Grain Boundaries in olivine…and Dislocations

Ulrich Faul

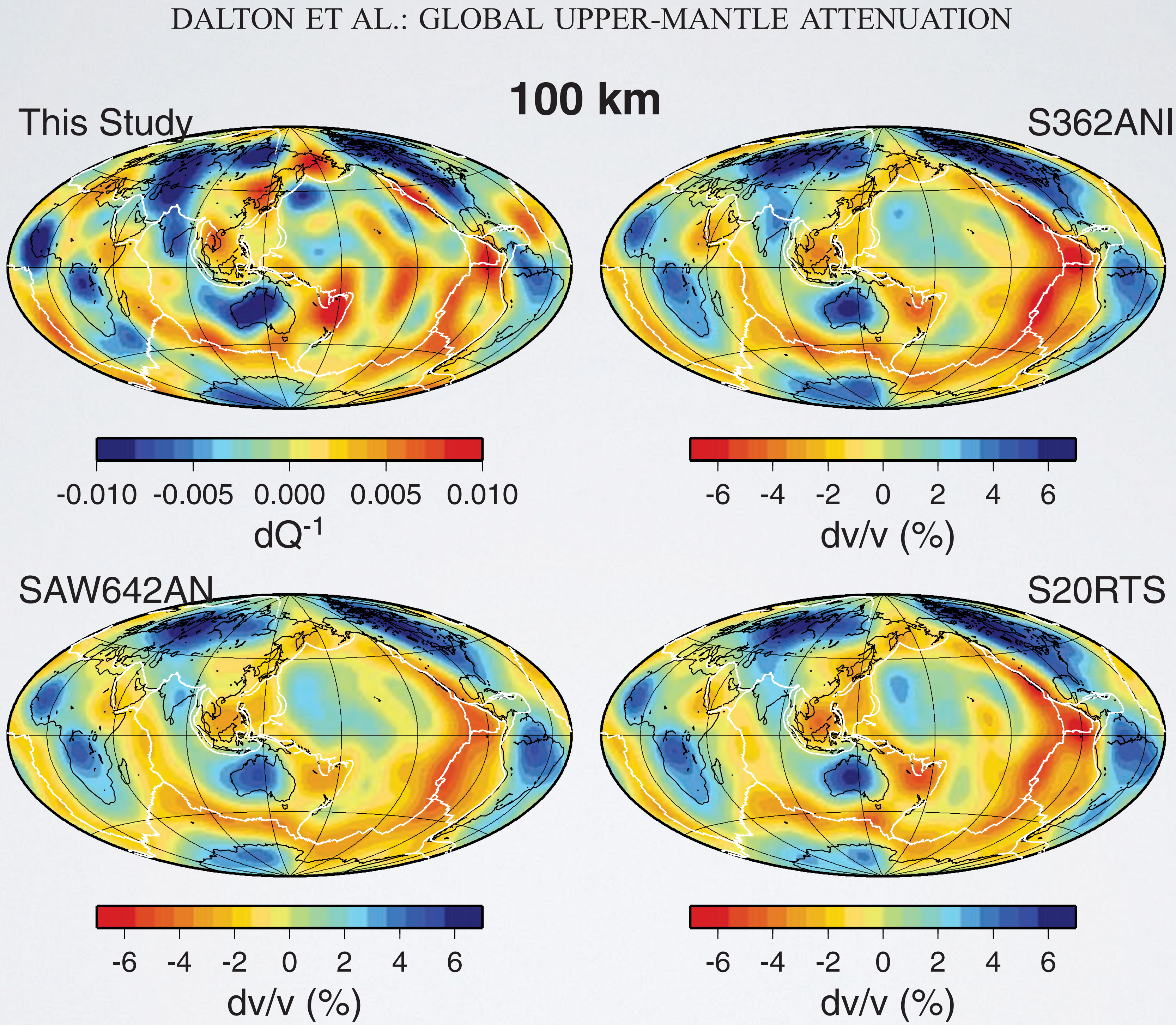
MIT / SUNY New Paltz

collaborators:
Ian Jackson, ANU
Katharina Marquardt, Imperial College

two parts

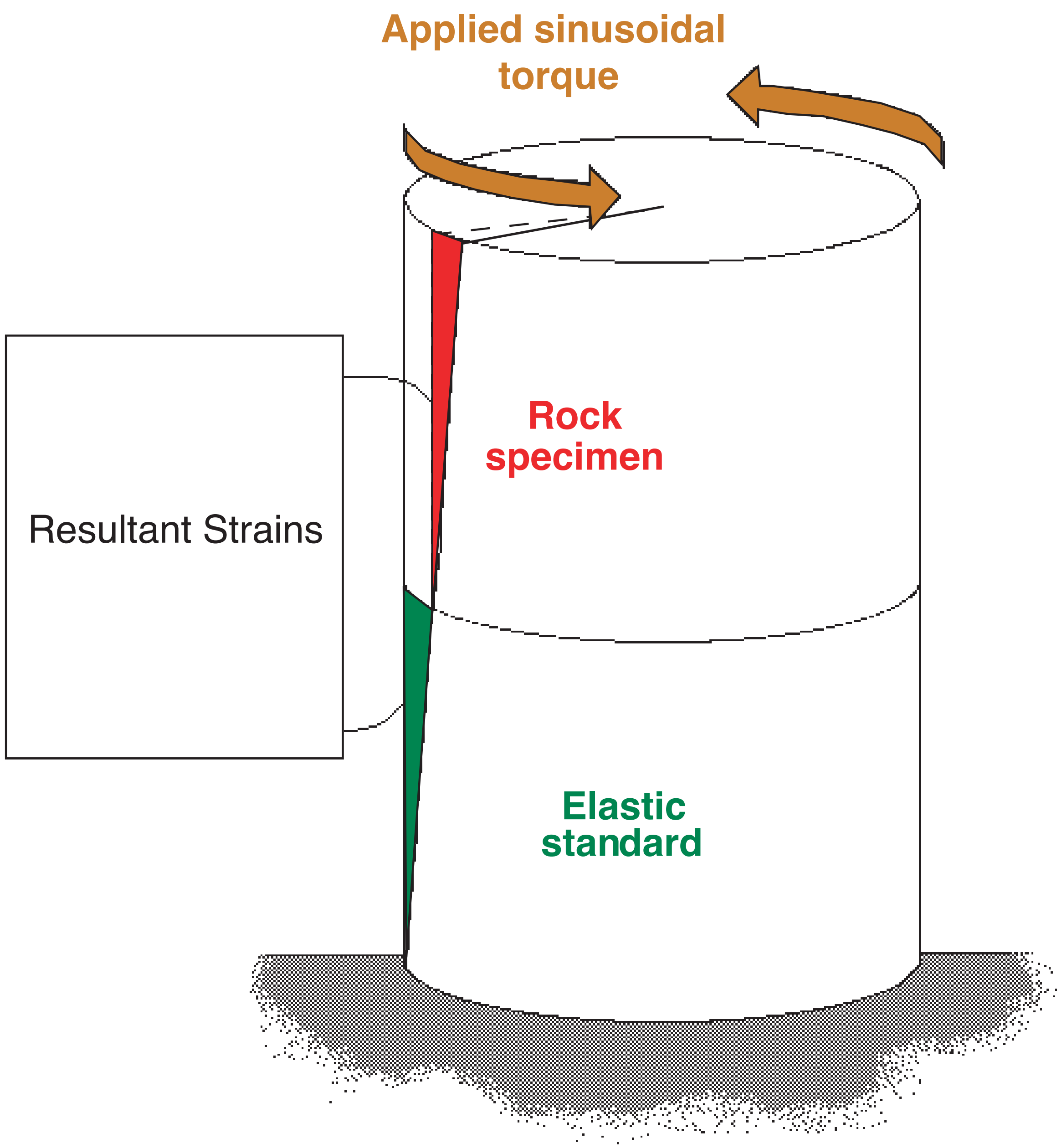
1. Backgound and motivation for microstructural investigations: seismic properties of the Earth's upper mantle
2. Dislocation density by conventional EBSD

Upper mantle does not behave purely elastically at seismic periods



energy loss due to ‘intrinsic’ attenuation

Seismic property experiments



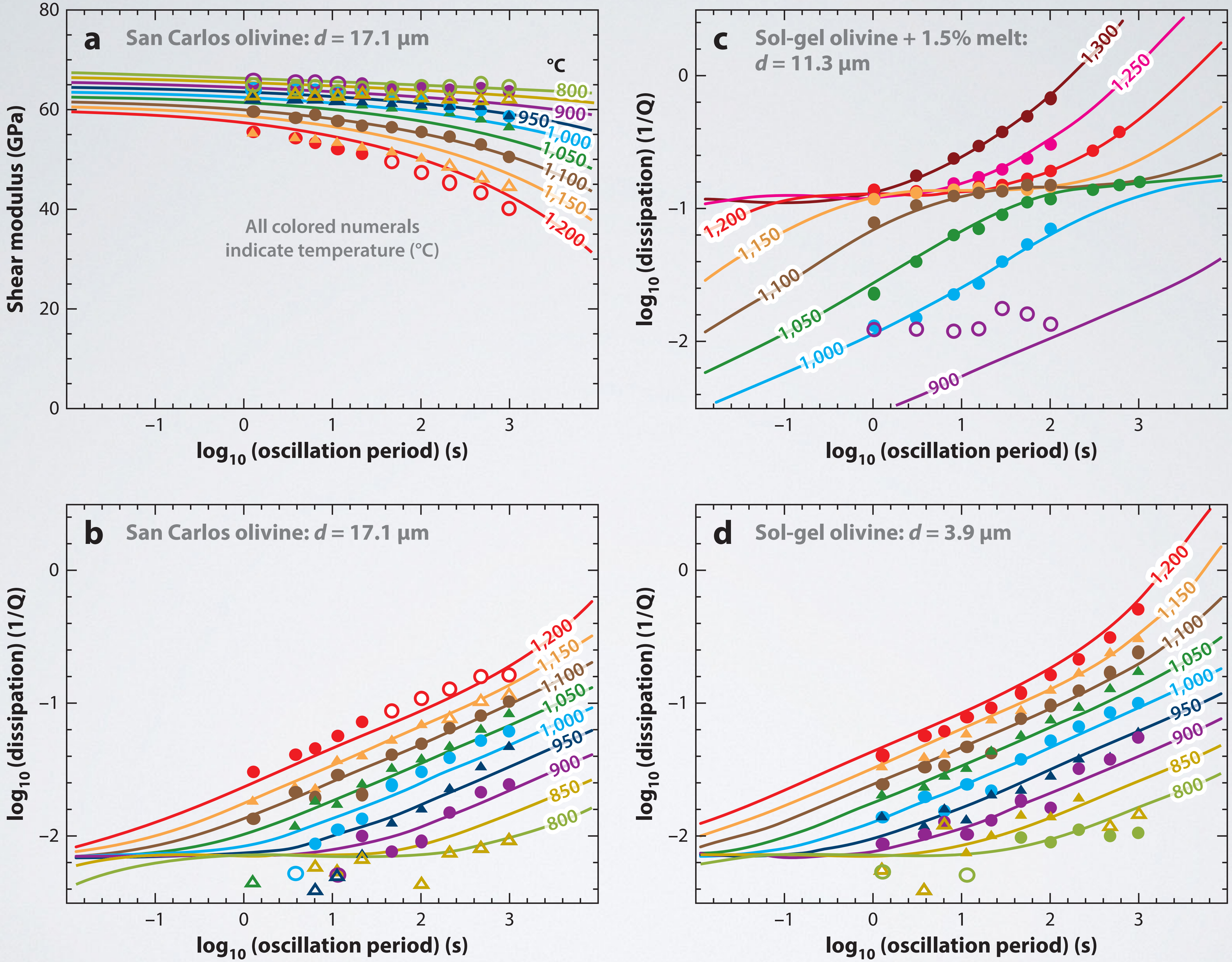
Experiments at
- temperatures to 1300°C
- periods 1 - 1000s
- 200 MPa confining pressure

Measure shear modulus G and dissipation/attenuation

Attenuation/dissipation (1/Q): energy loss per cycle

Research School of Earth Sciences, Australian National University

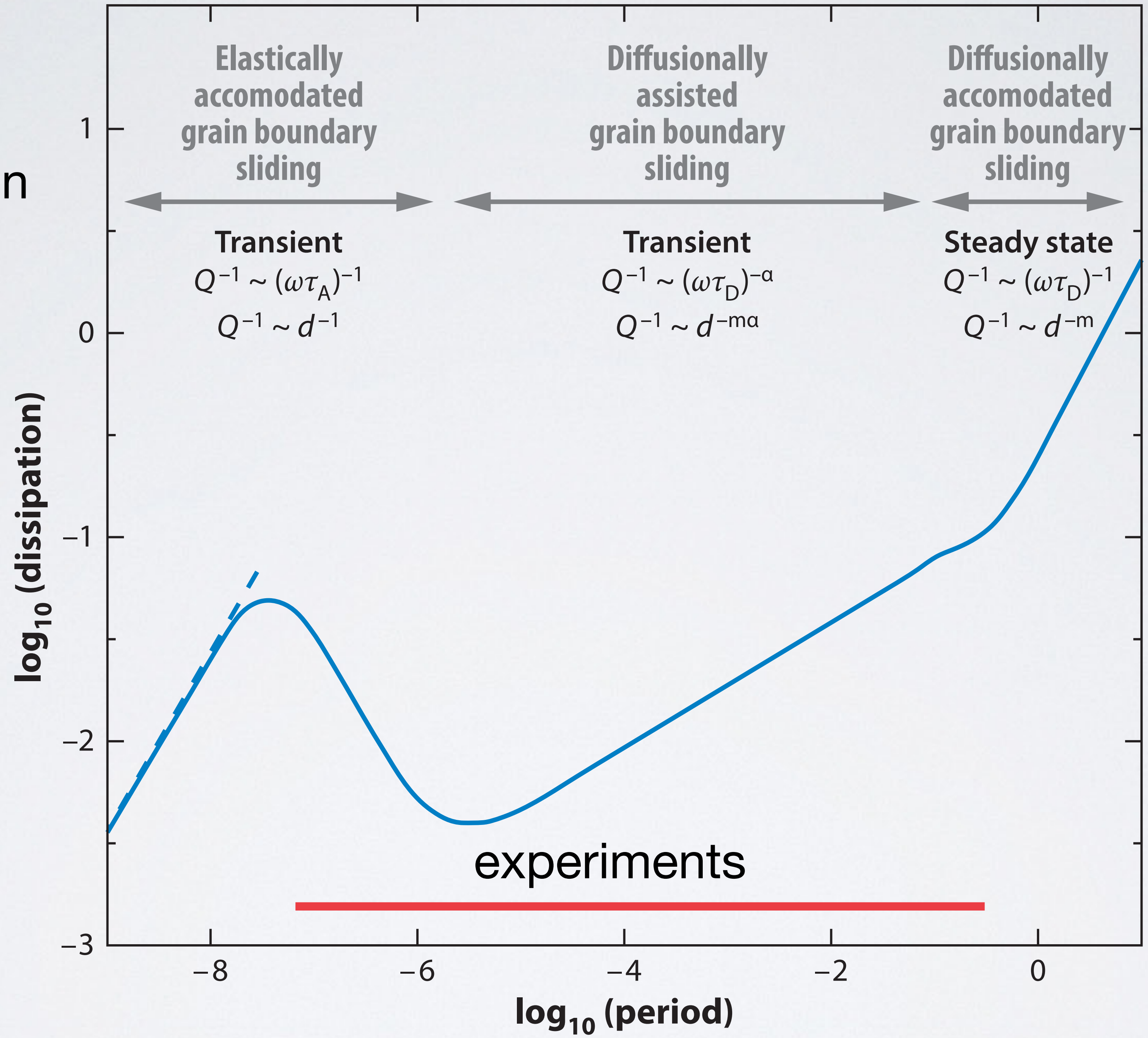
Ian Jackson and colleagues



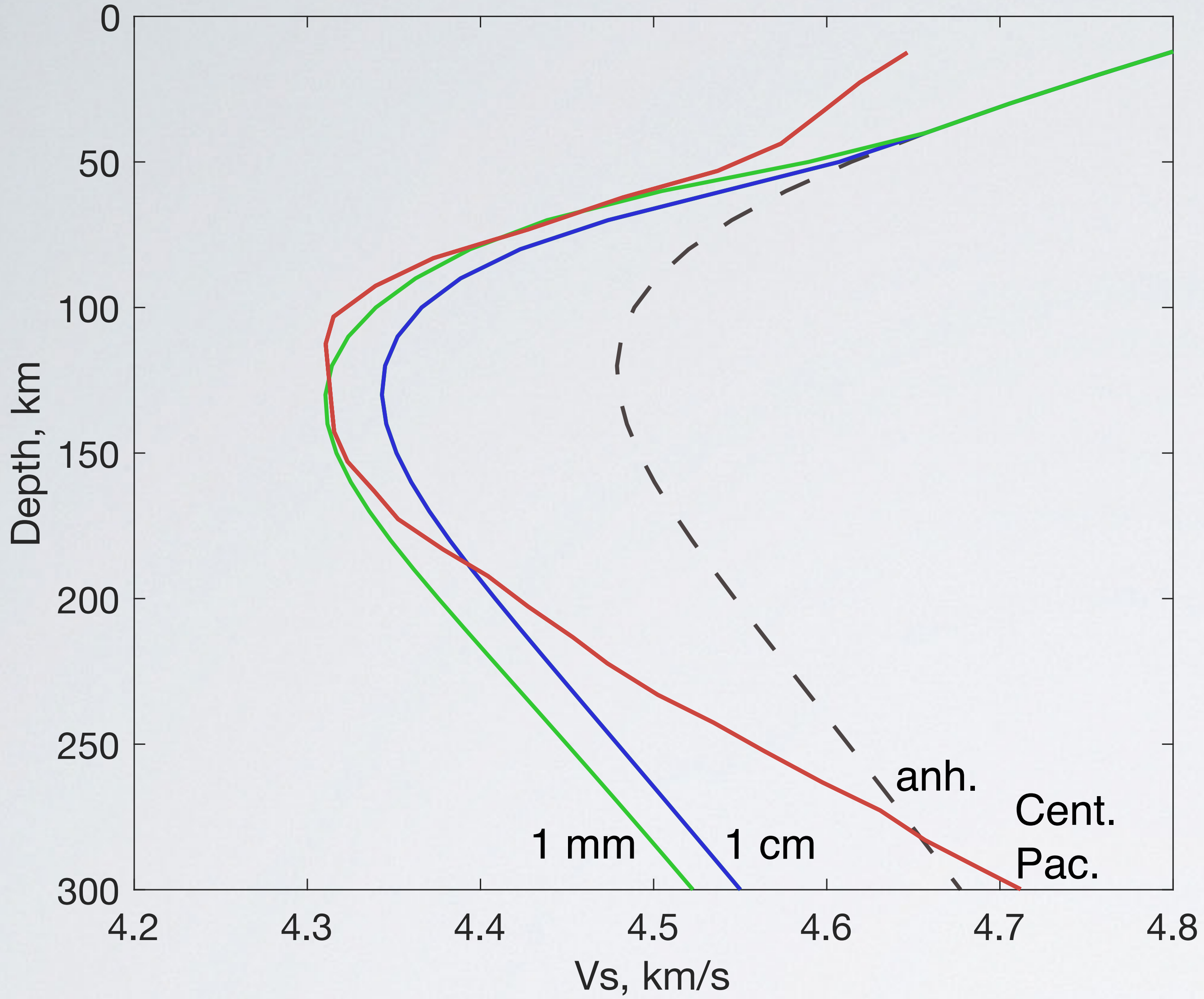
Faul and Jackson, AREPS 2015

Intrinsic attenuation due to grain boundaries: deformation regimes as a function of time scale of the applied stress

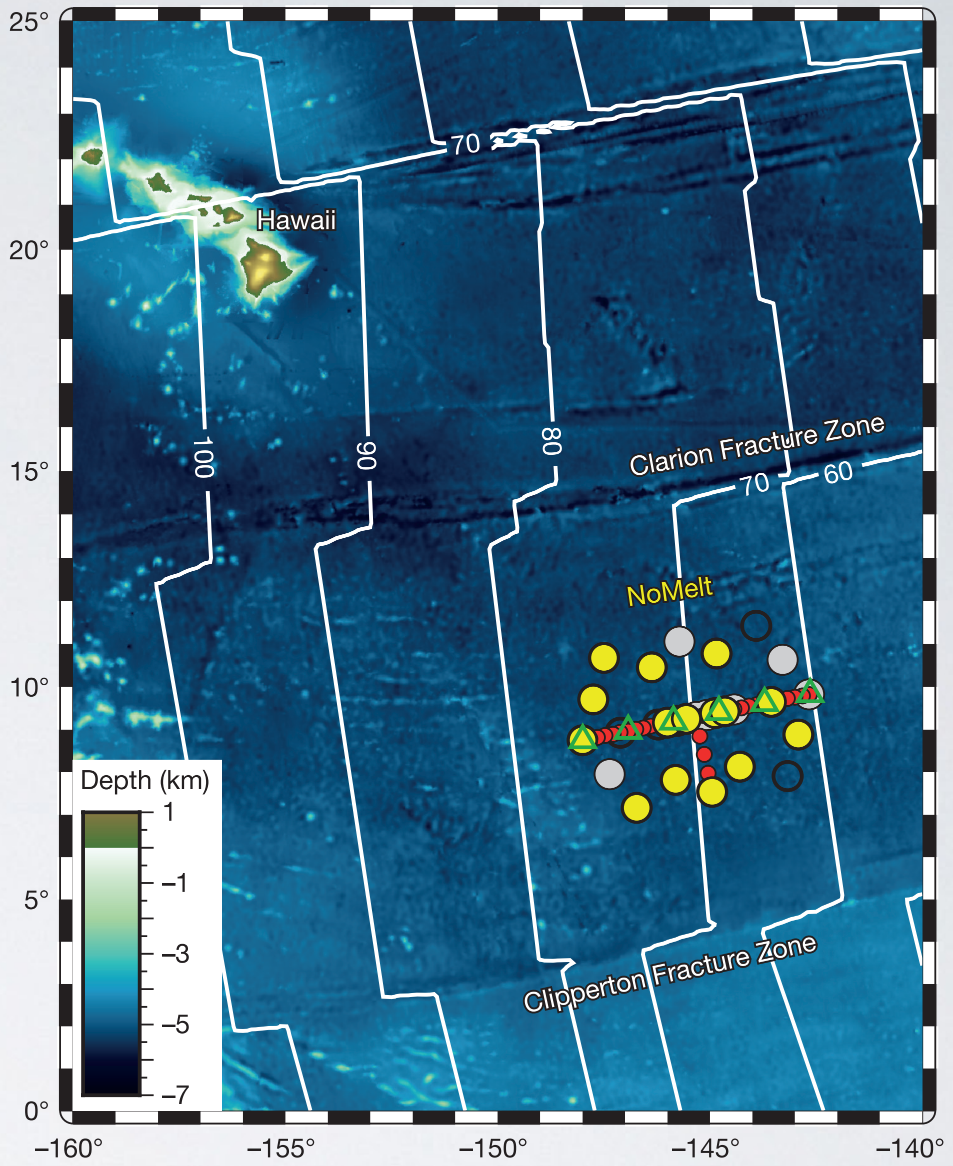
elastic
(anharmonic)
ultrasonic/Brillouin



Faul and Jackson, 2015
(Morris and coworkers, Raj and Ashby…)



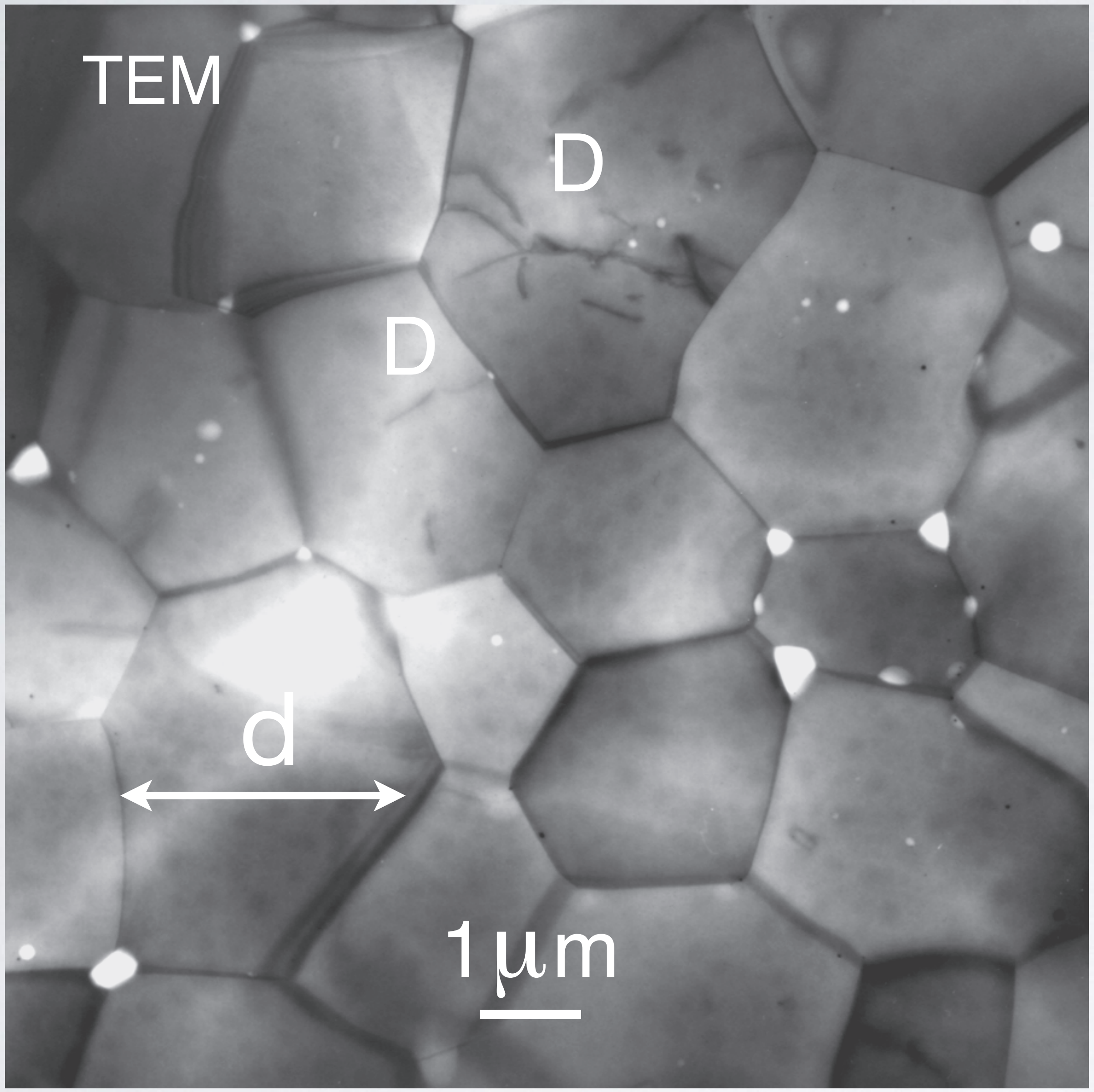
fit to experimental data
(Jackson and Faul, 2010)



Lin et al. 2016,
'NoMelt' experiment

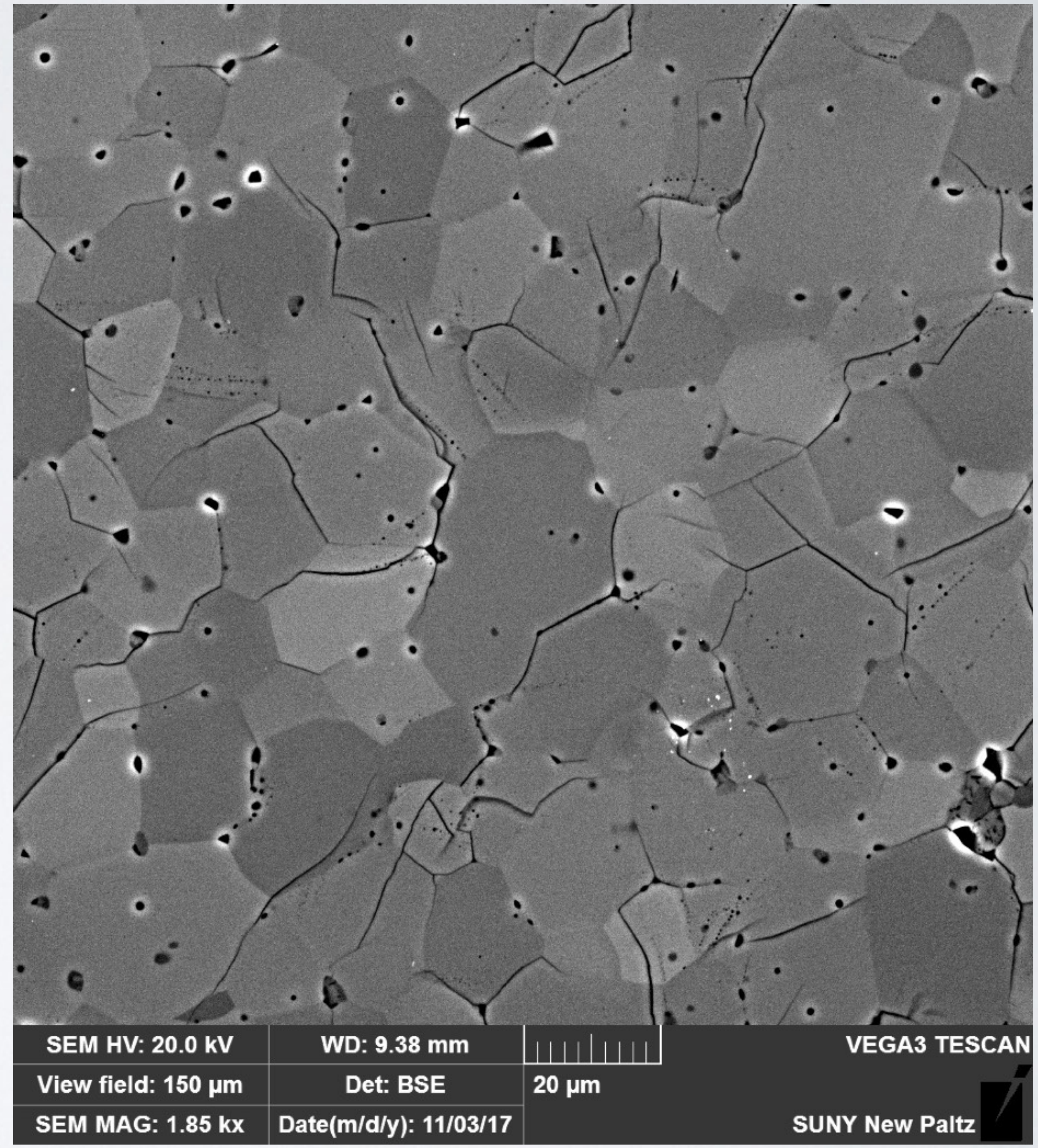
Measured moduli can be extrapolated to upper mantle grain sizes.
Calculated velocities match seismic data quite well.

Microstructure: melt-free polycrystalline olivine

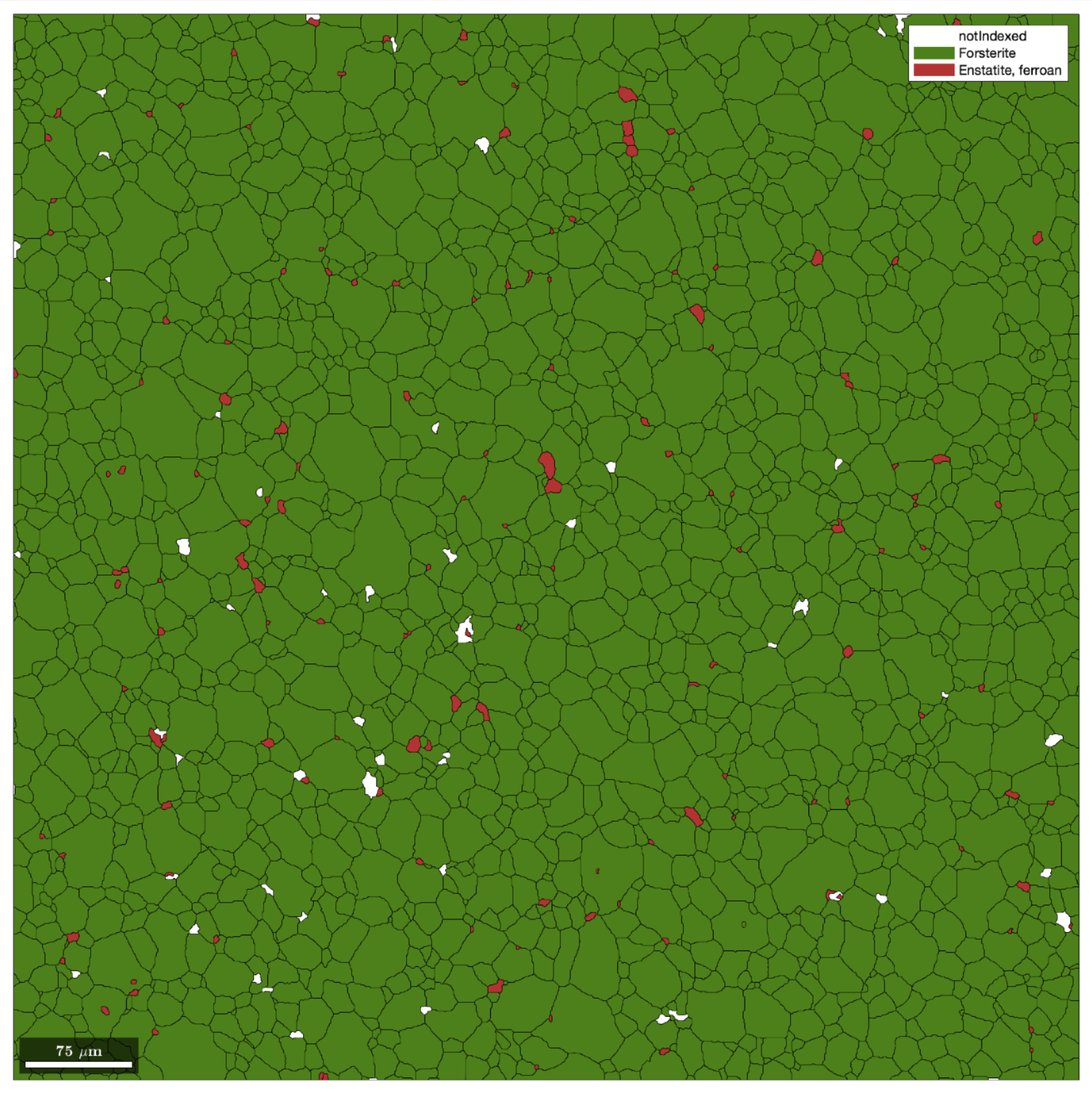


Jackson et al., 2002

mean gs: 3 μm



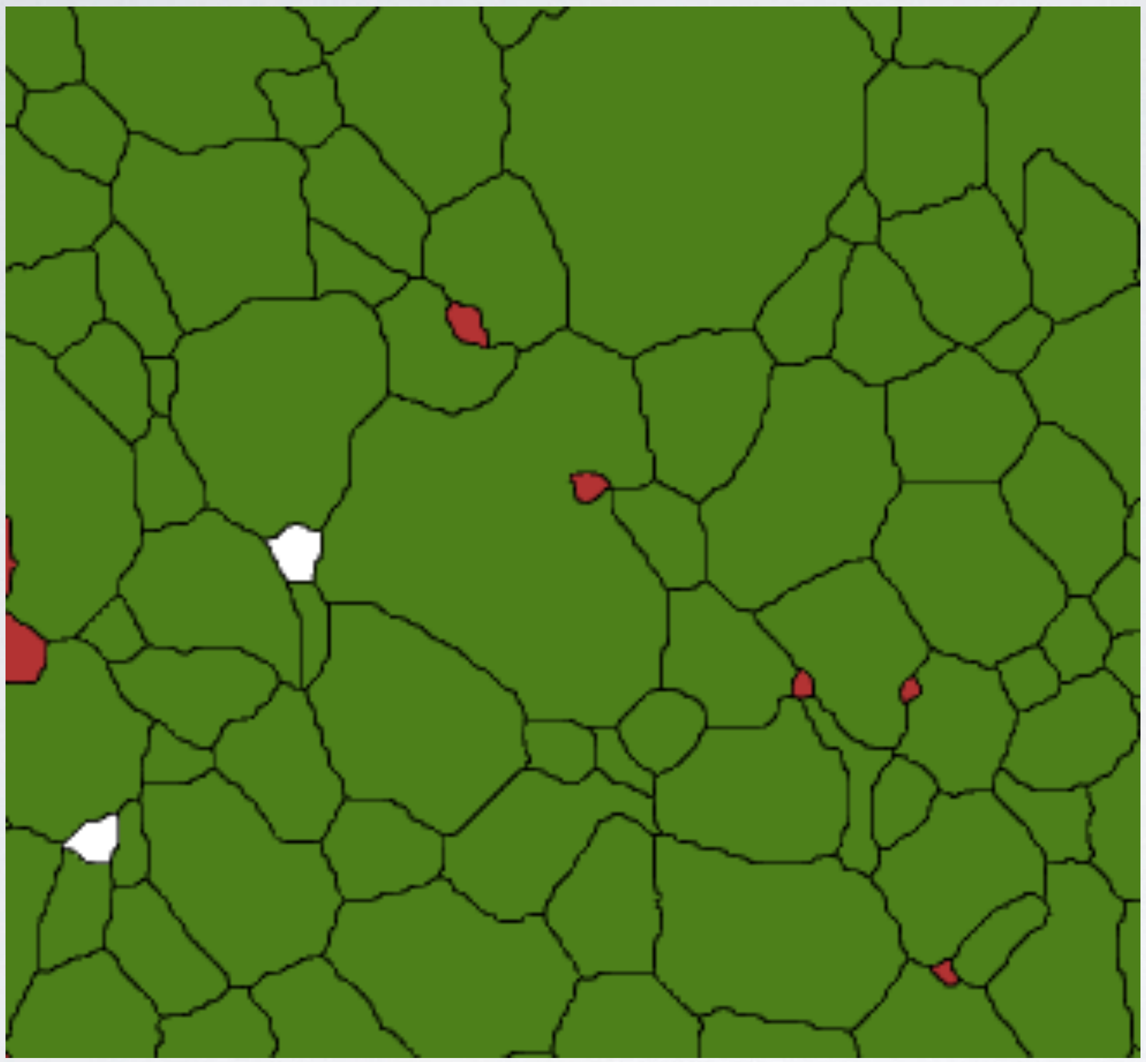
mean gs: 19 μm



synthetic Fe-bearing olivine, Ti-doped encapsulated in Pt for a total of about 70 h at 1200°C, 200 MPa

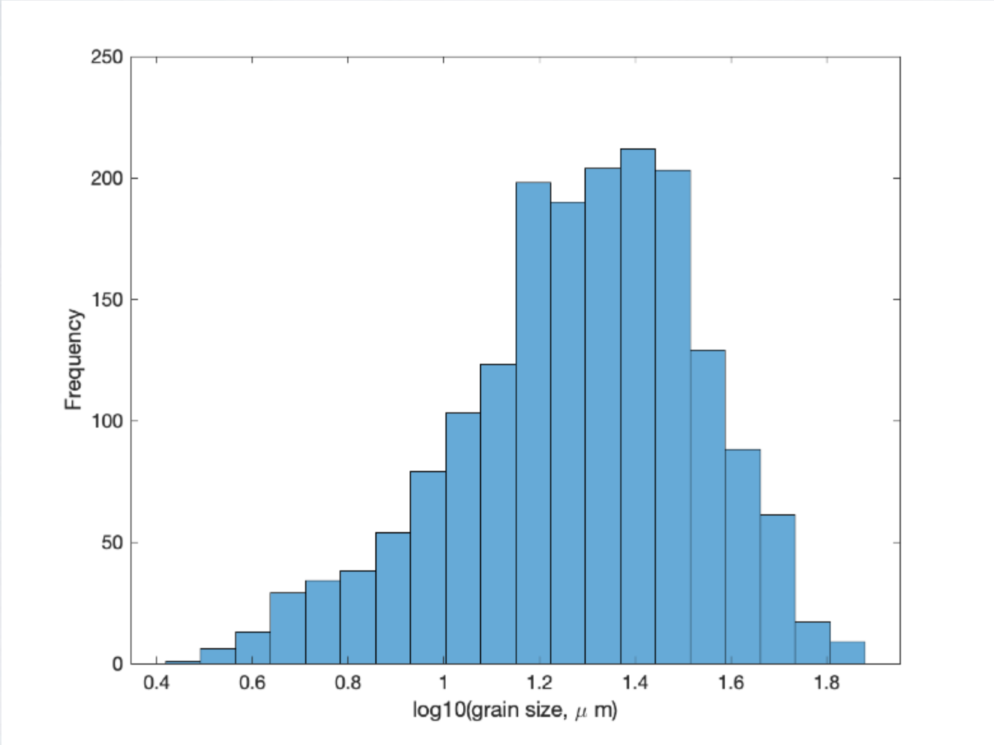
sample 1515

slight Si oversaturation to buffer opx (Si) activity (~ 2 - 3% opx)

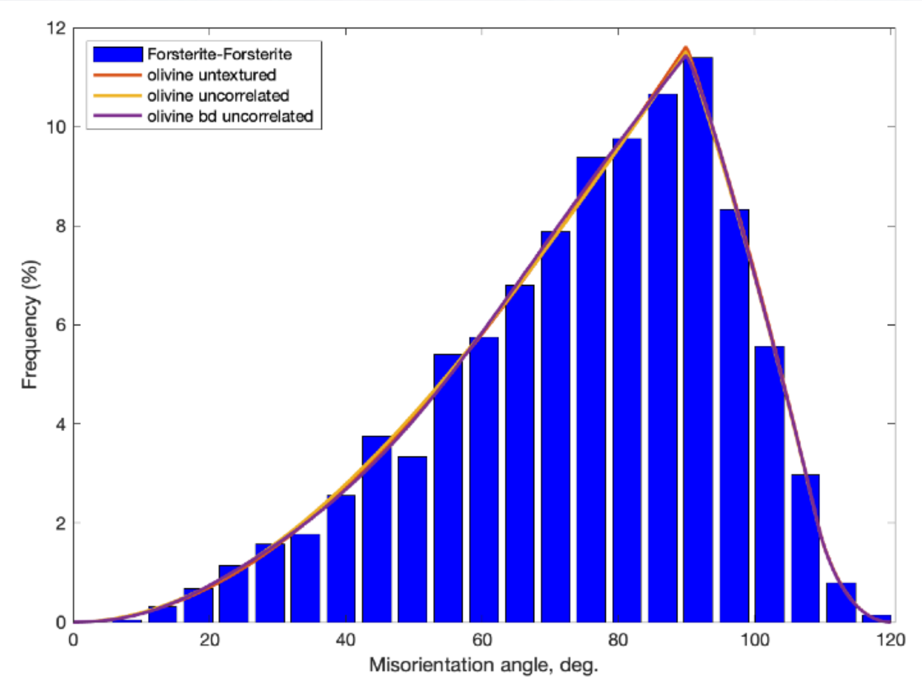


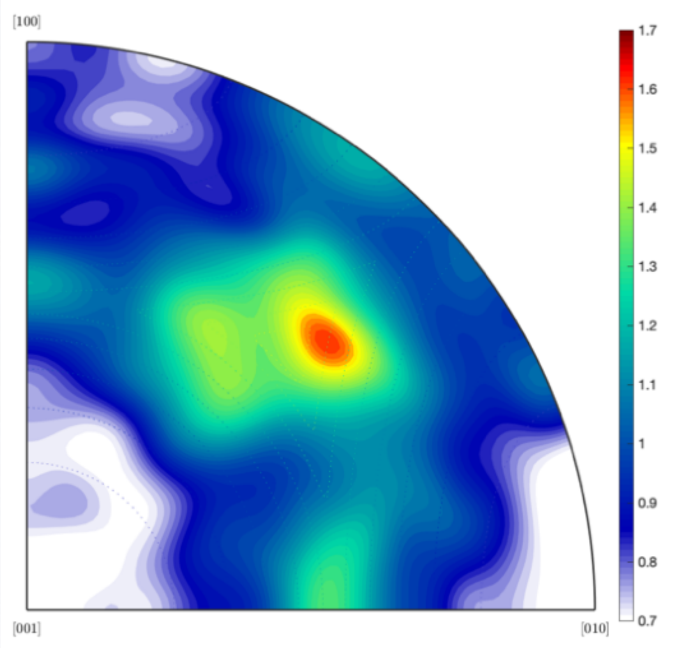
here opx grains act as pinning particles to moderate grain growth rates

sample 1515
(Cline et al. Nature, 2018)



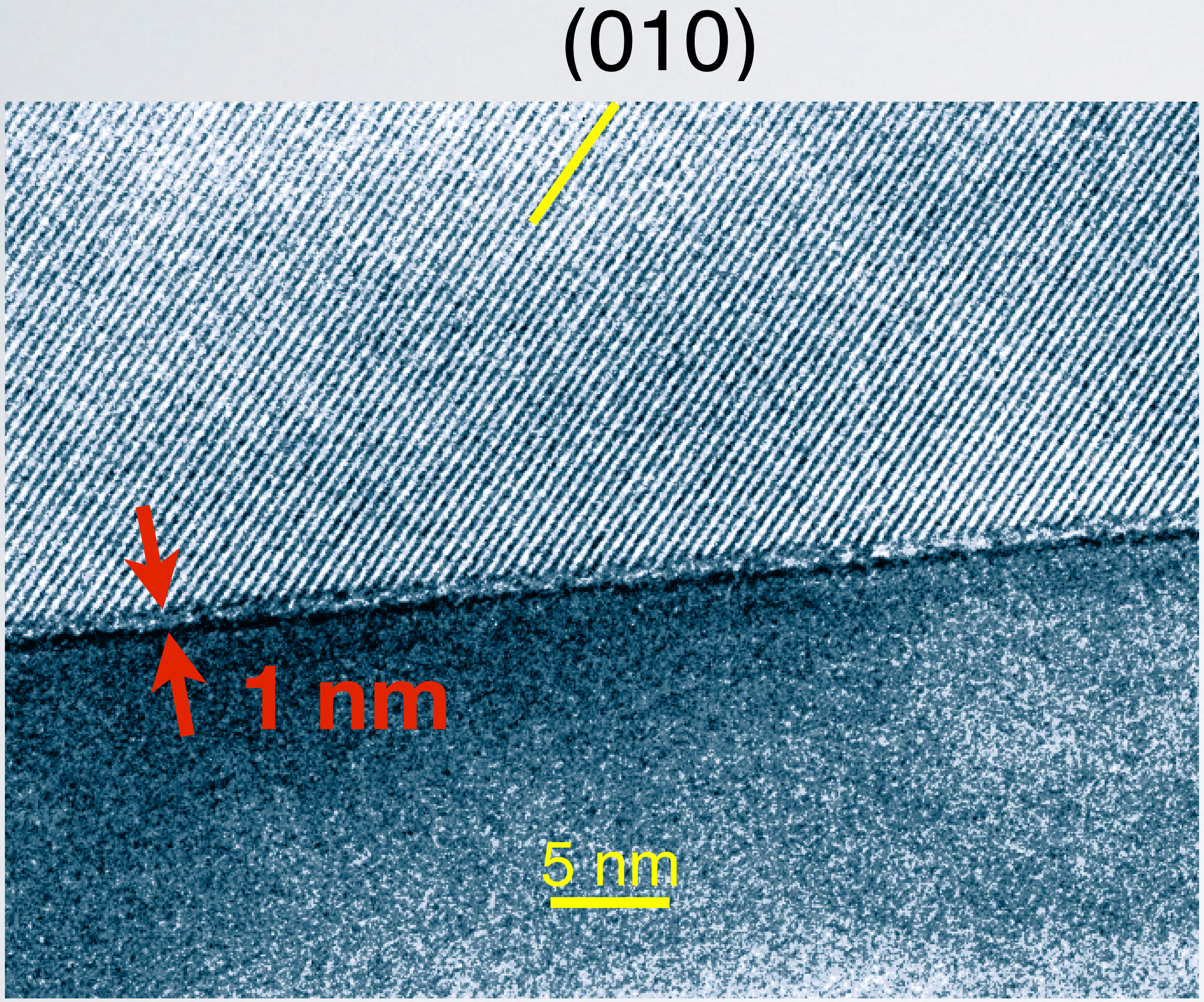
~ log-normal grain size distribution: normal grain growth

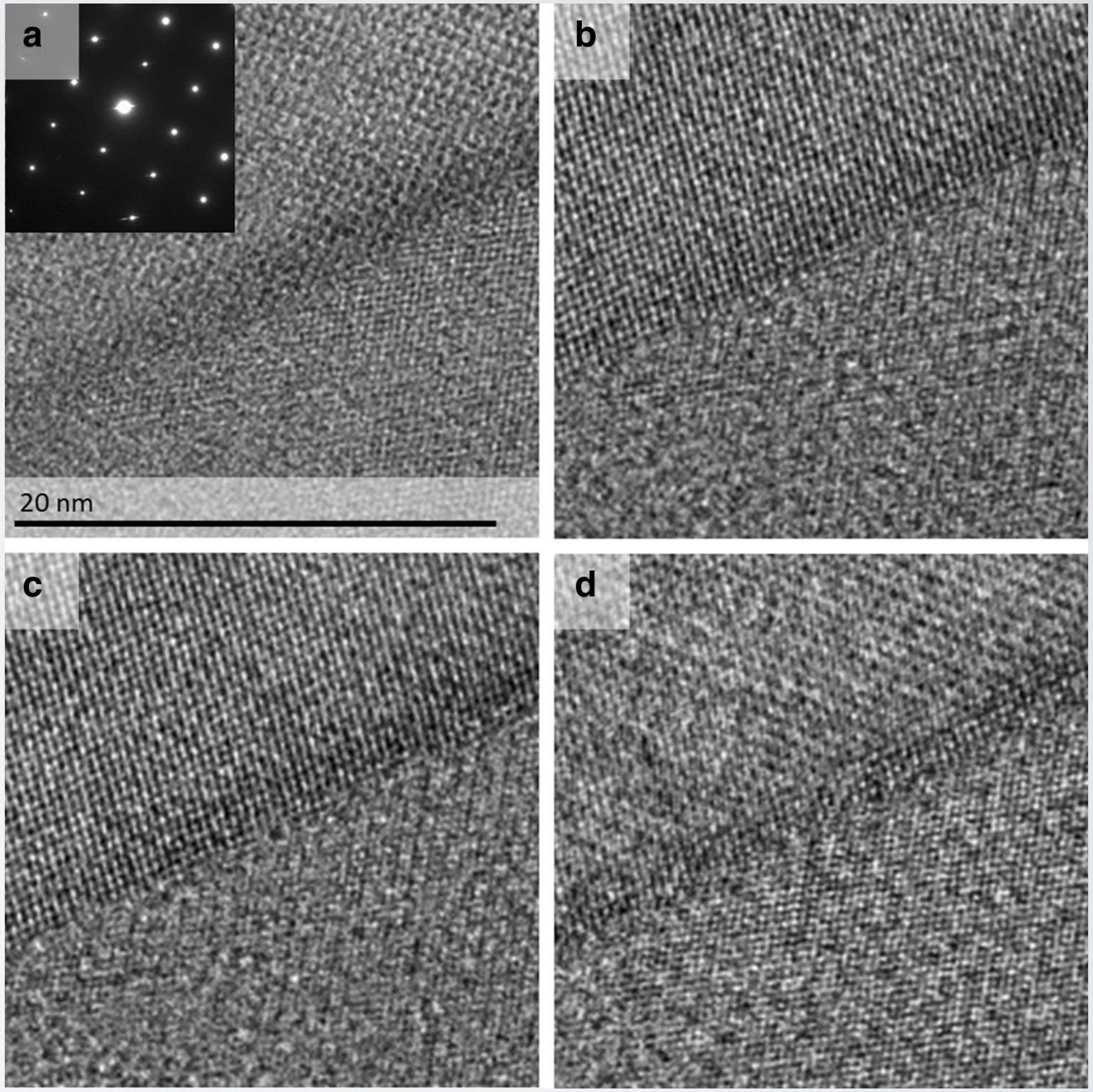




microstructure due to grain growth: random distribution of grain boundary misorientations -> no special boundaries

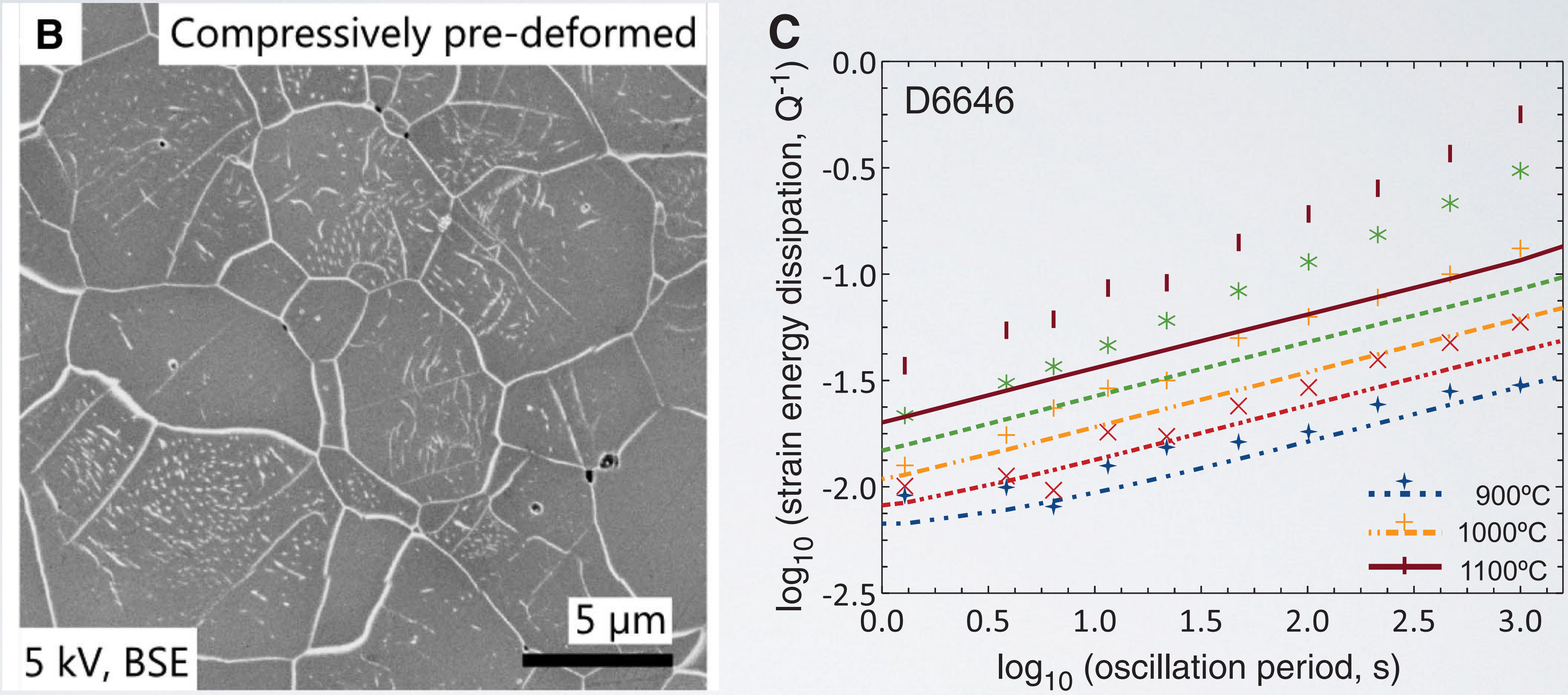
High angle (general) grain boundaries in olivine: smooth (no evidence of steps or dislocation structures), structurally distinct, ~ 1nm wide, chemically enriched





Faul et al., 2004, Marquardt and Faul, 2018

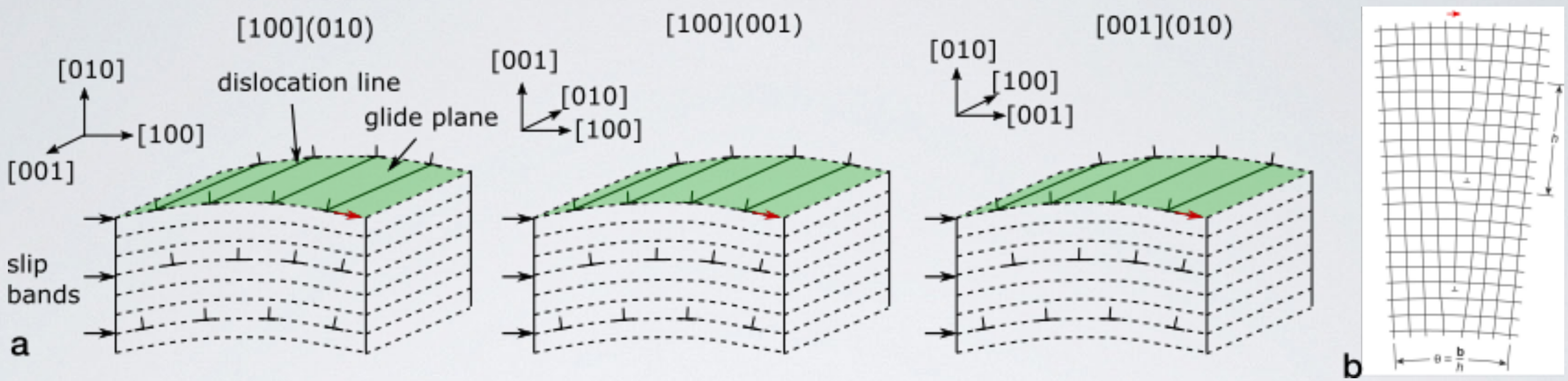
Dislocations…complicated



One principal problem is to characterize / quantify dislocation densities

(Farla et al. Science, 2012)

Dislocations in olivine: HR-EBSD



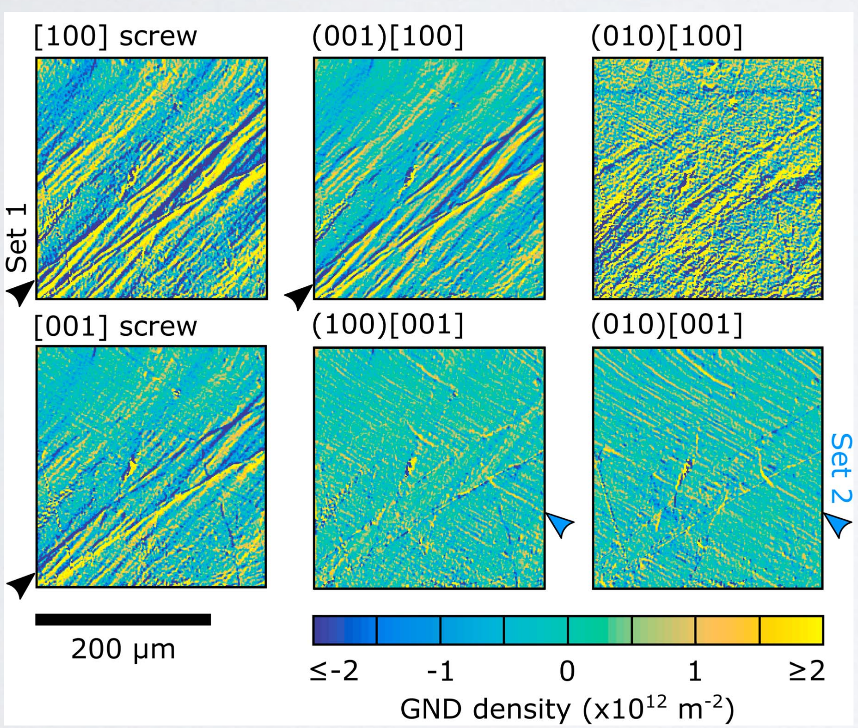
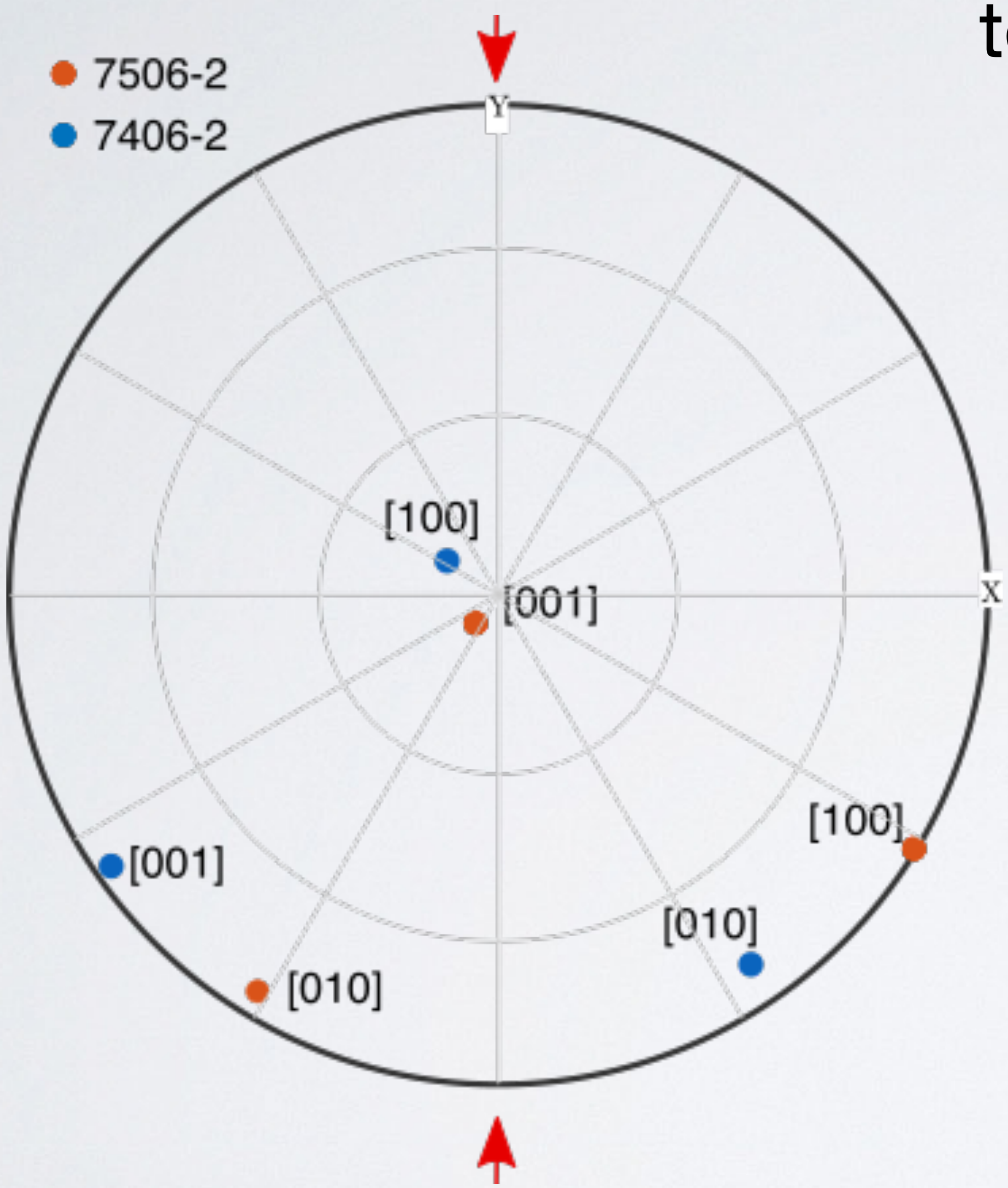


Table 1
Olivine slip systems used in dislocation density calculations.

Dislocation type	Slip system
Edge	(010)[100]
Edge	(001)[100]
Edge	(100)[001]
Edge	(010)[001]
Screw	[100]
Screw	[001]

Wallis, Hansen, Britton, Wilkinson, 2016, 2017, 2019…

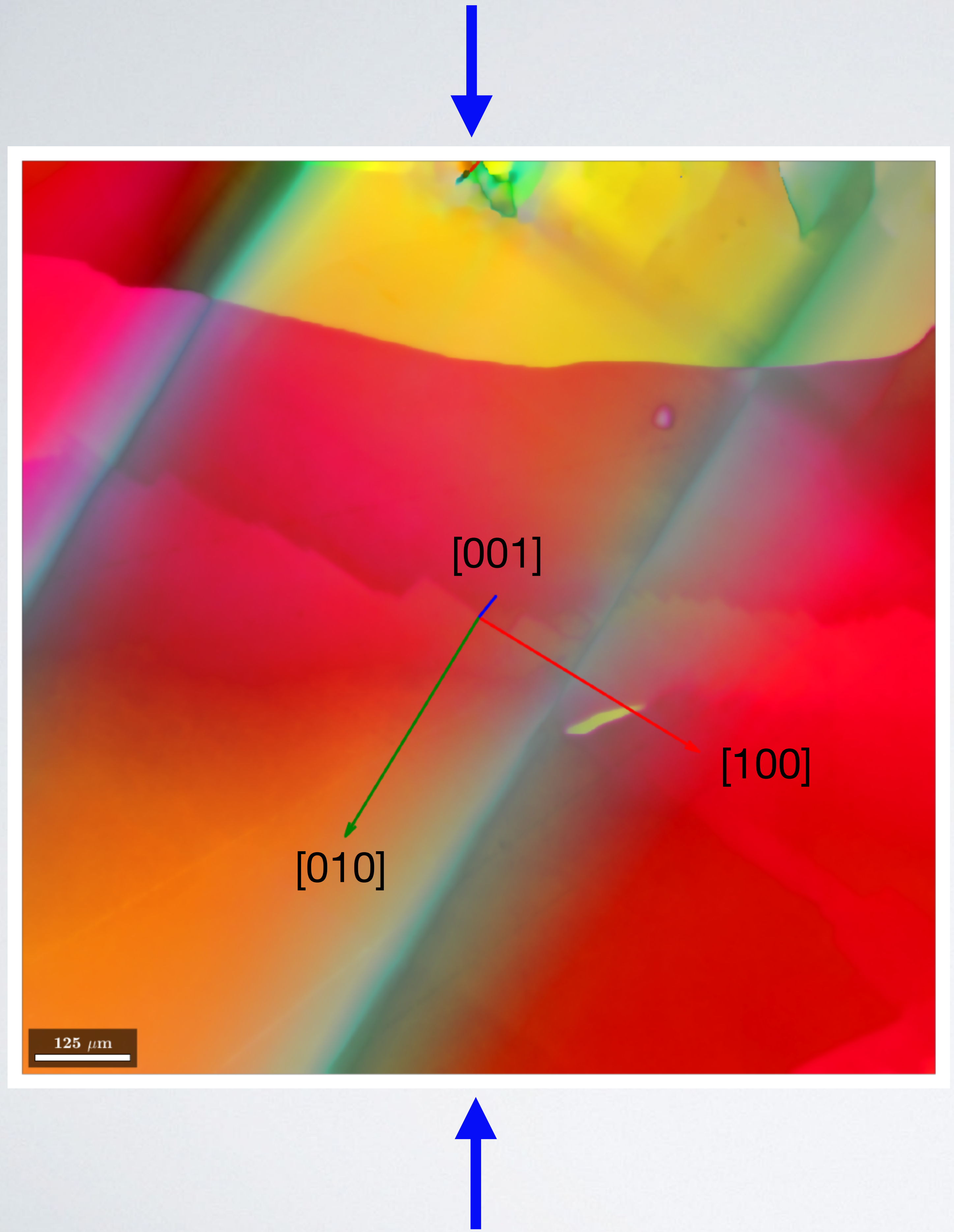
Is is possible to extract dislocation densities for olivine from conventional EBSD maps?



test case: single crystals deformed to activate specific slip systems

compressive deformation
at 1600°C to > 20% strain

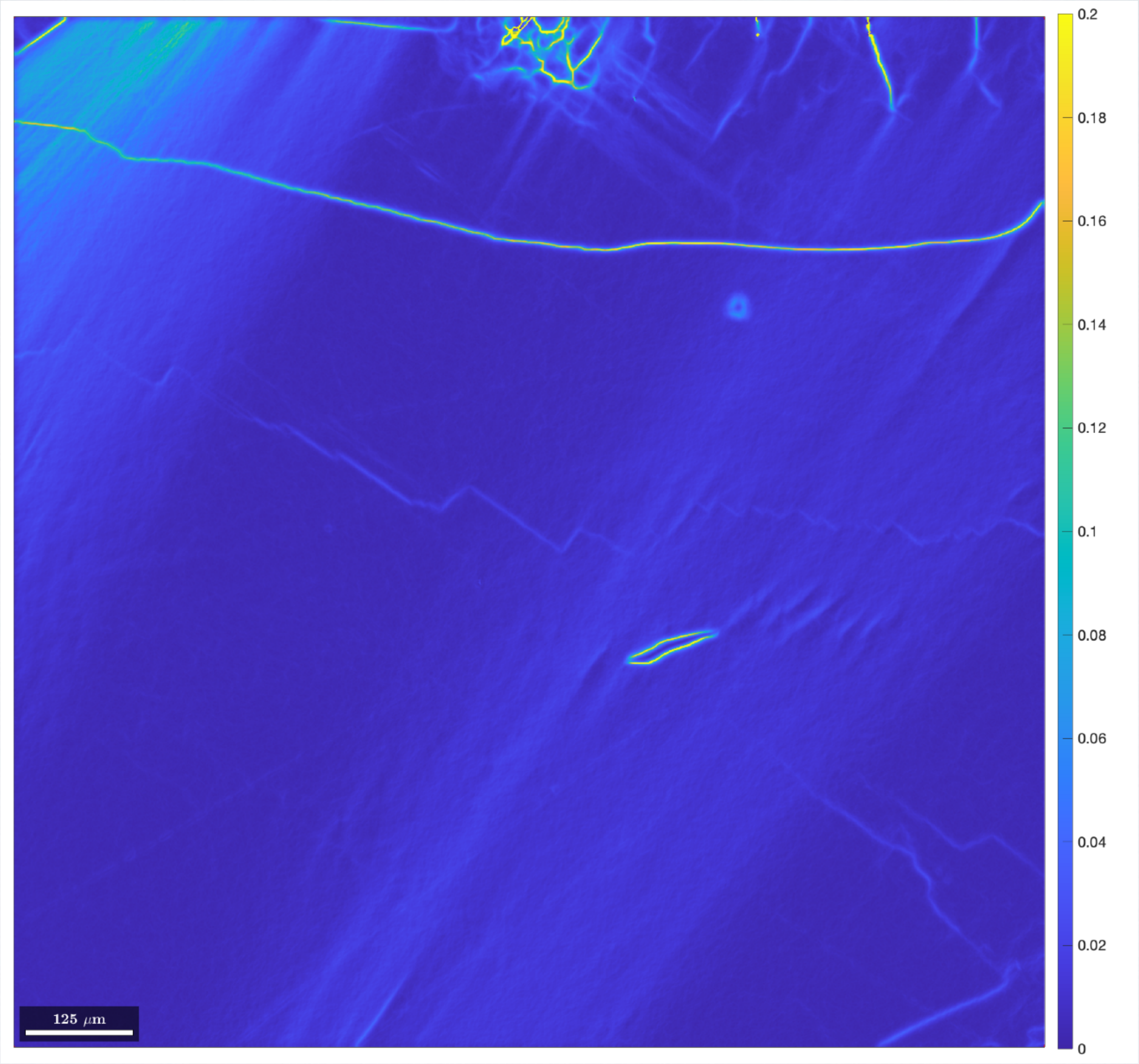
dislocation structures investigated by oxidative decoration and TEM (Durham et al. 1977a, b)

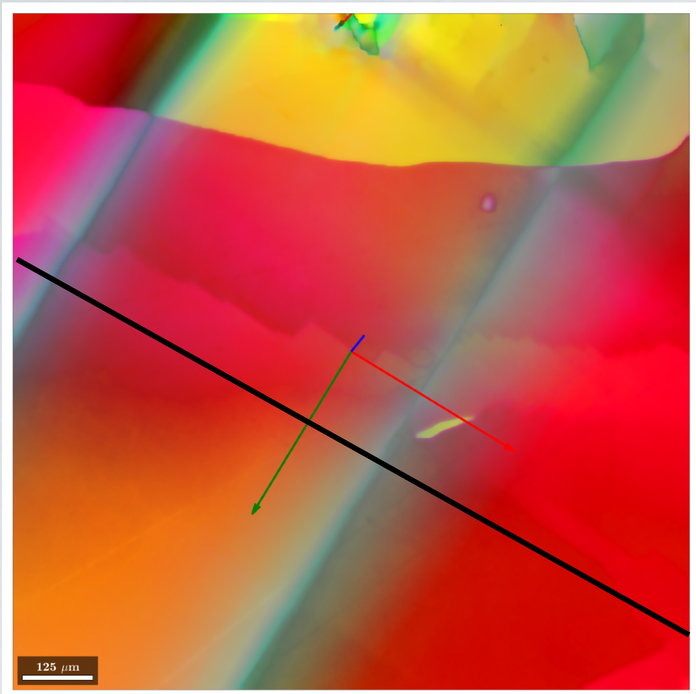


EBSD map 1.2 x 1.2 mm,
step size 1 µm
color coding: misorientation axes from the mean orientation,
red: rotation around [001]

denoising: half-quadratic filter, with F.alpha = 5
(Hielscher et al., 2019)

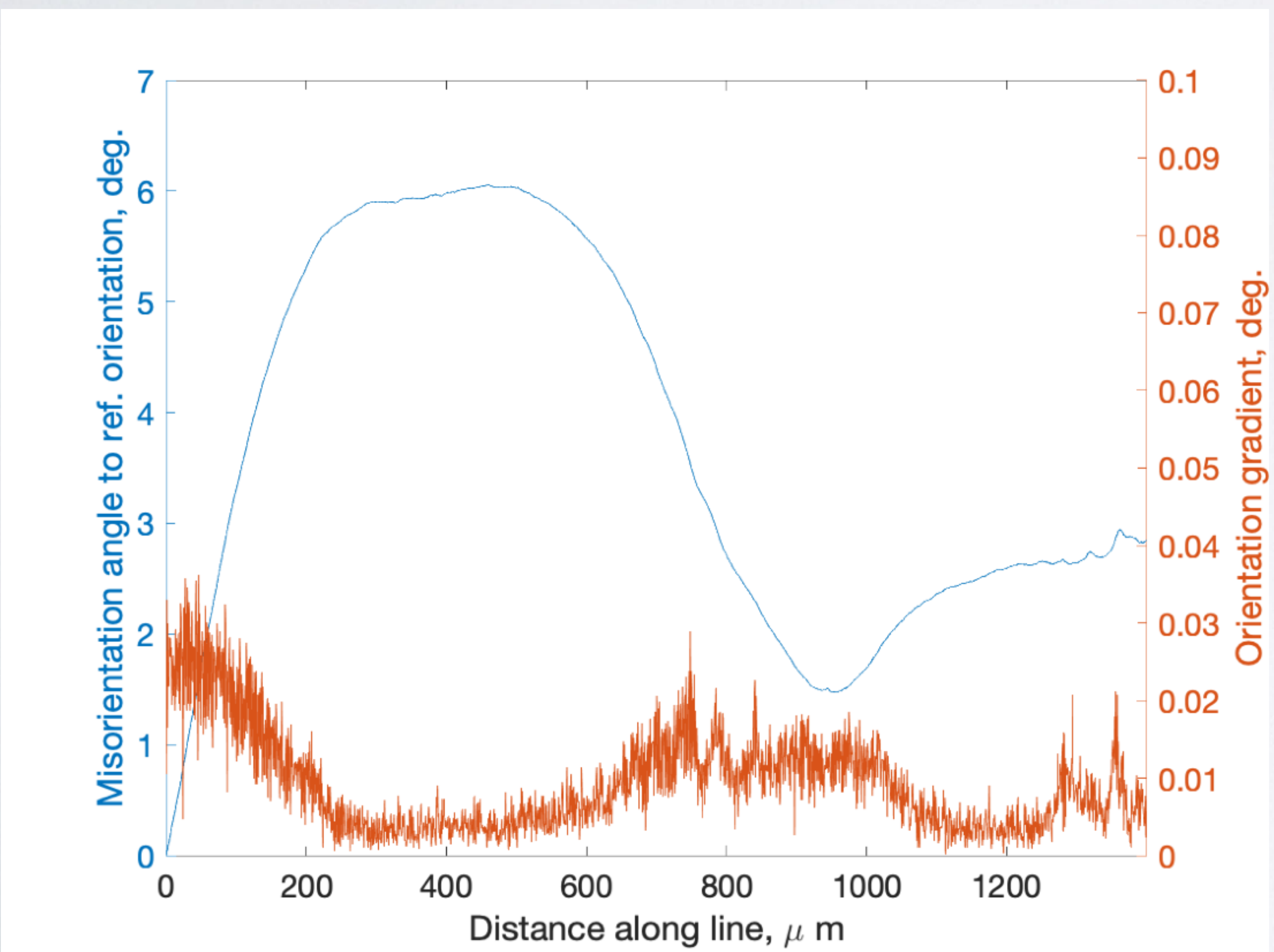
KAM map





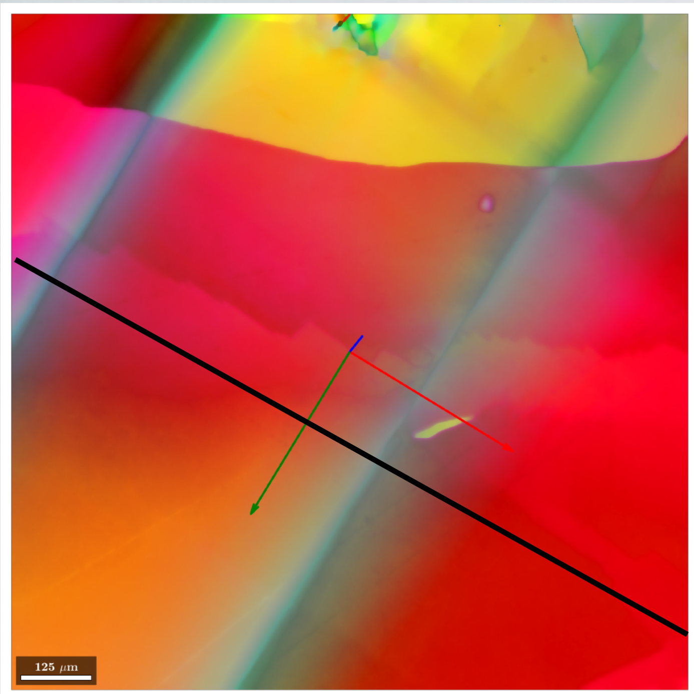
Line parallel to [100]

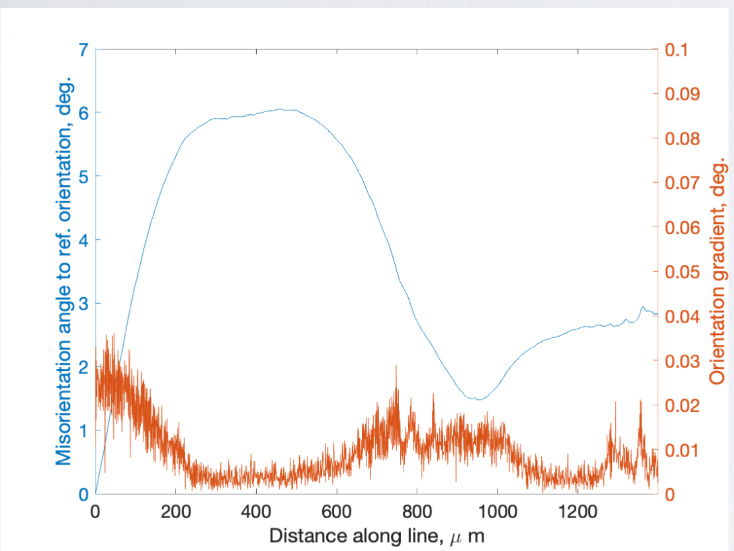
Orientation change

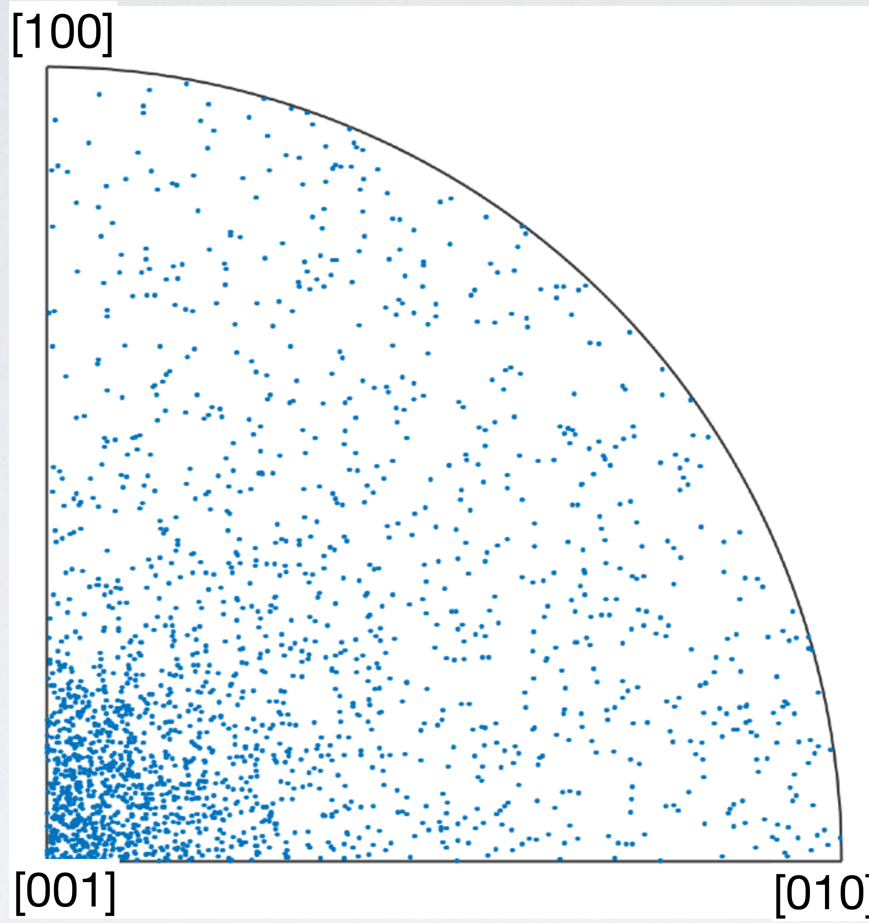


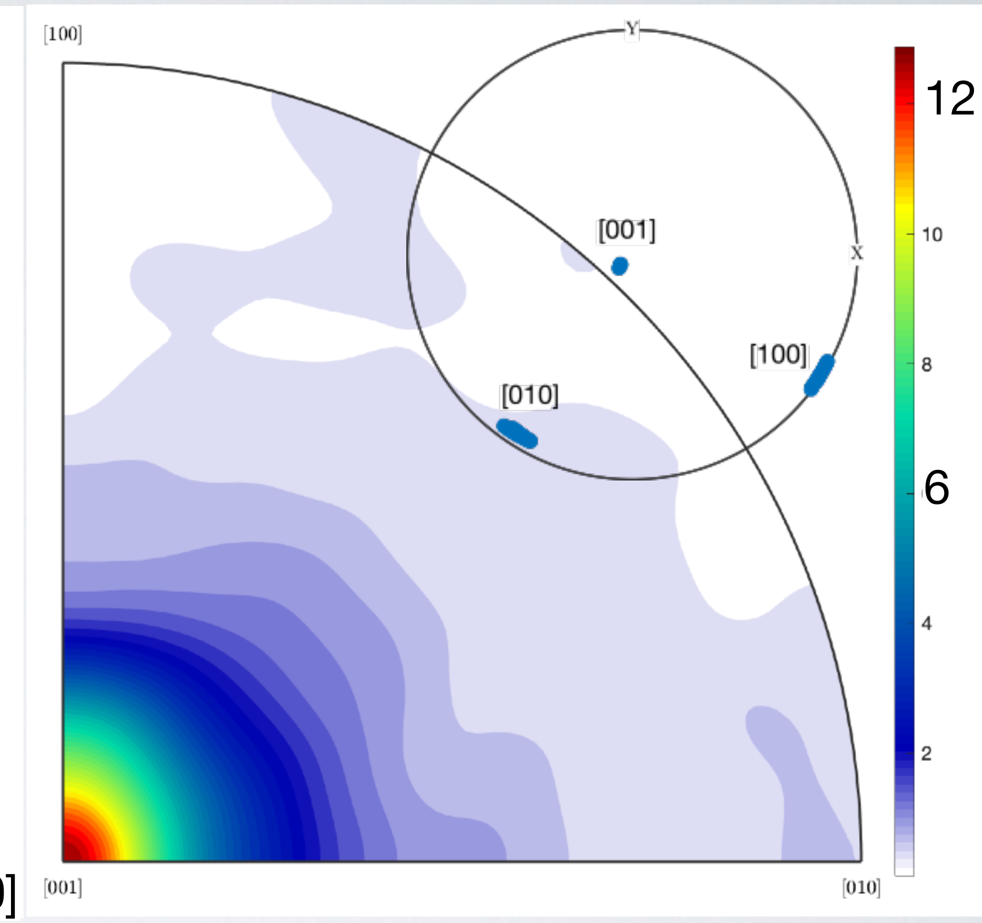
orientation gradients
~ 0.1°

Misorientation axes





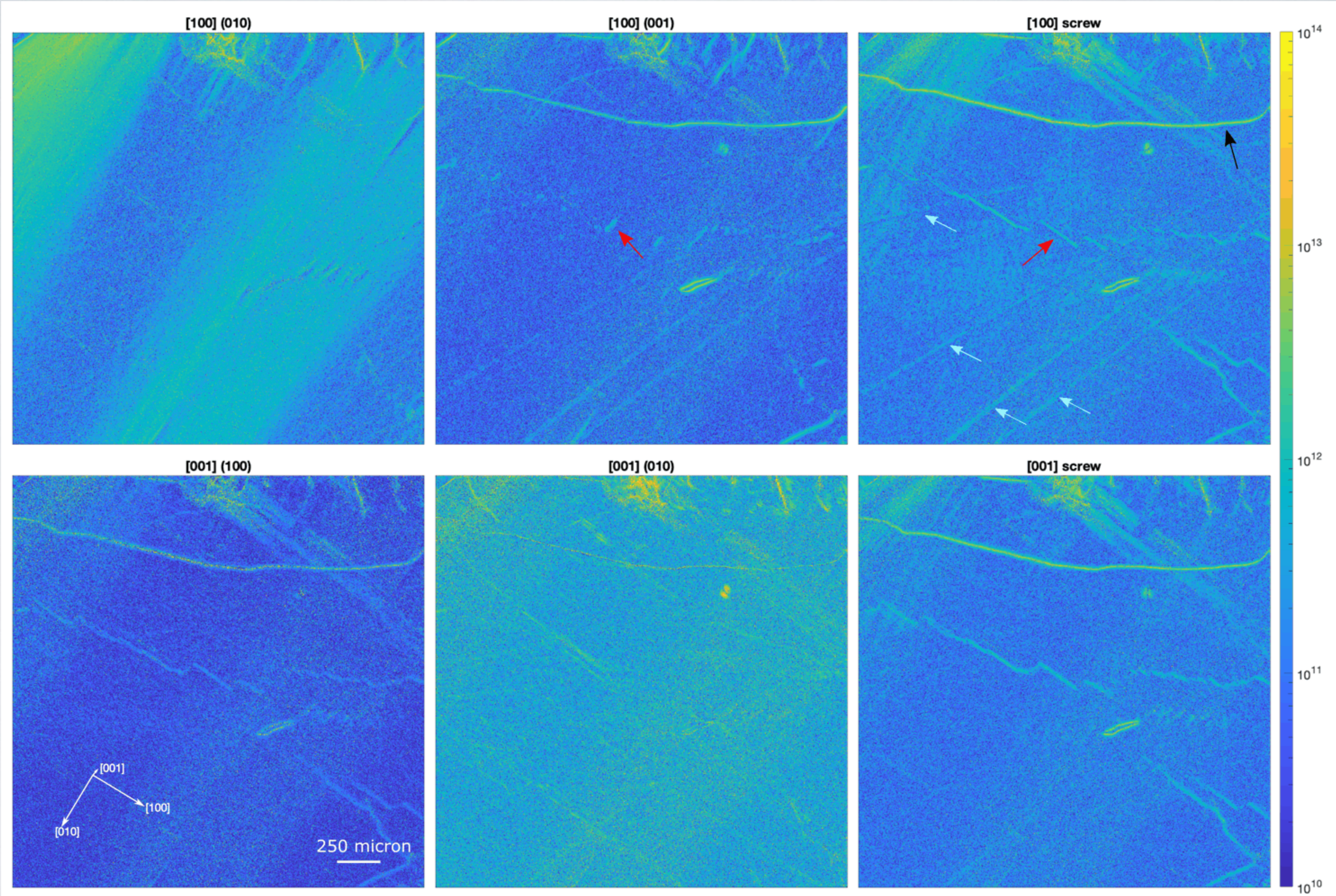




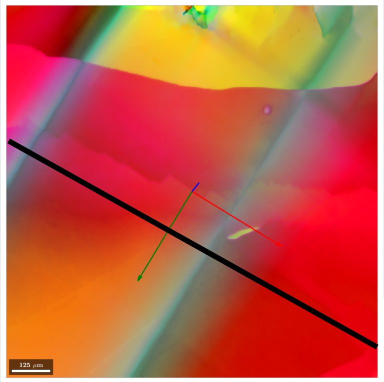
Individual axes: noise - scatter limit of angular fidelity of conventional EBSD.

Smoothed data shows strong concentration at the expected misorientation axis for [100](010) slip system

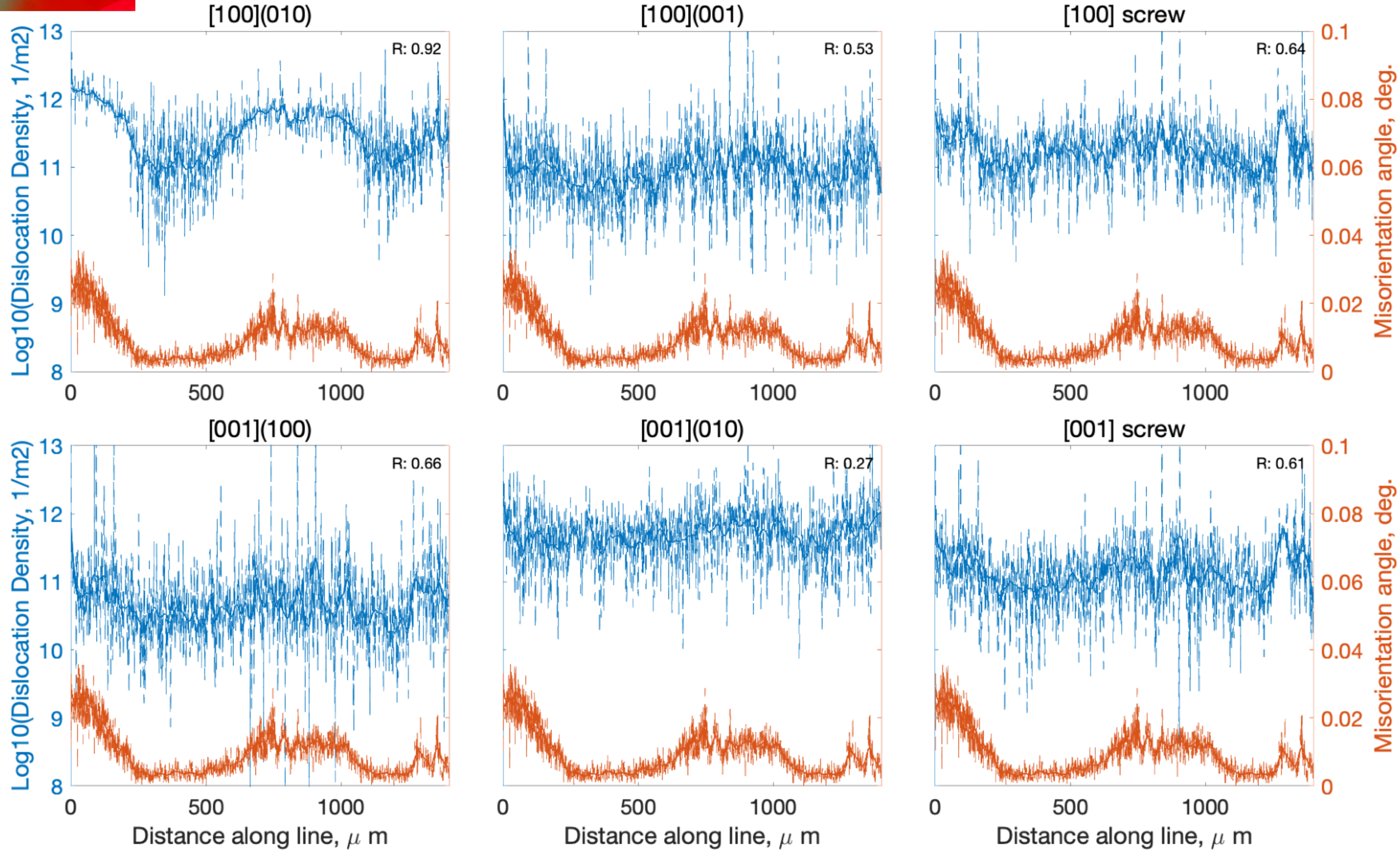
Dislocation densities



as expected and known from earlier light microscope and TEM imaging [100](010) is most active slip system

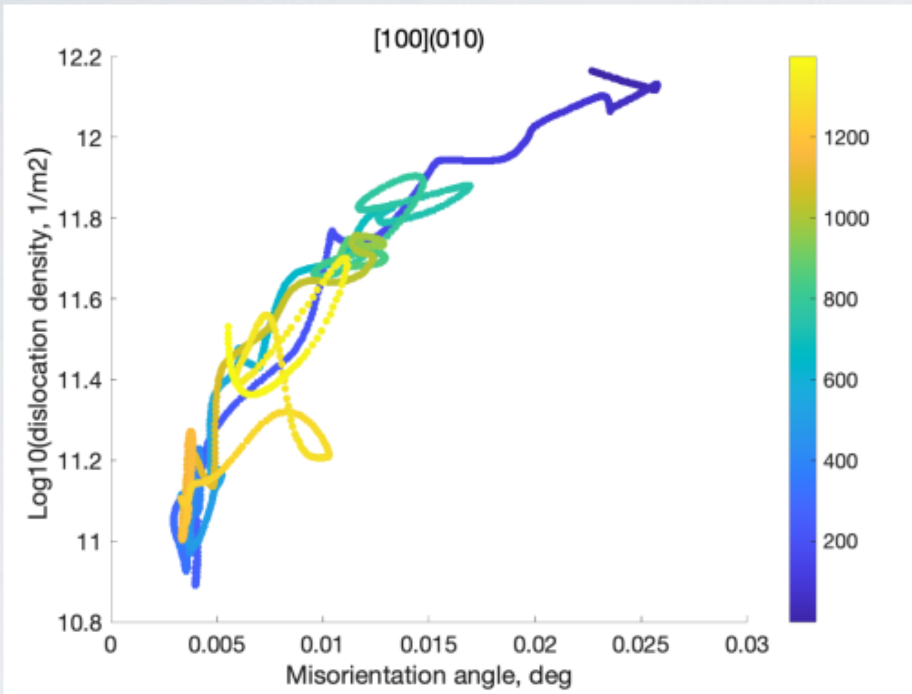


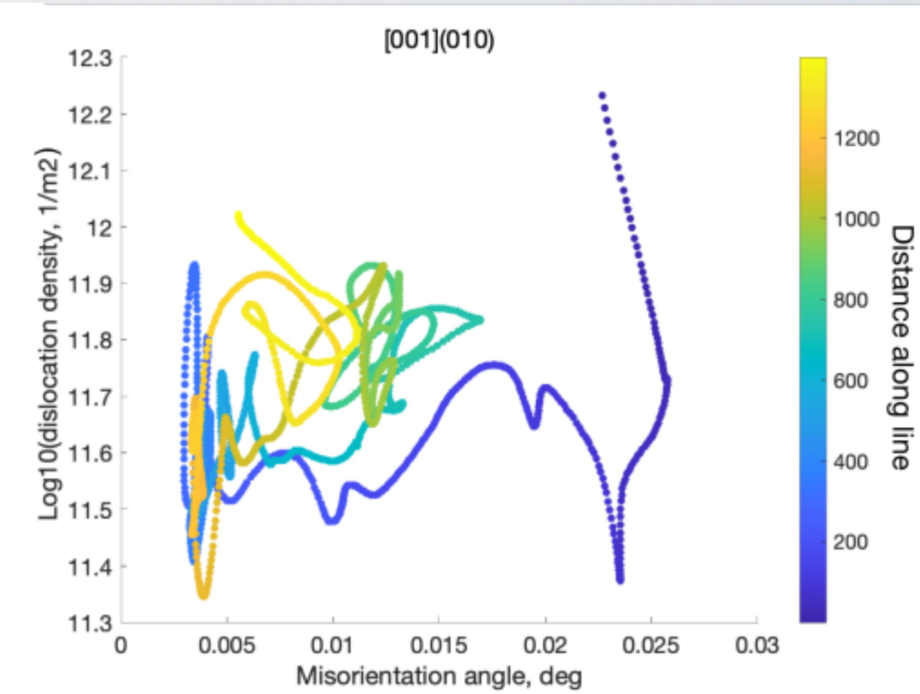
Correlation of dislocation density with orientation gradient



confirms [100](010) as most active slip system

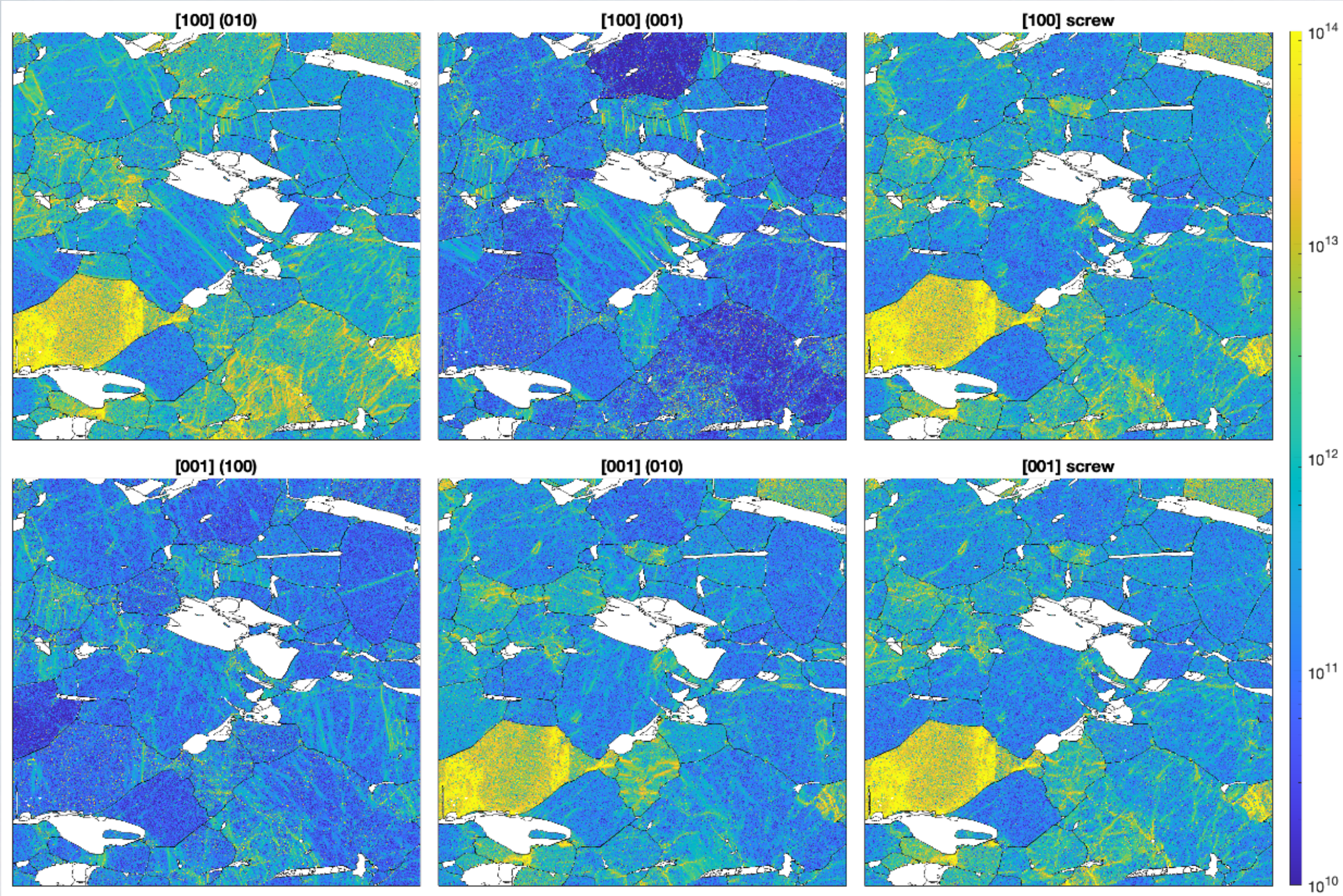
Dislocation density as function of misorientation angle color coded by distance from first point



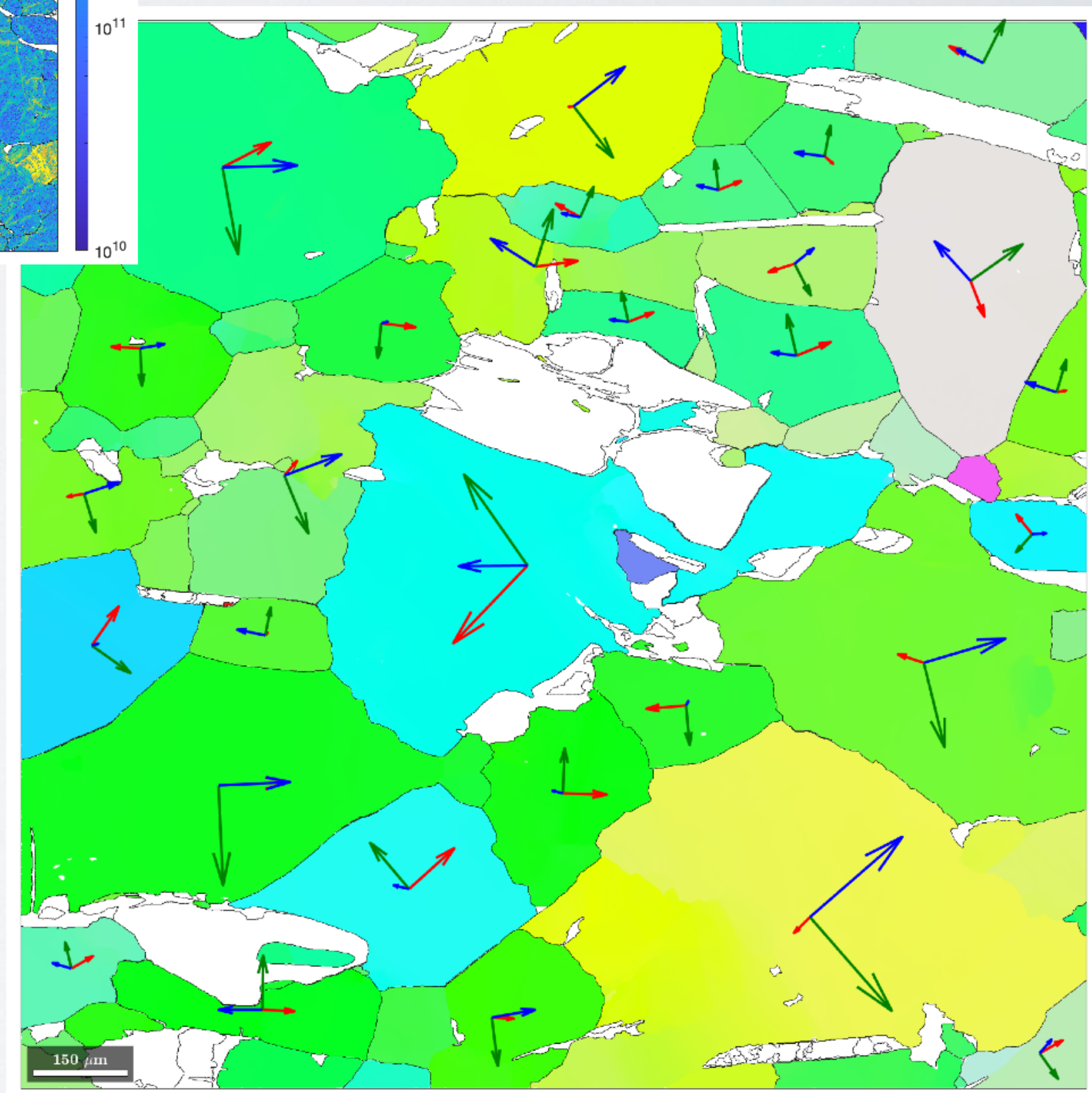


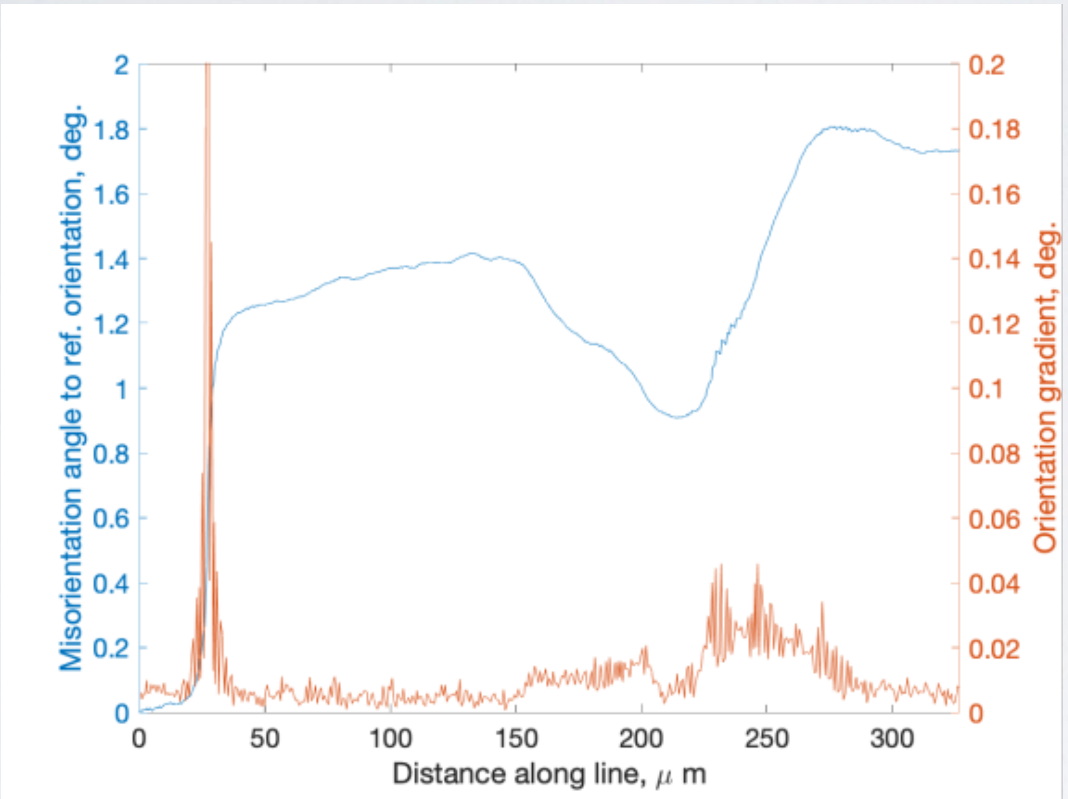
Conclusion:

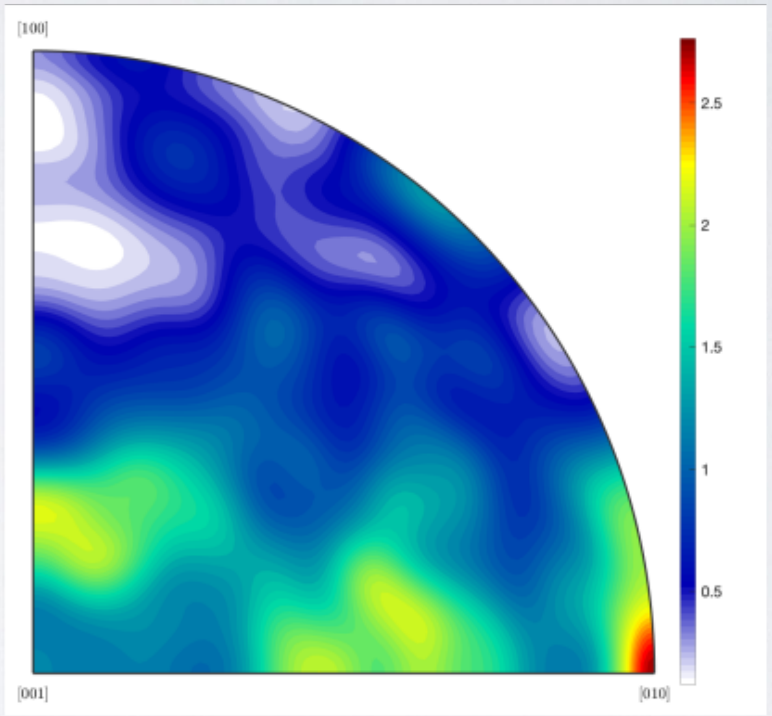
- meaningful dislocation structures and densities can be extracted from conventional EBSD data

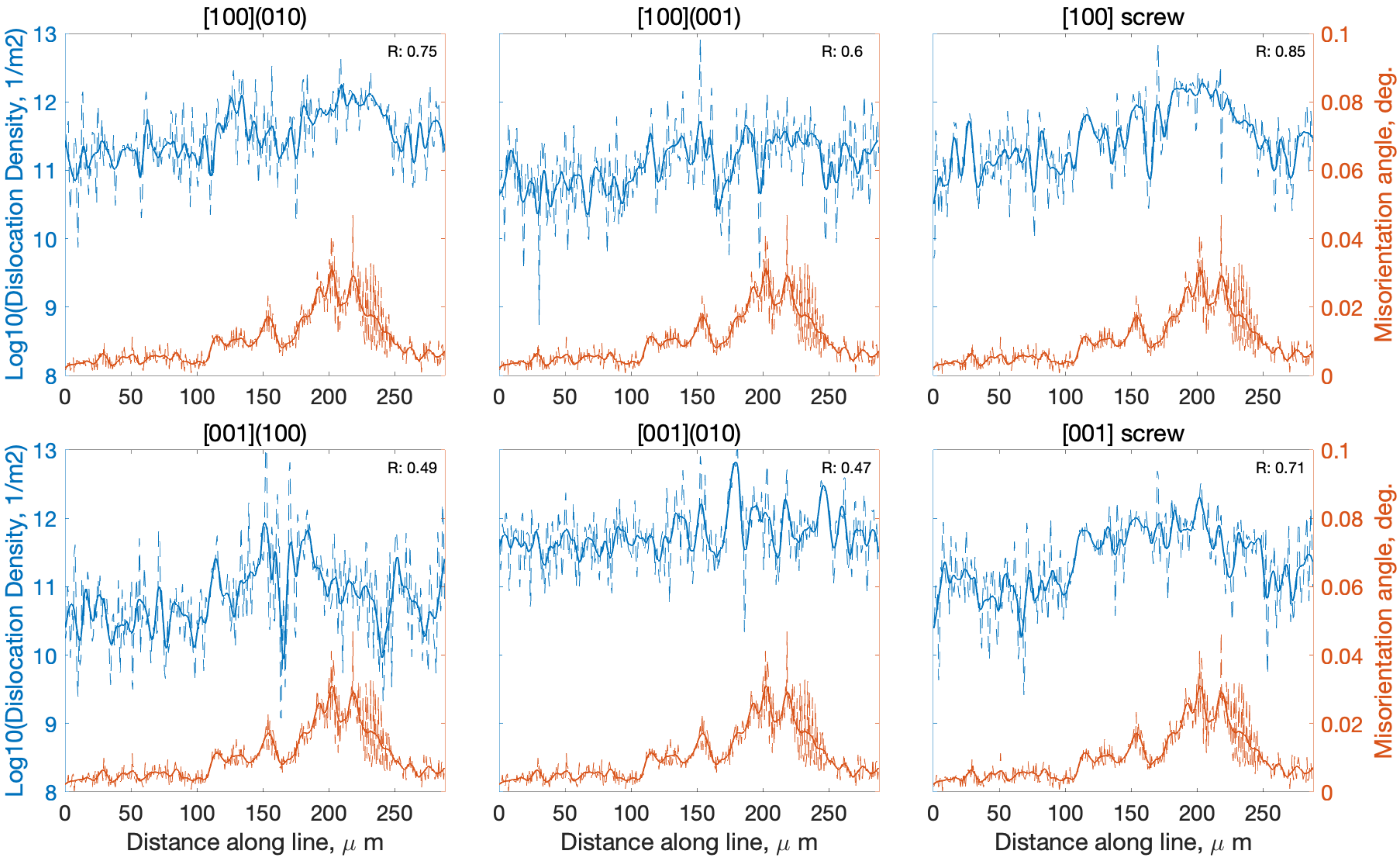


Problems: Certain ‘singular’ orientations




Misorientation angle to ref. orientation, deg.
Orientation gradient, deg.
Distance along line, μ m
0
50
100
150
200
250
300
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2


[100]
[001]
[010]
0.5
1
1.5
2
2.5



[100](010)
R: 0.75
[100](001)
R: 0.6
[100] screw
R: 0.85
[001](100)
R: 0.49
[001](010)
R: 0.47
[001] screw
R: 0.71
Log10(Dislocation Density, 1/m2)
Misorientation angle, deg.
Distance along line, μ m