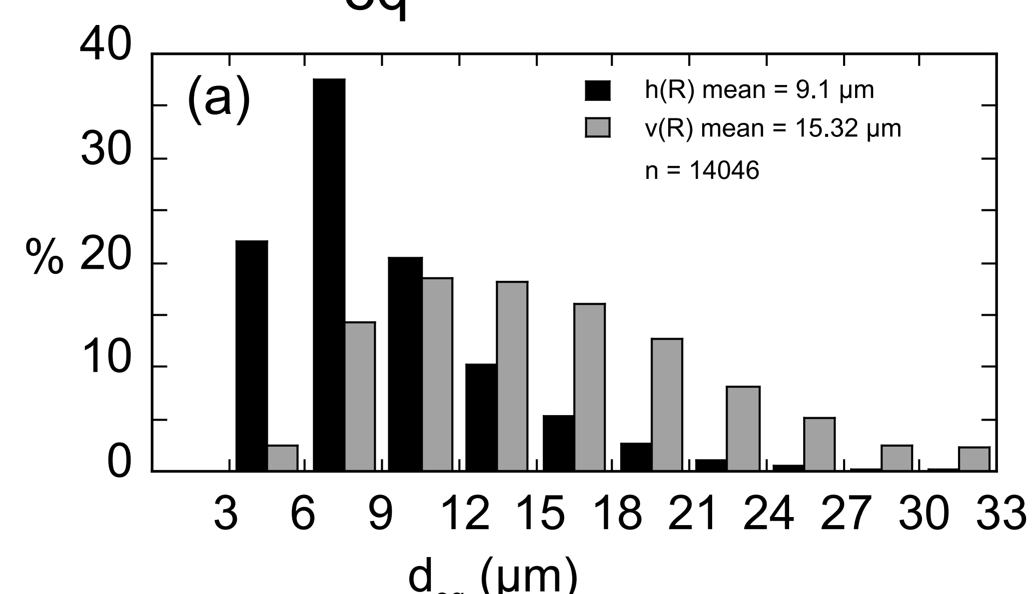
ipf (001)

Which type of grains carry the non-random texture?

With MTEX it is very easy to map grain properties and compare textures obtained from different subsets. e.g. grain size



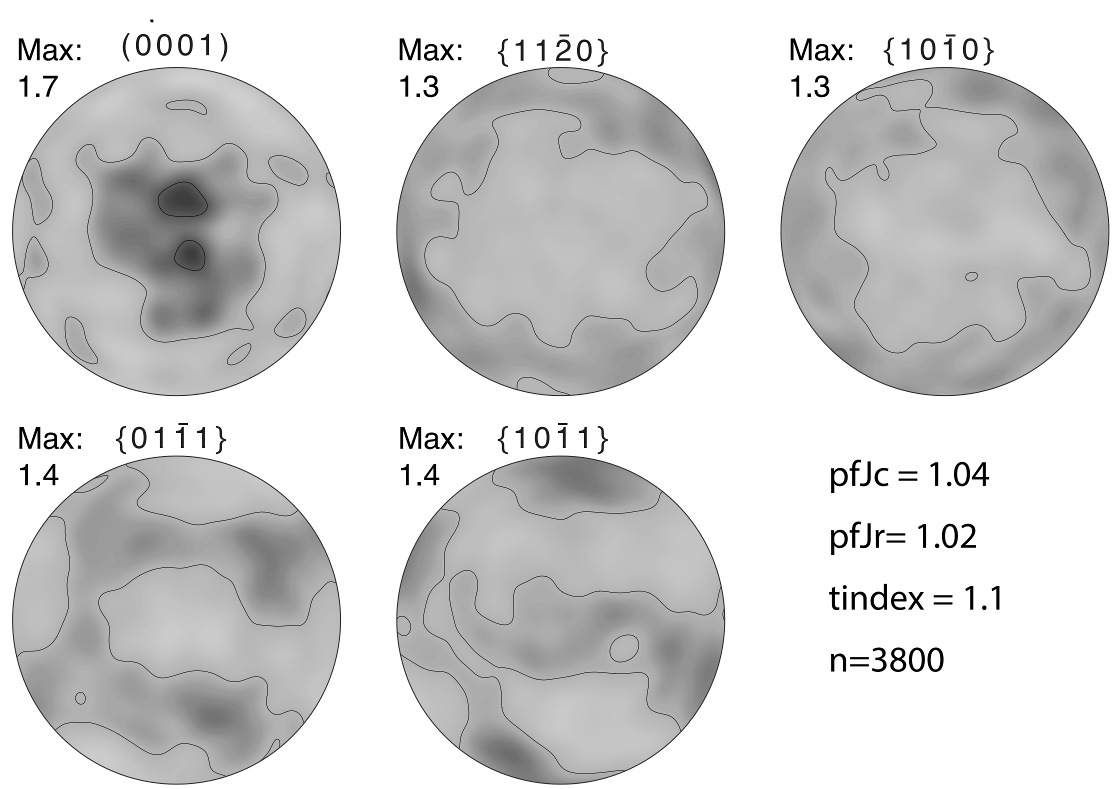

```
plot(grains('q'),grains('q').equivalentRadius.*2)
% shortcut for
plot(grains,2*sqrt(grains.area/pi))
```



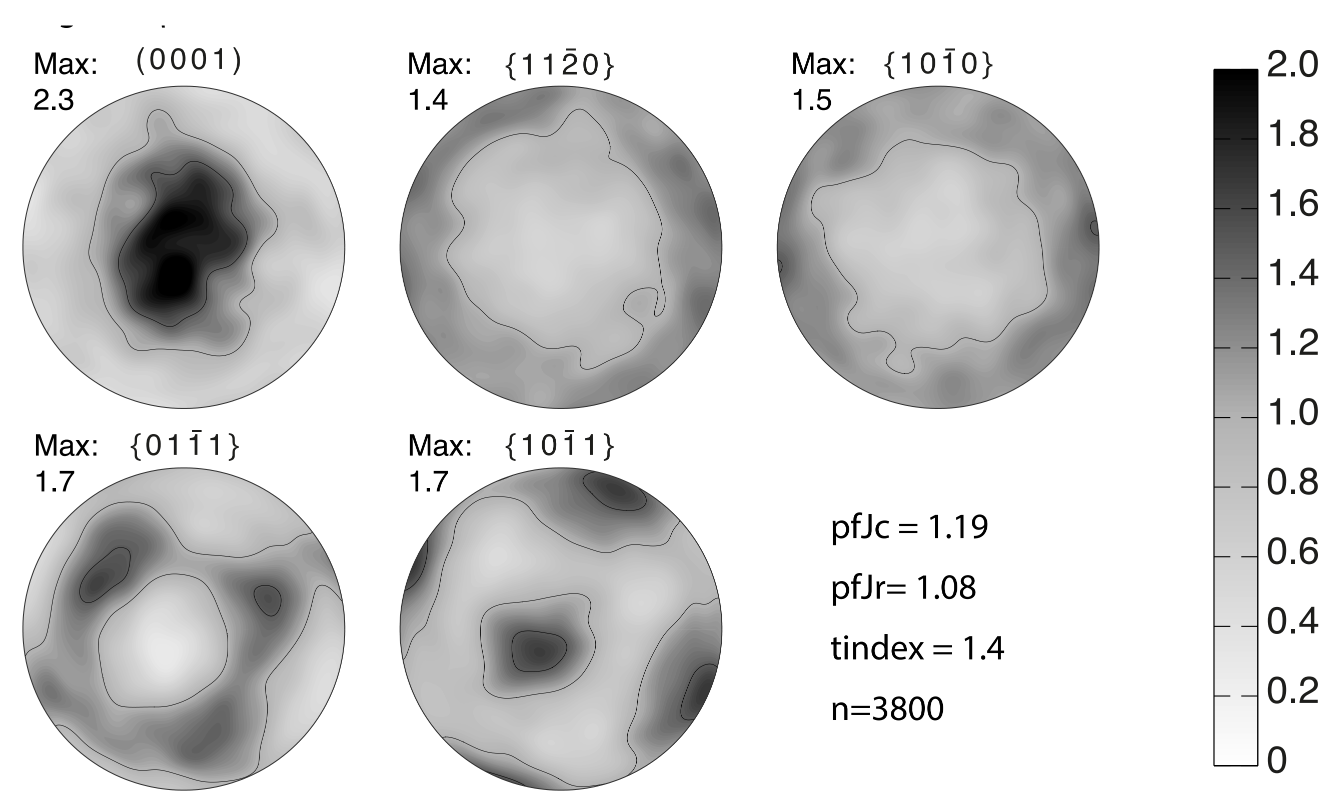
Which type of grains carry the non-random texture?

With MTEX it is very easy to map grain properties and compare textures obtained from different subsets. e.g. grain size

diameter < 5 μm

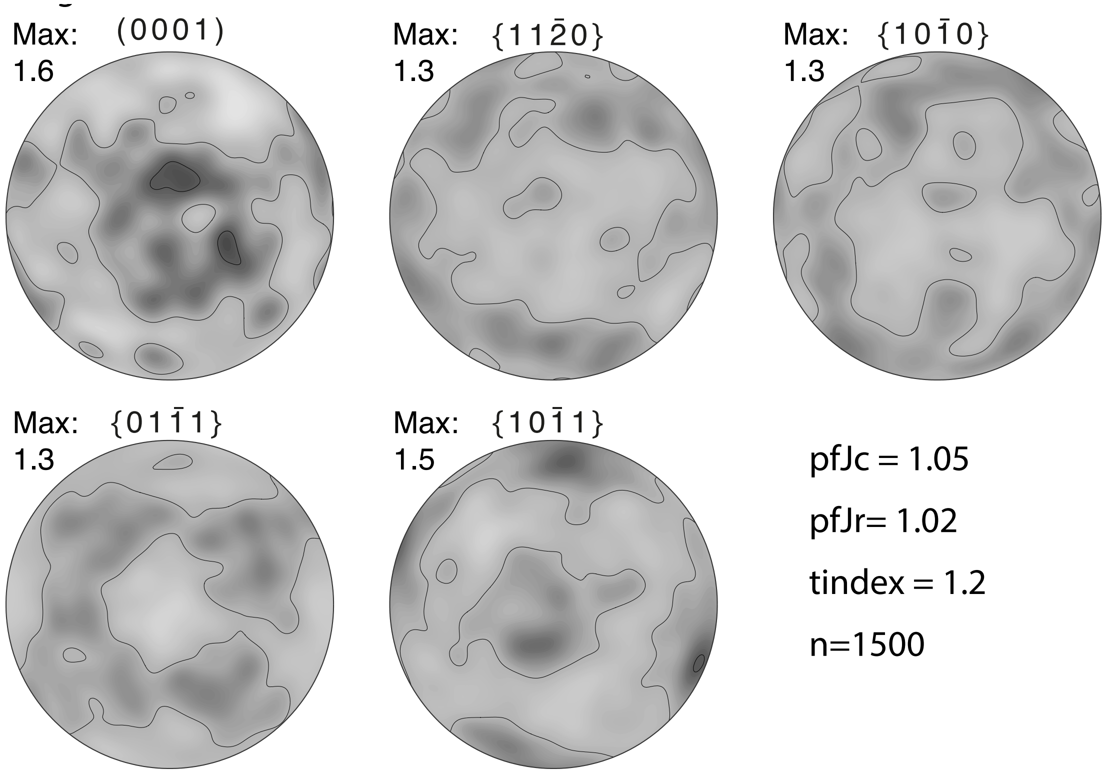


diameter > 10 μm

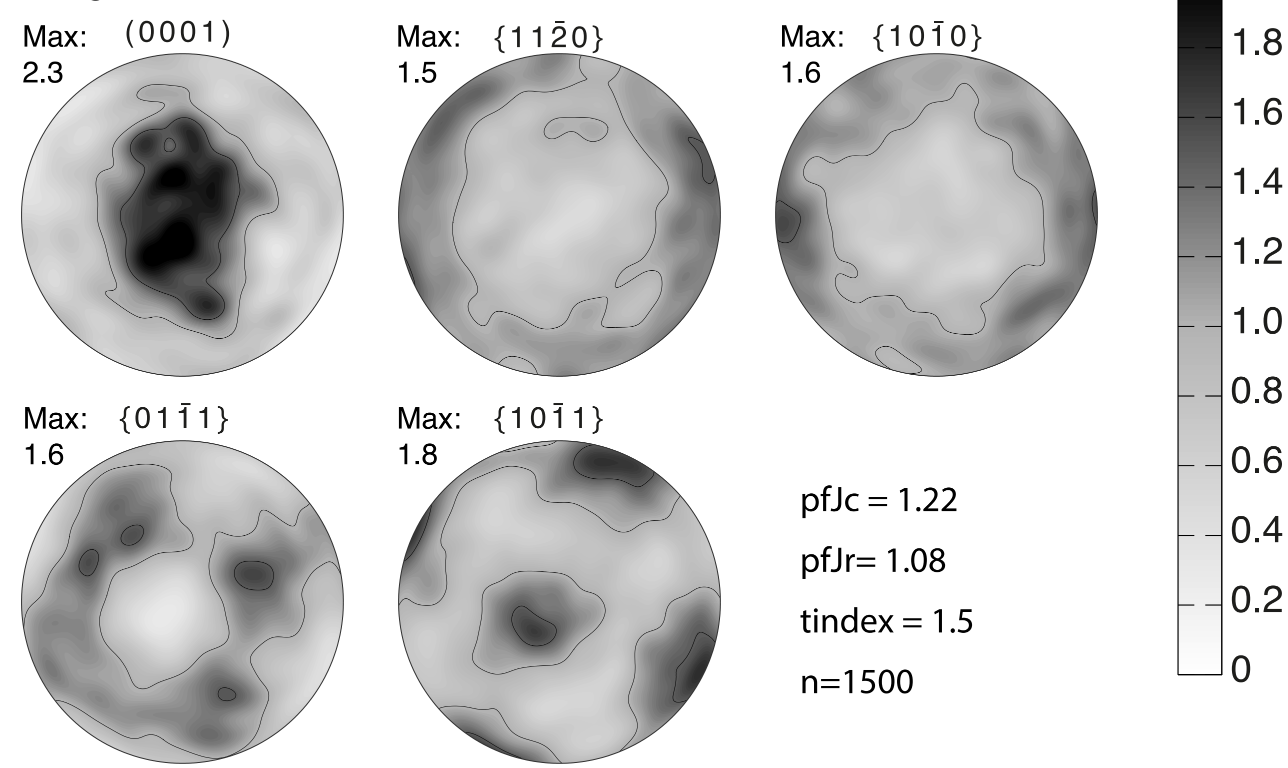


isolated grains vs. those with grain boundaries: neighbor count

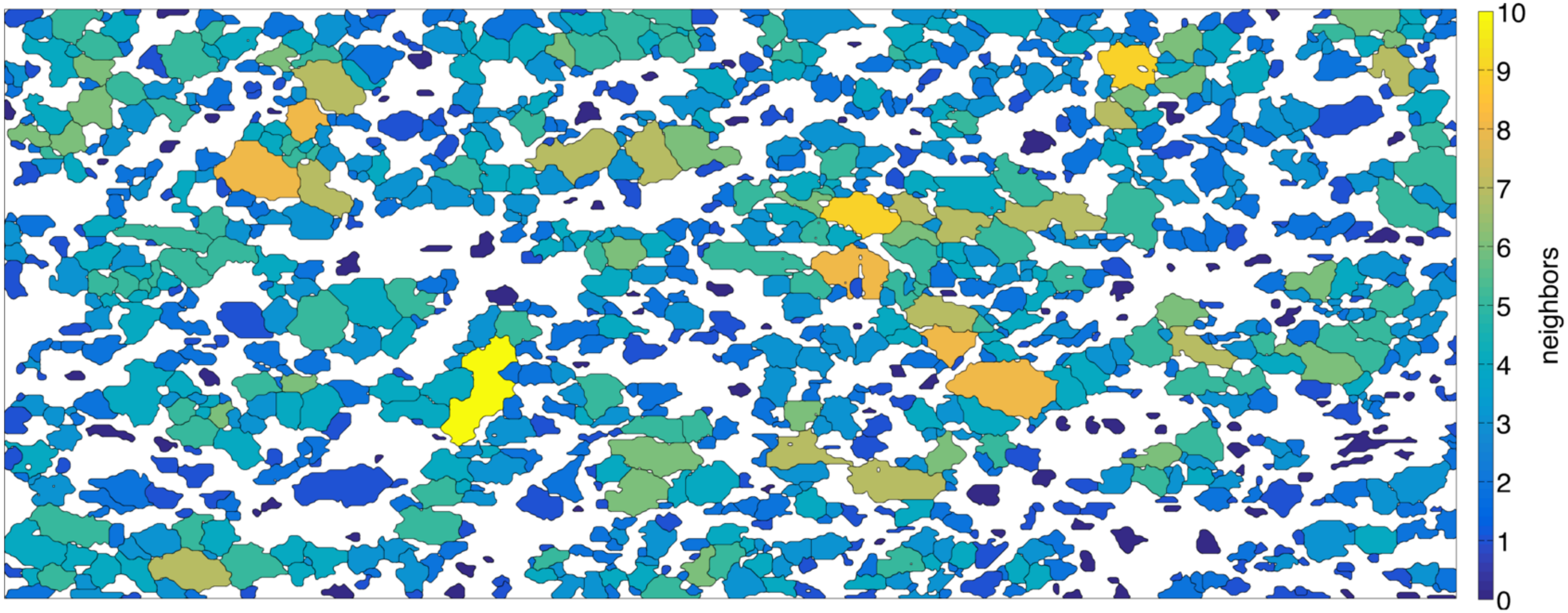
isolated grains (2D)



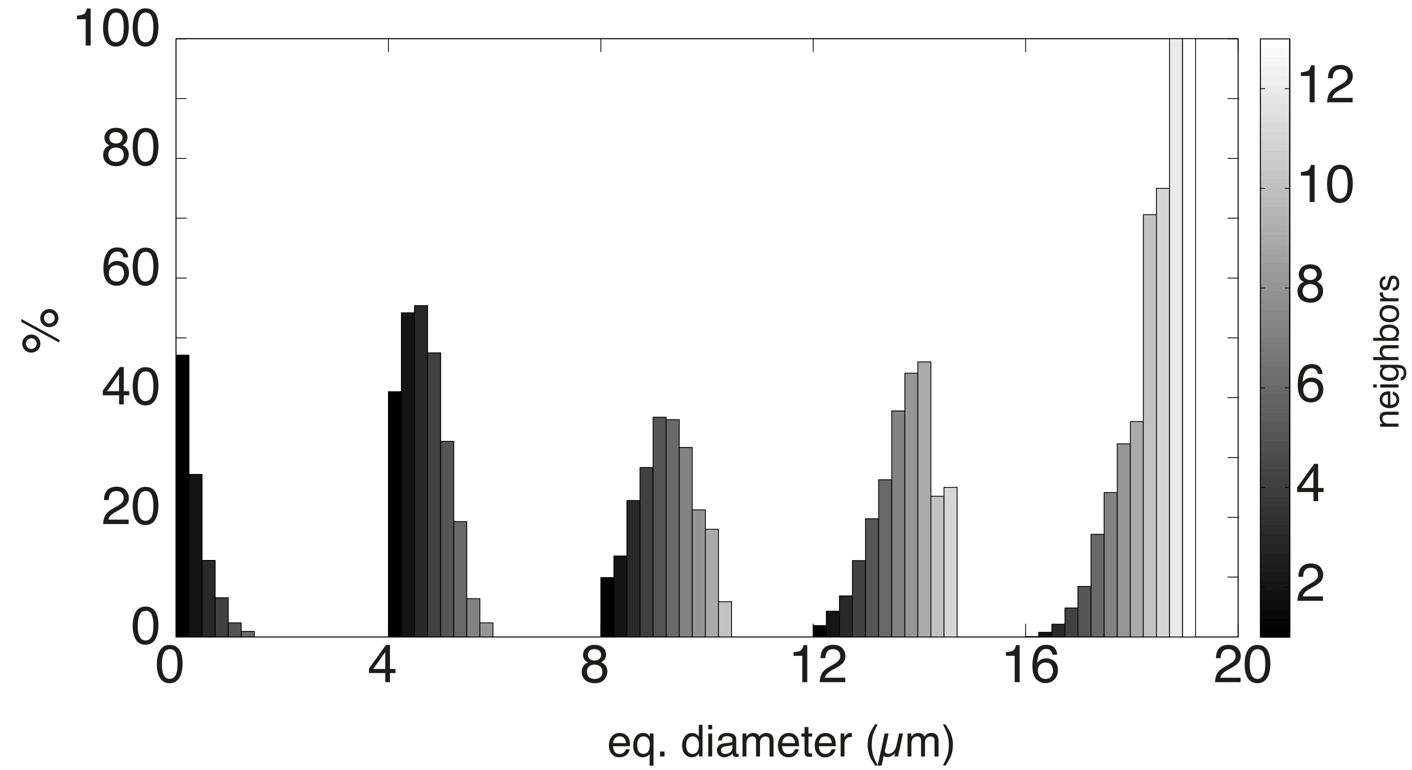
> 4 neighbours (2D)



isolated grains vs. those with grain boundaries: neighbor count

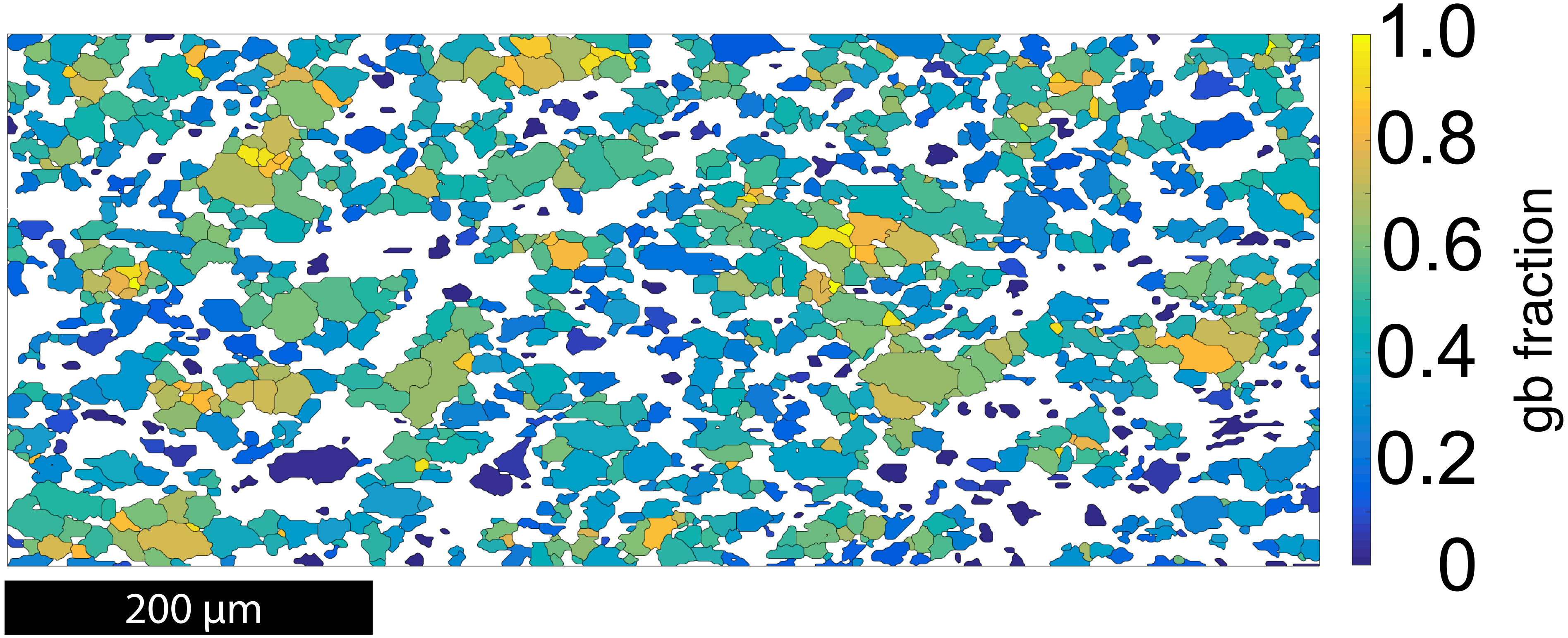



```
plot(grains('q'),grains('q').neighbors)
```

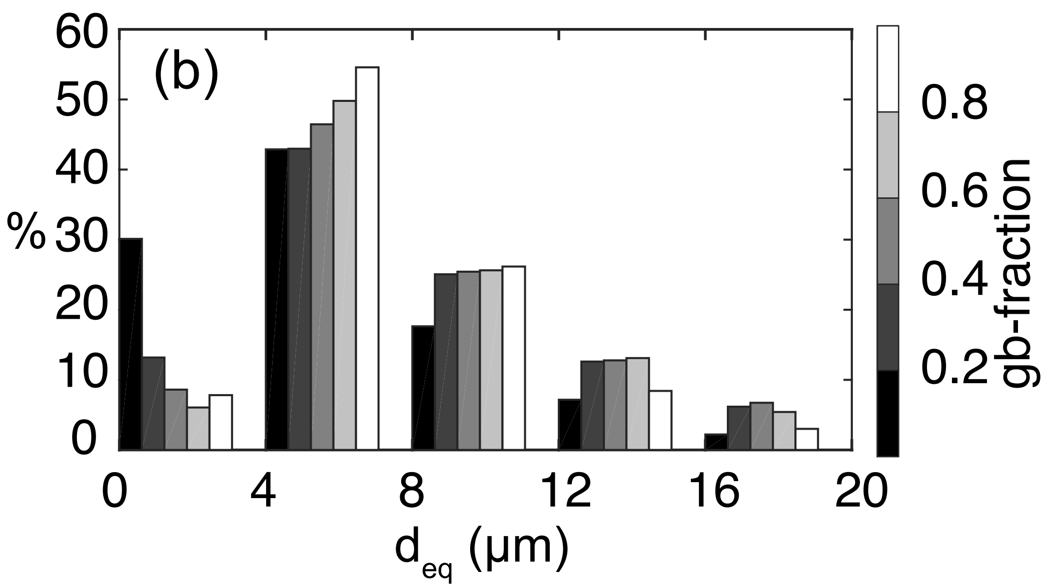


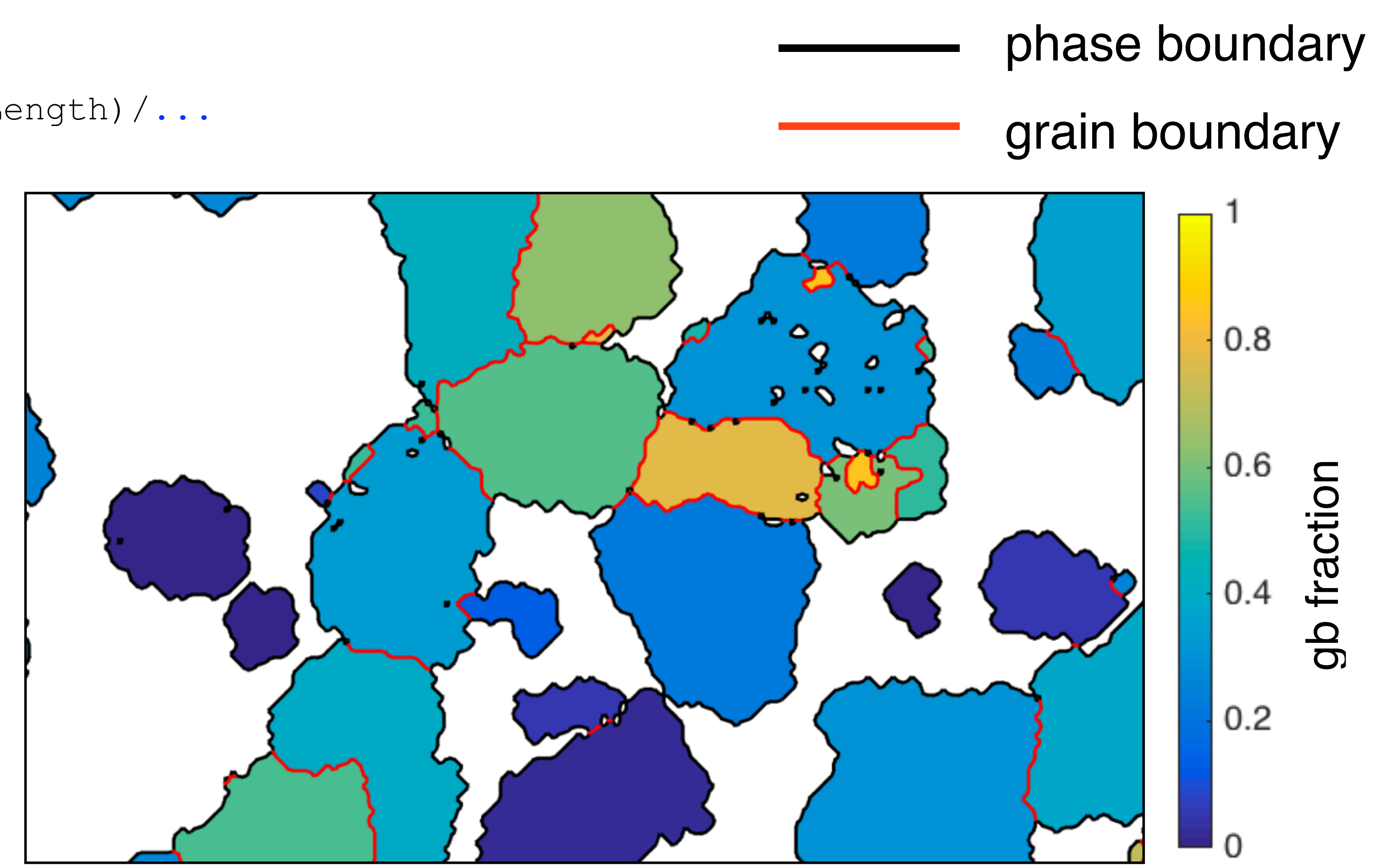
however, neighbor counts seem not to be independent from grain size

isolated grains vs. those with grain boundaries: grain boundary fraction



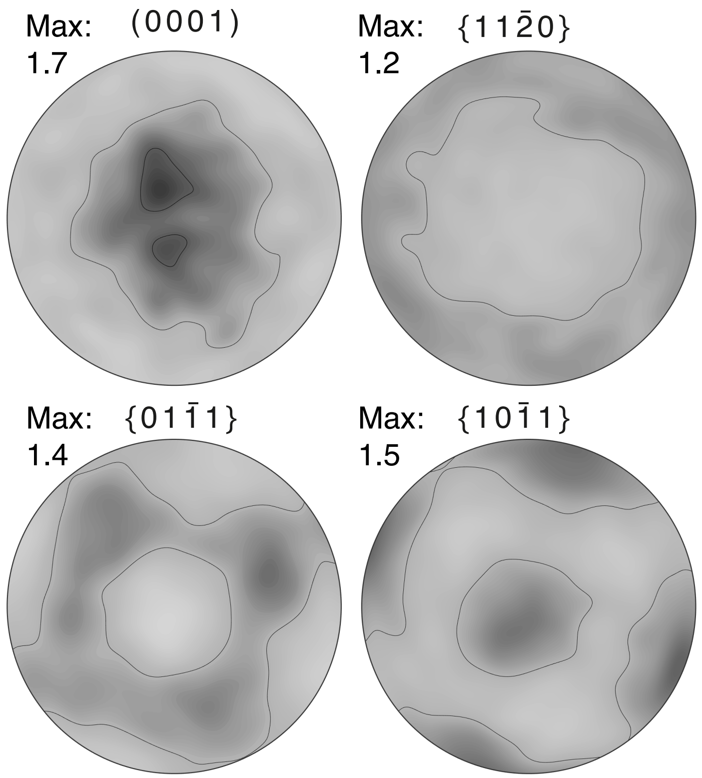

```
for j = 1:length(grains('q'))
gbfrac(j) = sum(grains('q',j).boundary('q','q').segLength)/...
            sum(grains('q',j).boundary.segLength);
end
plot(grains('q'),gbfrac)
```





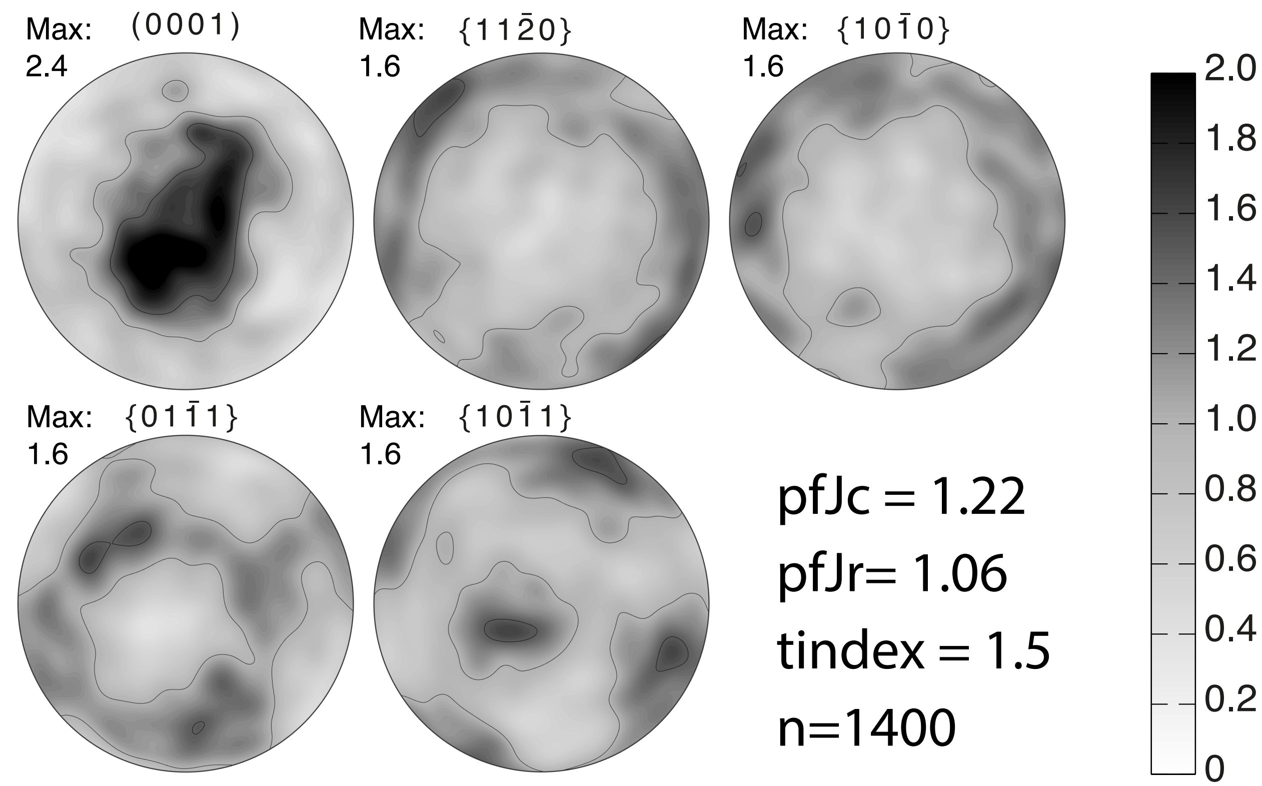
isolated grains vs. those with grain boundaries: grain boundary fraction

< 40% grain boundary (c)



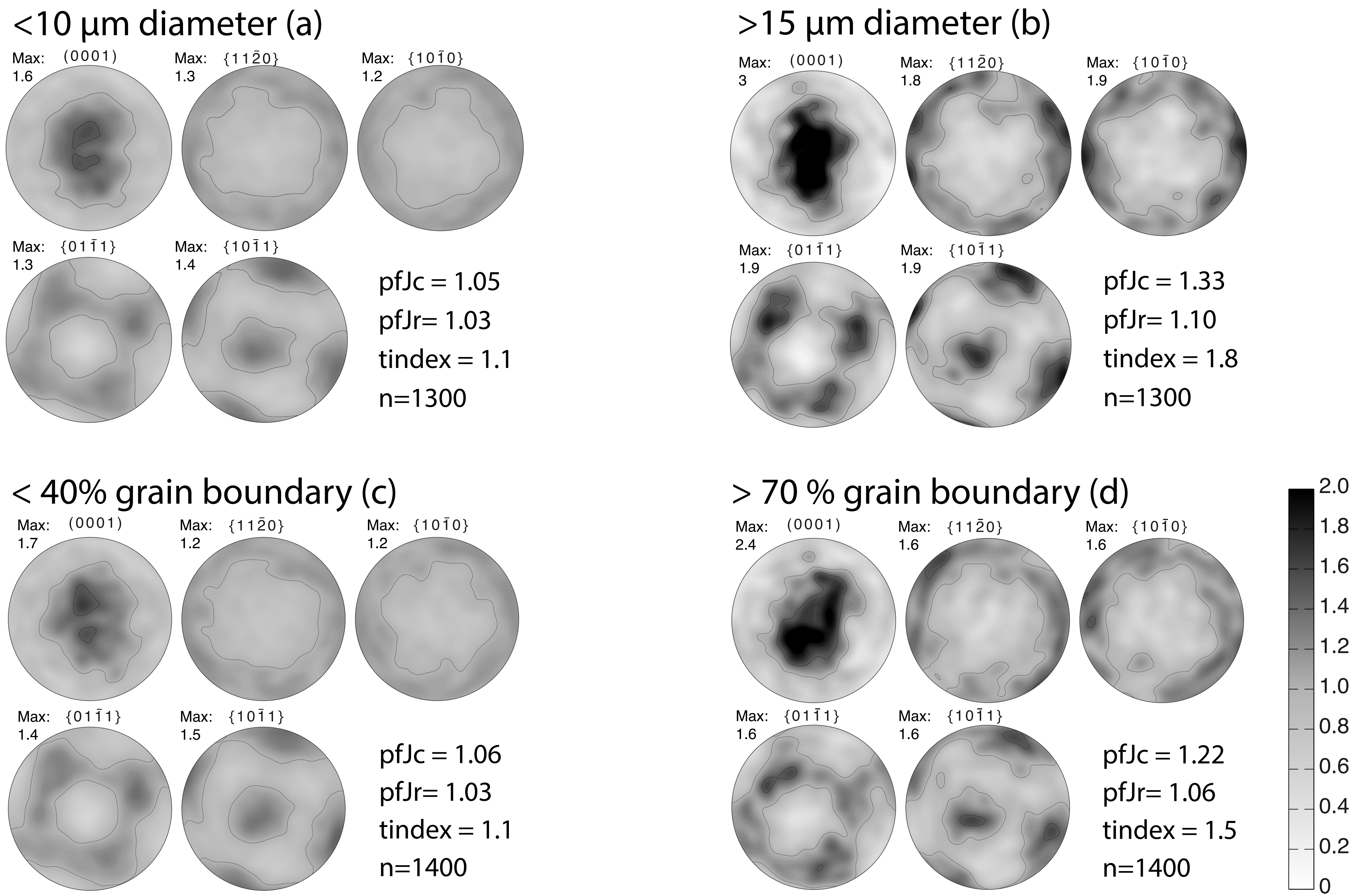
pfJc = 1.06
pfJr= 1.03
tindex = 1.1
n=1400

> 70 % grain boundary (d)

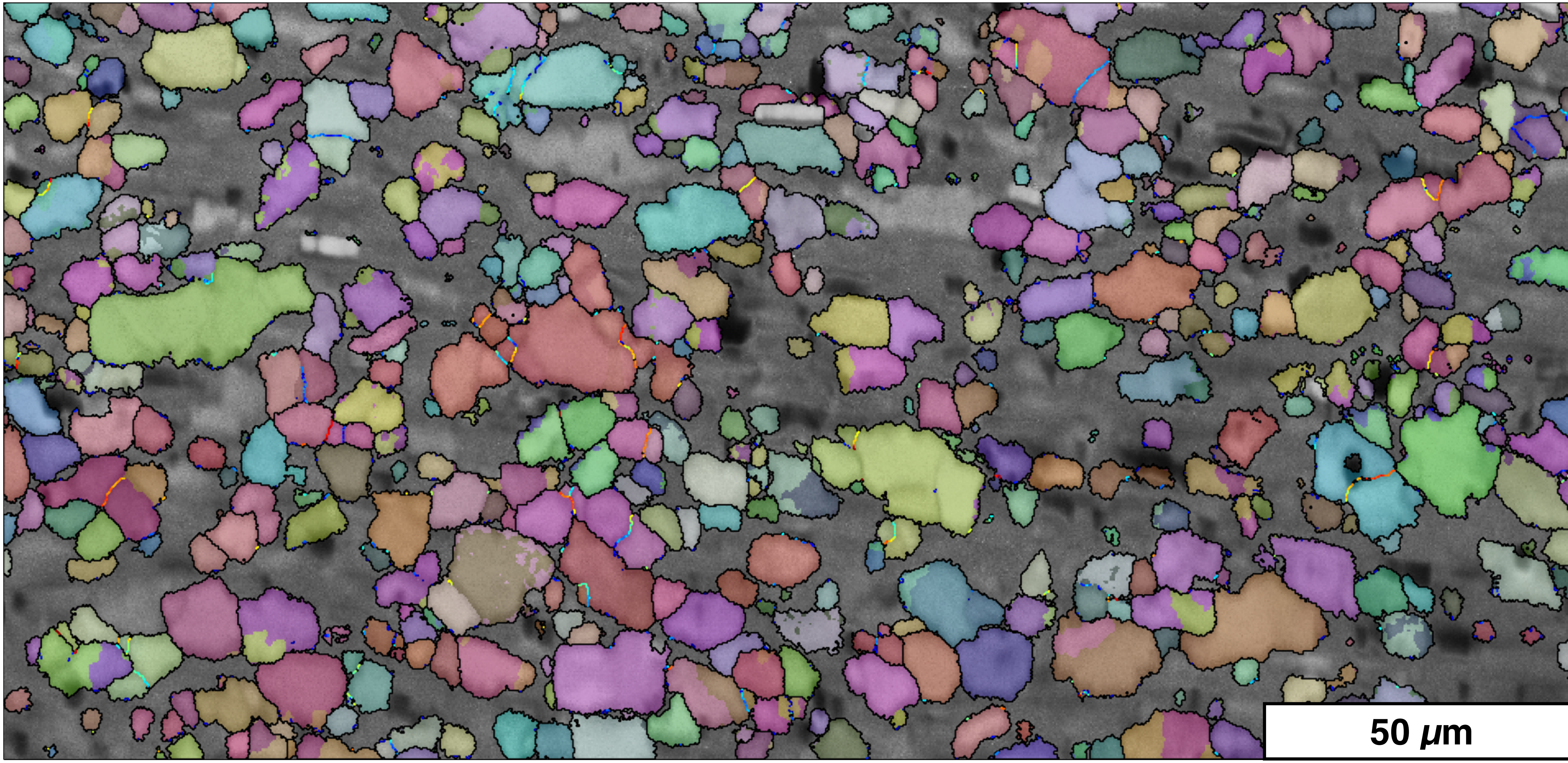


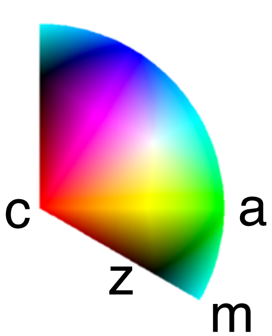
pfJc = 1.22
pfJr= 1.06
tindex = 1.5
n=1400

apparently large grains and grains with a high grain boundary ratio contribute to the non-random texture

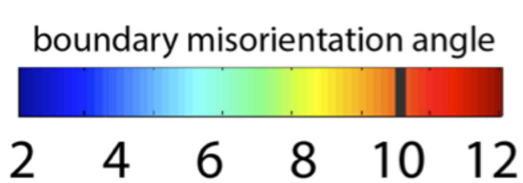


indications for crystal plasticity? scarce low angle boundaries

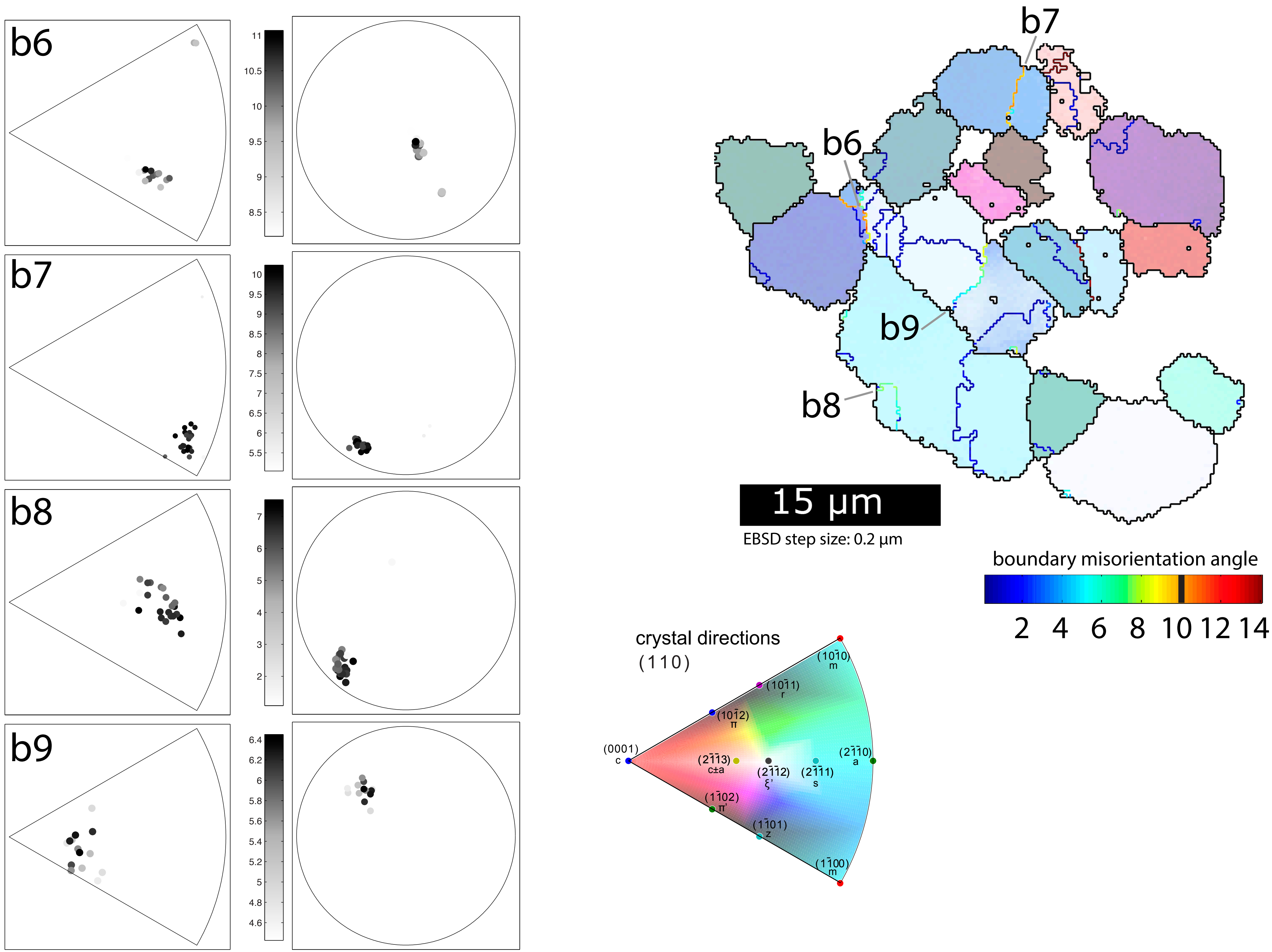




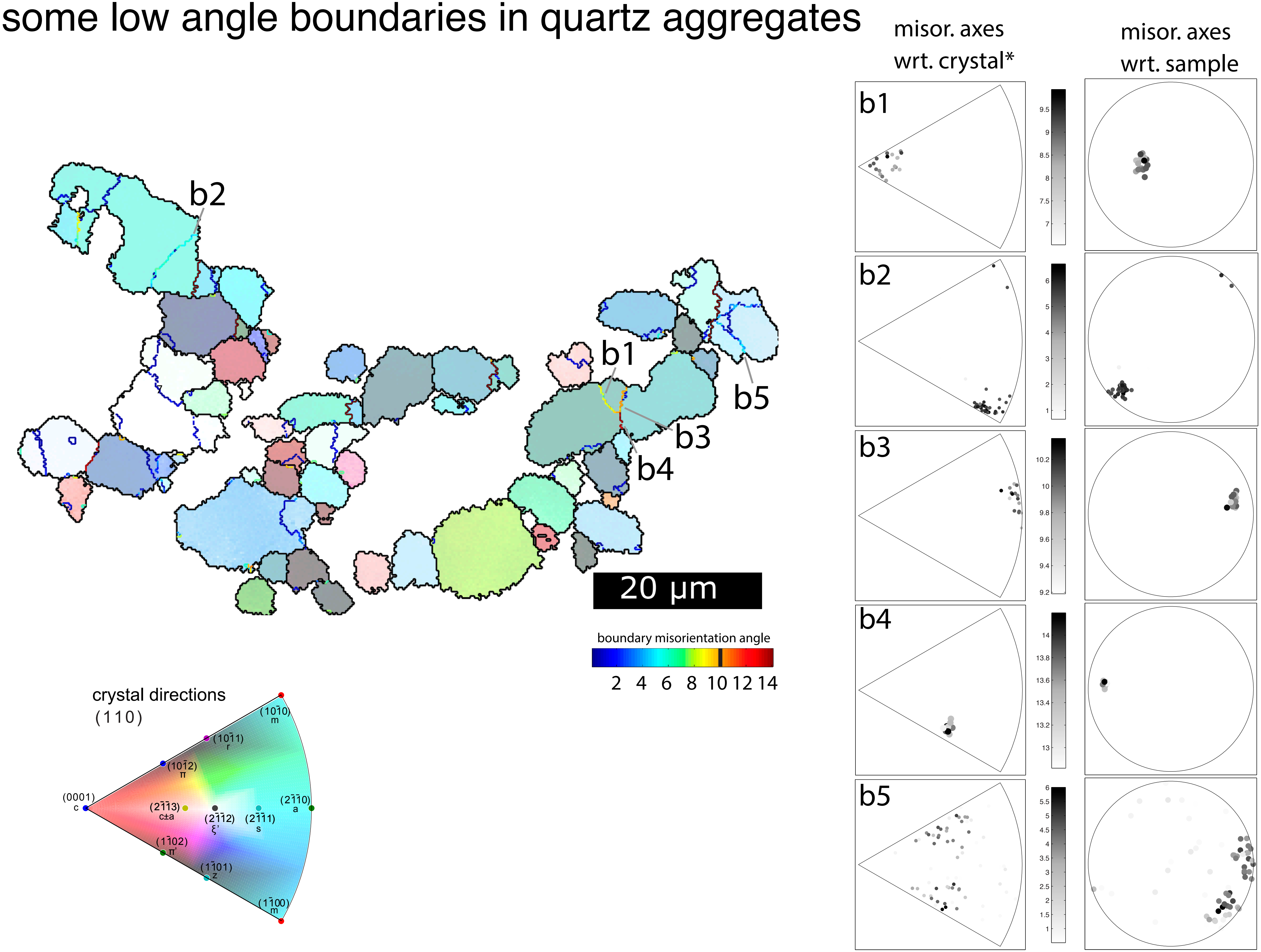
ipf colorcoding
wrt. 001



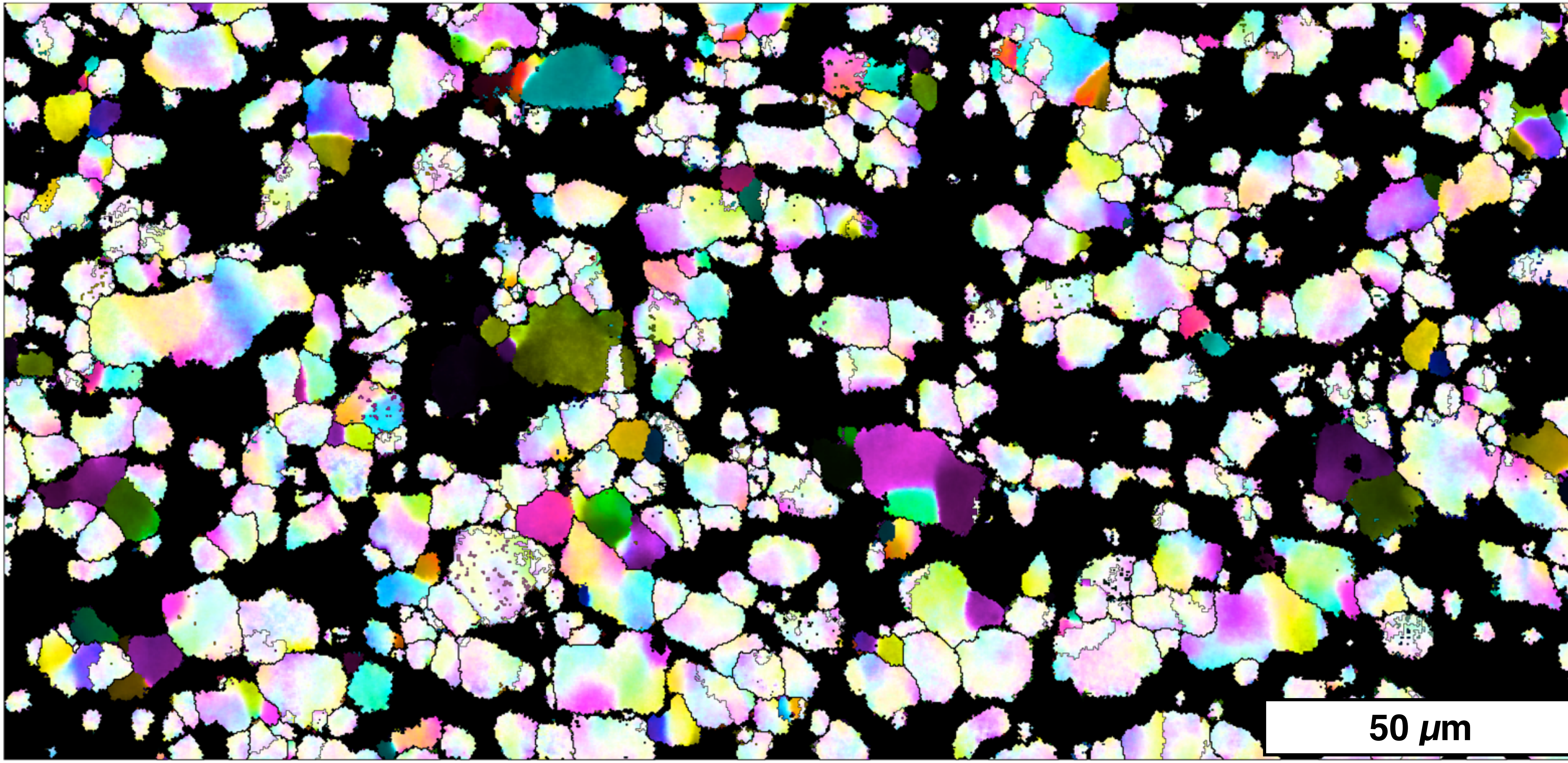
some low angle boundaries in quartz aggregates

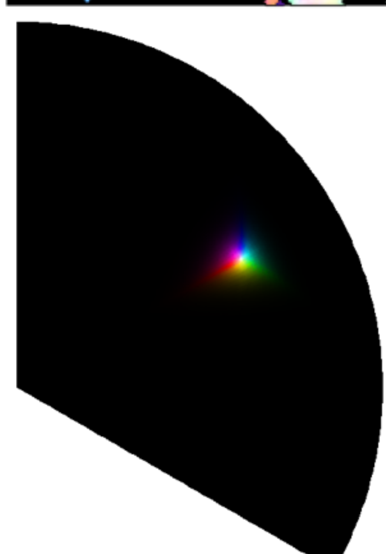


some low angle boundaries in quartz aggregates



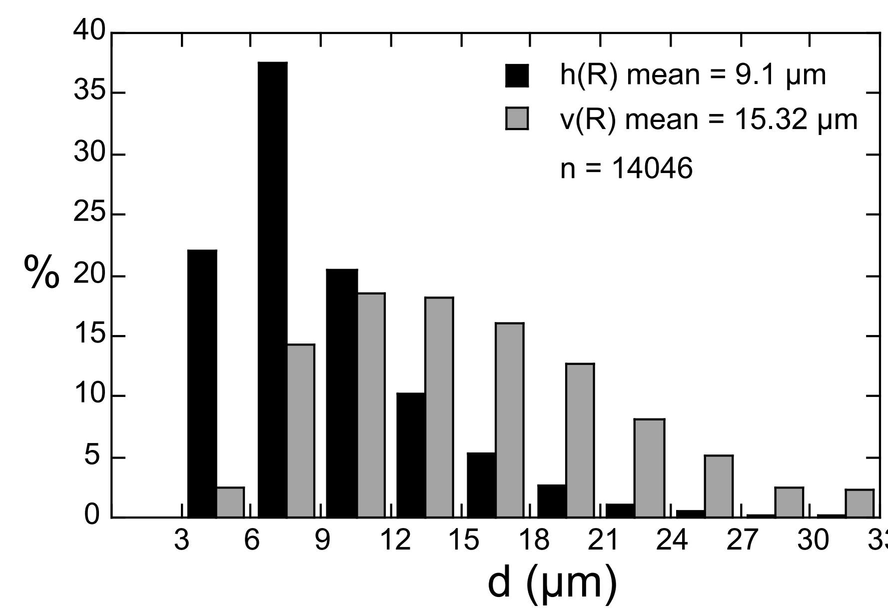
Quartz crystallographic preferred orientation: intragranular orientation deviations

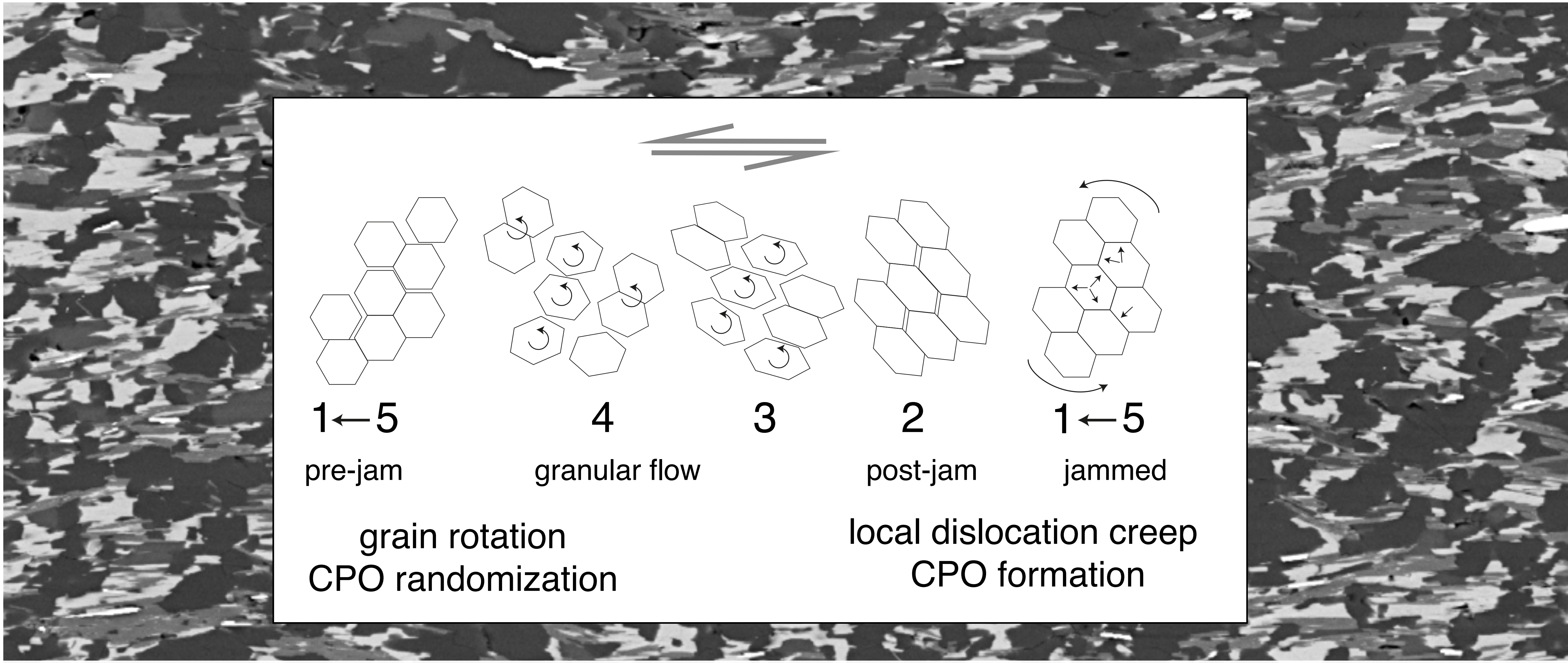




sharp color-coding for each grain

- misoriented areas ~ size of small grains
- if small grains form by dynamic recrystallization of quartz in clusters, differential stresses in quartz clusters must be fairly high (~100MPa)





Conclusions:

1. oblique quartz clusters comparable particles in jammed granular flow
2. kinematics of granular flow fits to relative position of individual phases (of stable assemblage)
3. stresses in force chains high enough to allow for crystal plastic processes
4. rheology might be non-linear despite "diffusion creep" microstructure