MTEX for Structural Geologists

- Benefits of using MTEX to plot and analyze field data
- Rotating microstructural data to other reference frames
- Combining EBSD with overlapping maps/images/datasets

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MTEX Workshop 2021

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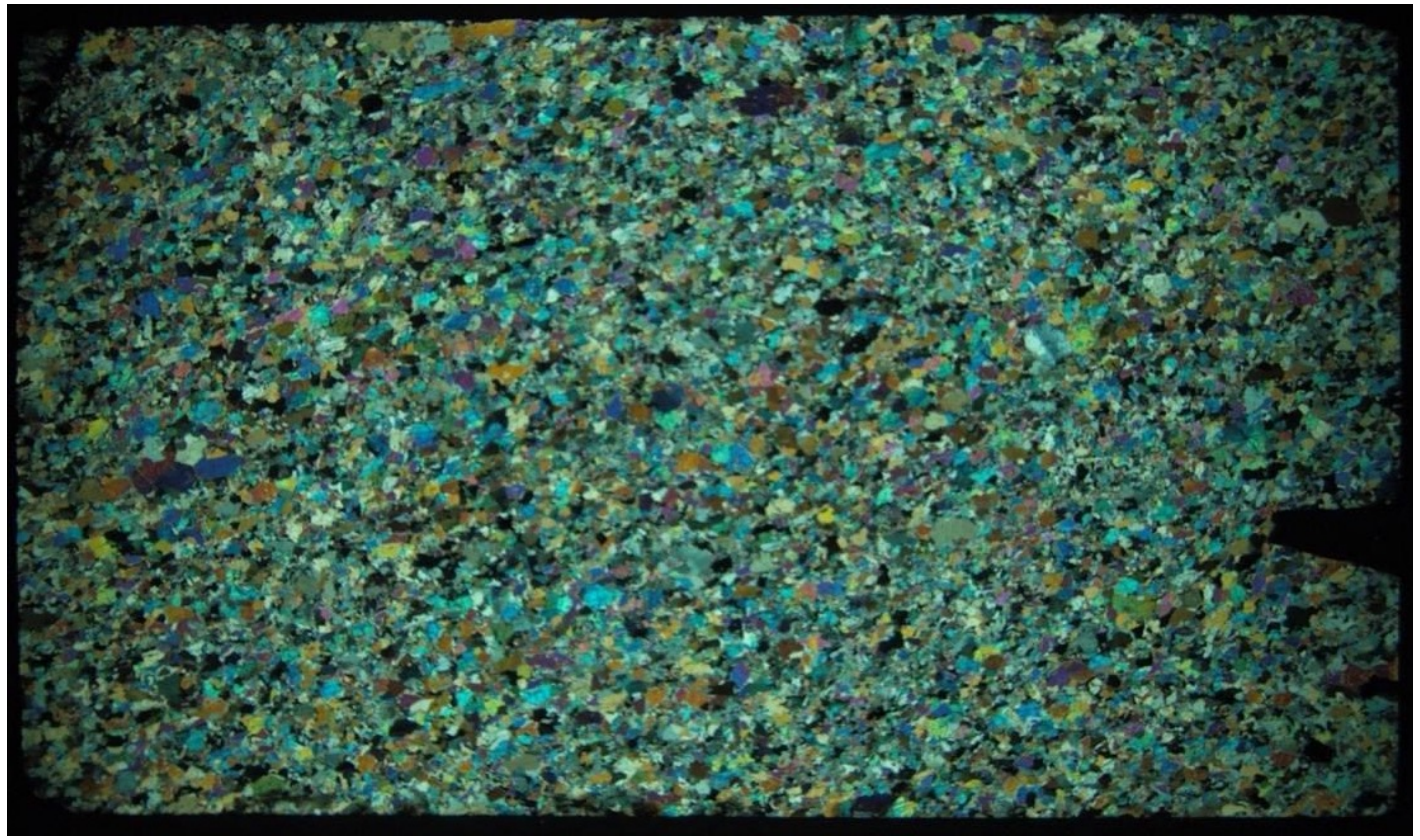

GEOGRAPHIC

↕

SPECIMEN

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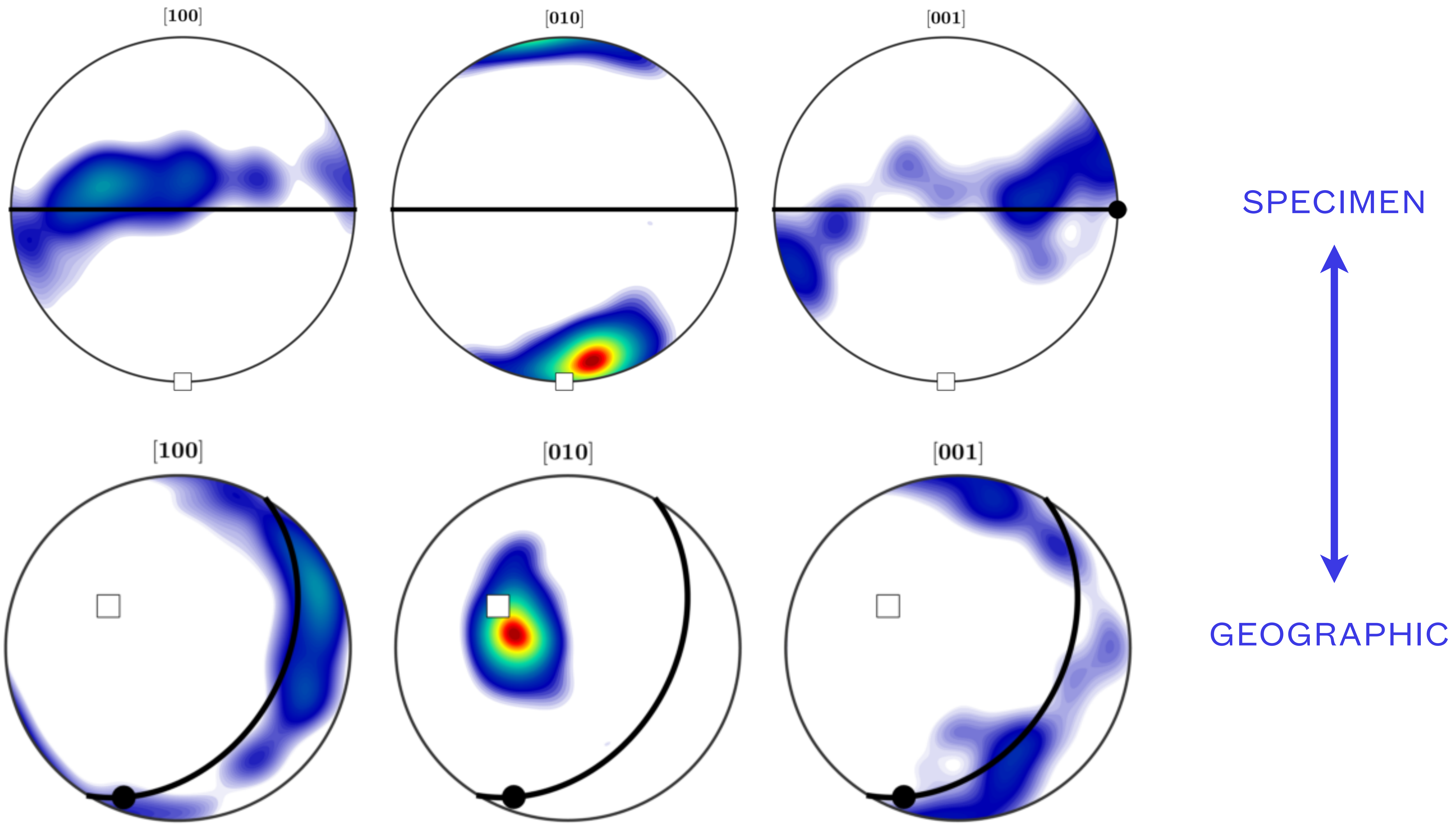
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SPECIMEN
GEOGRAPHIC

Topics for today

- First things first!
  - **Import correction** (rotate EBSD data to match acquisition reference frame)
    - may require iterative checks
    - often applies to all datasets from a specific system

- A geographic reference frame in MTEX
  - Benefits for analyzing field data (i.e., pairs of foliation and lineation)
  - Rotating microstructural data into a “geographic” context

- Combining EBSD with overlapping datasets
  - Example: grain-scale CL values (data unpublished and not included in code)

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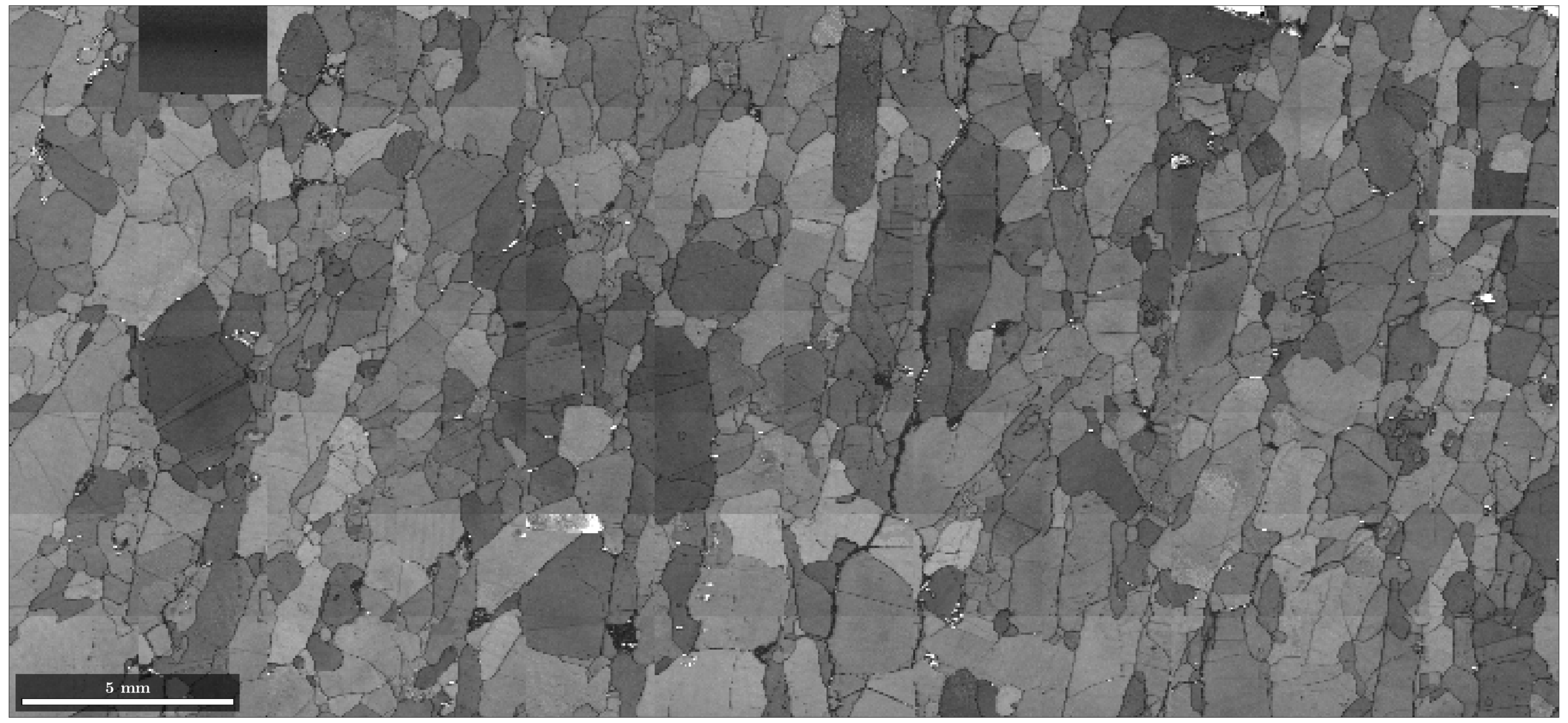
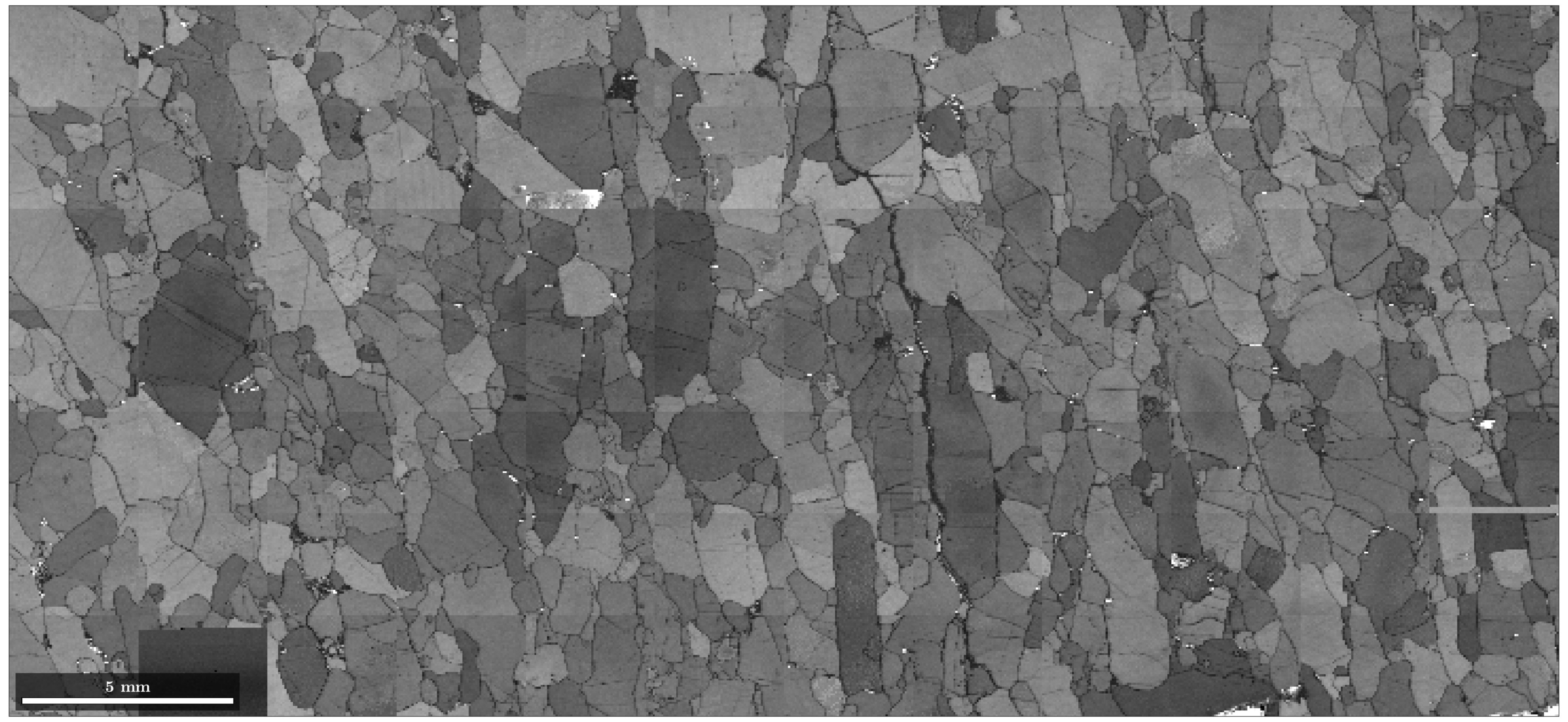
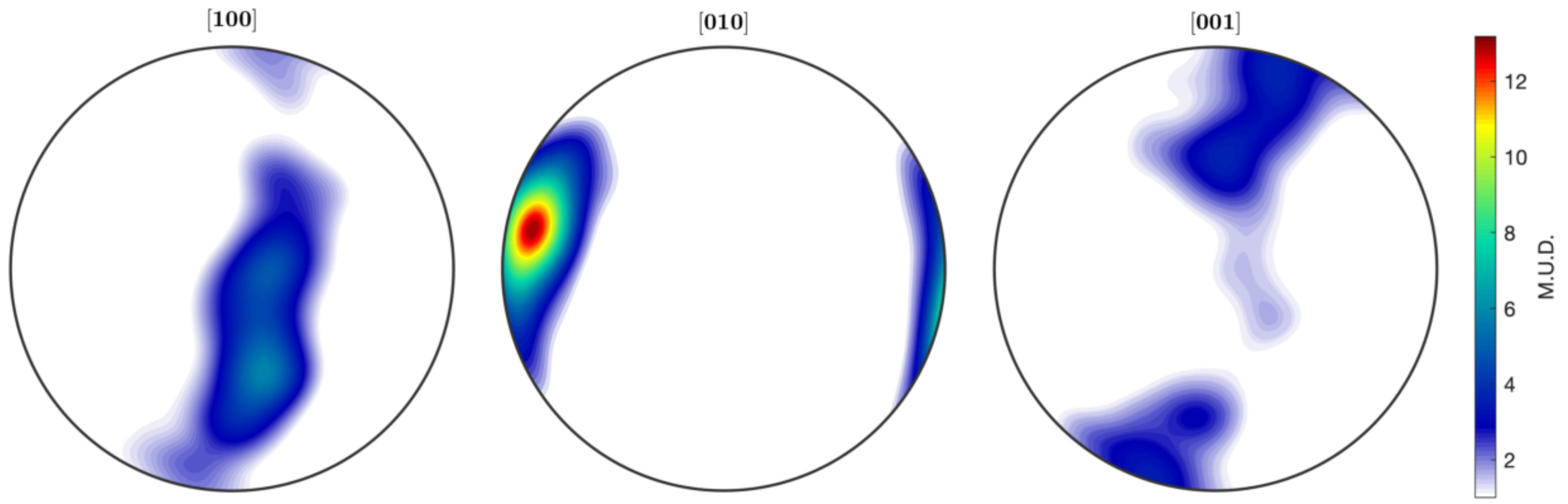
First things first... [confirming your geometry]

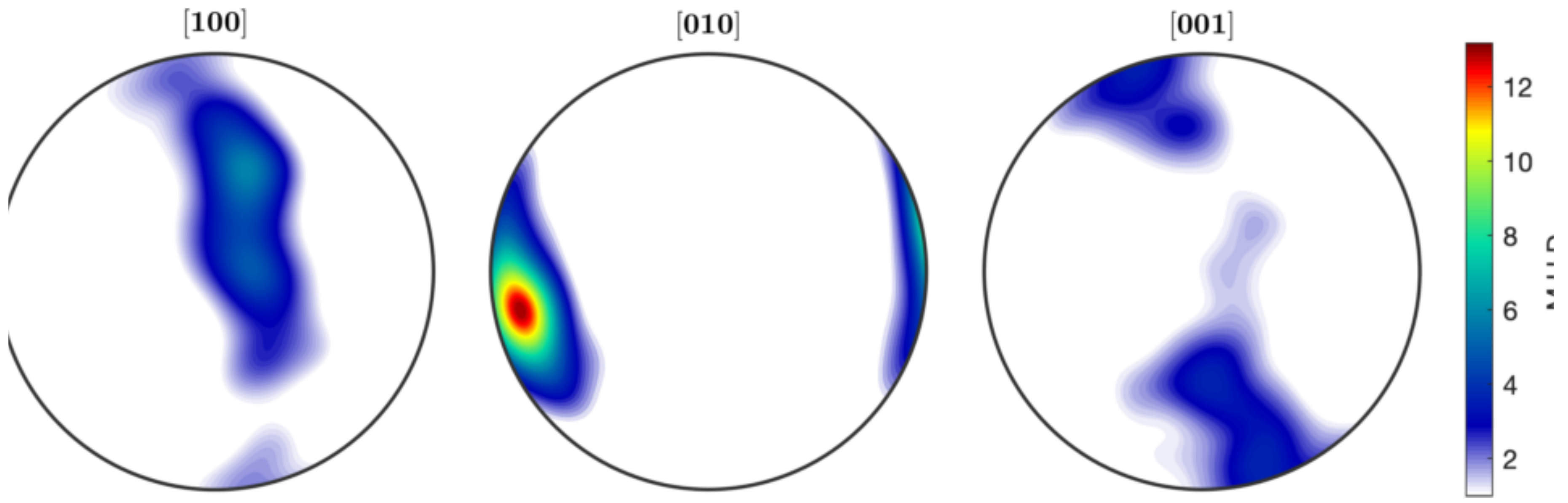
- Different configurations of SEM+EBSD+software
- Compare maps *and* pole figures in MTEX with those from acquisition software
- Apply necessary rotations and/or plotting conventions to align your data in MTEX
- NOT TRIVIAL!!! And crucial for structural / kinematic analysis



<— initial rotations —>







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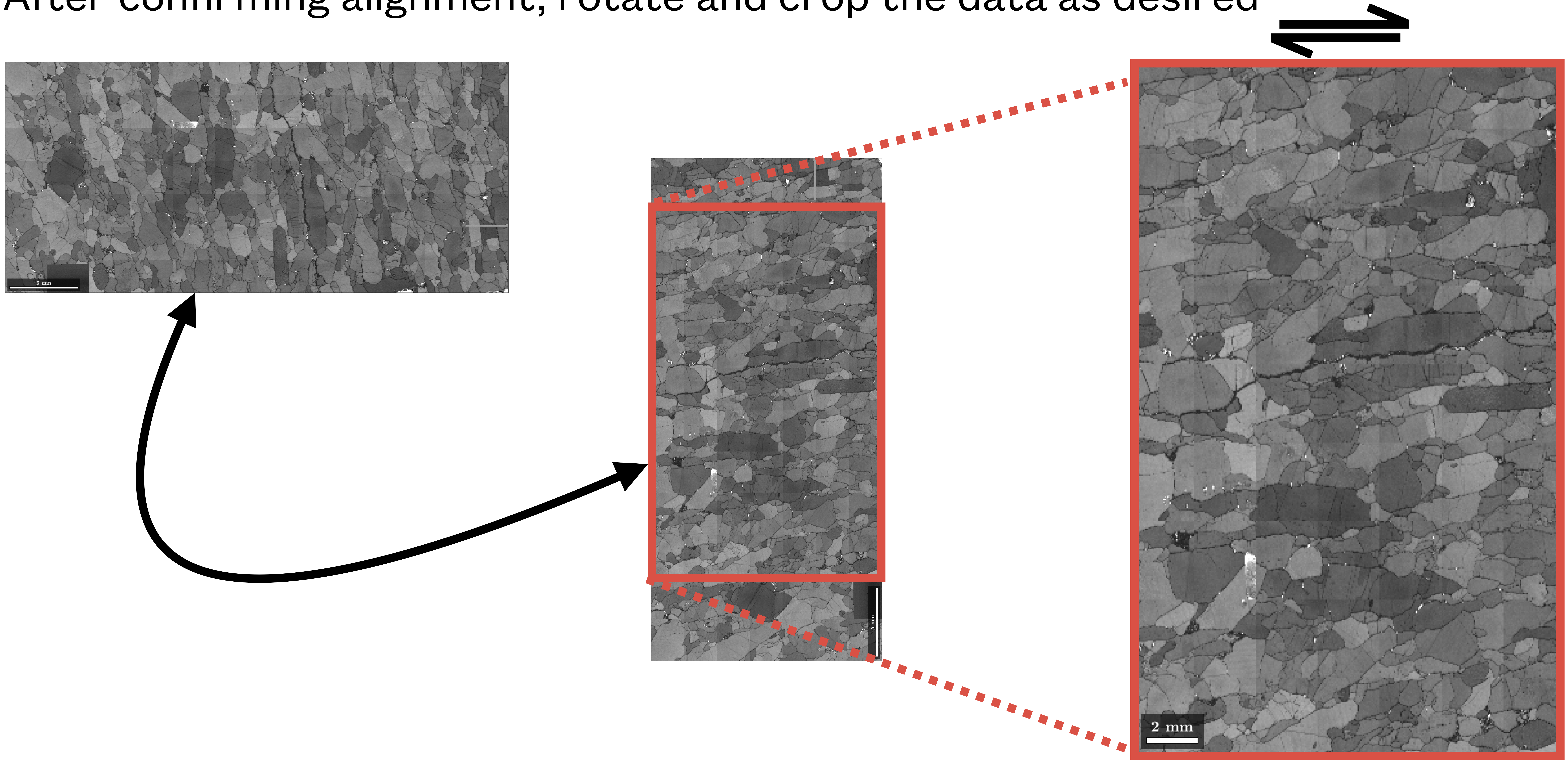
First things first... [defining your reference frame]

- After confirming alignment, rotate and crop the data as desired



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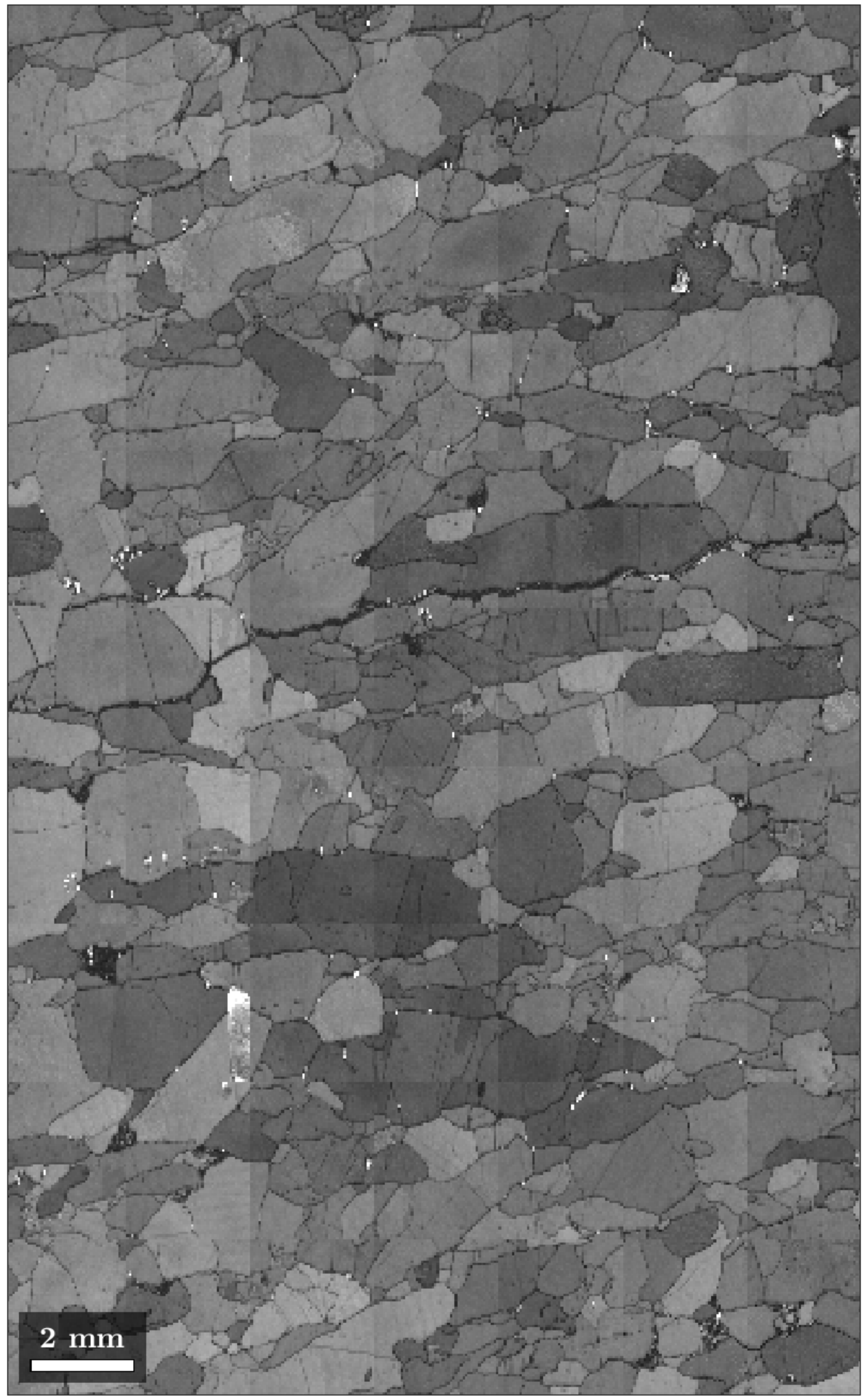
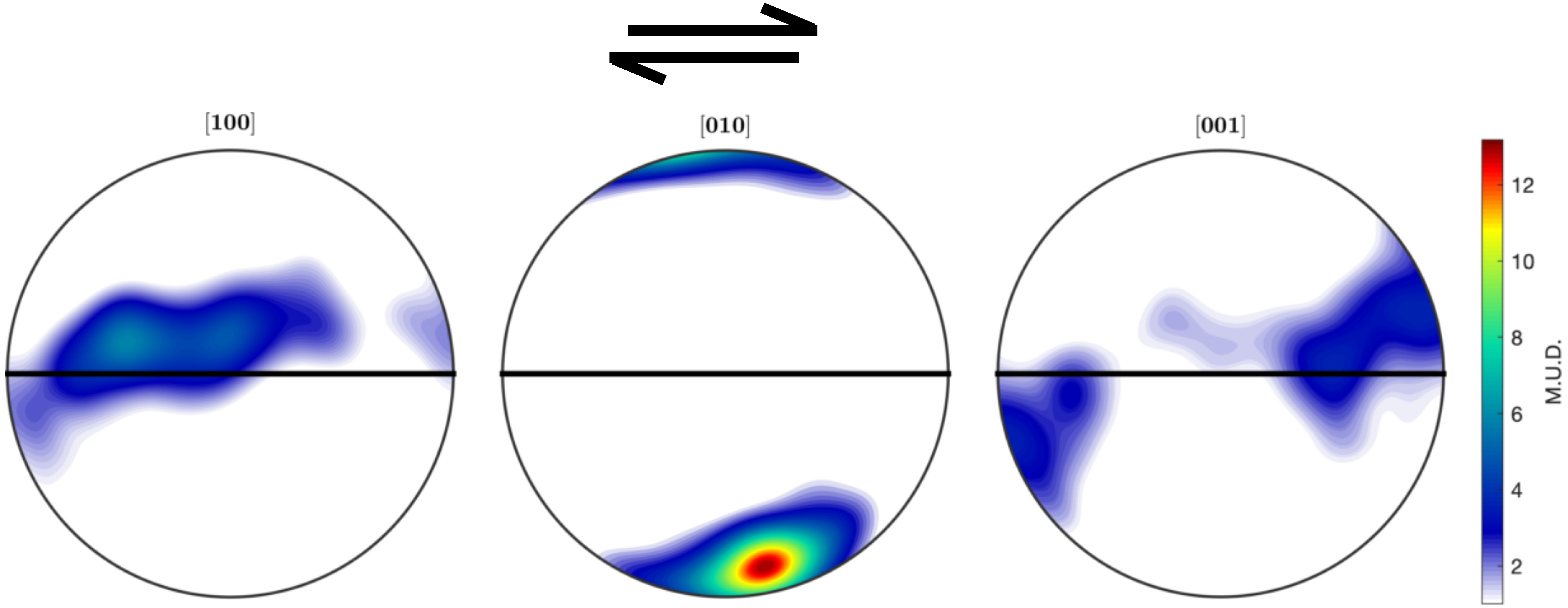
First things first...

[a good starting point]



- A final/initial double-check that everything is aligned how you want
- Looks good… save… proceed



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FIELD DATA

"geographic" plots

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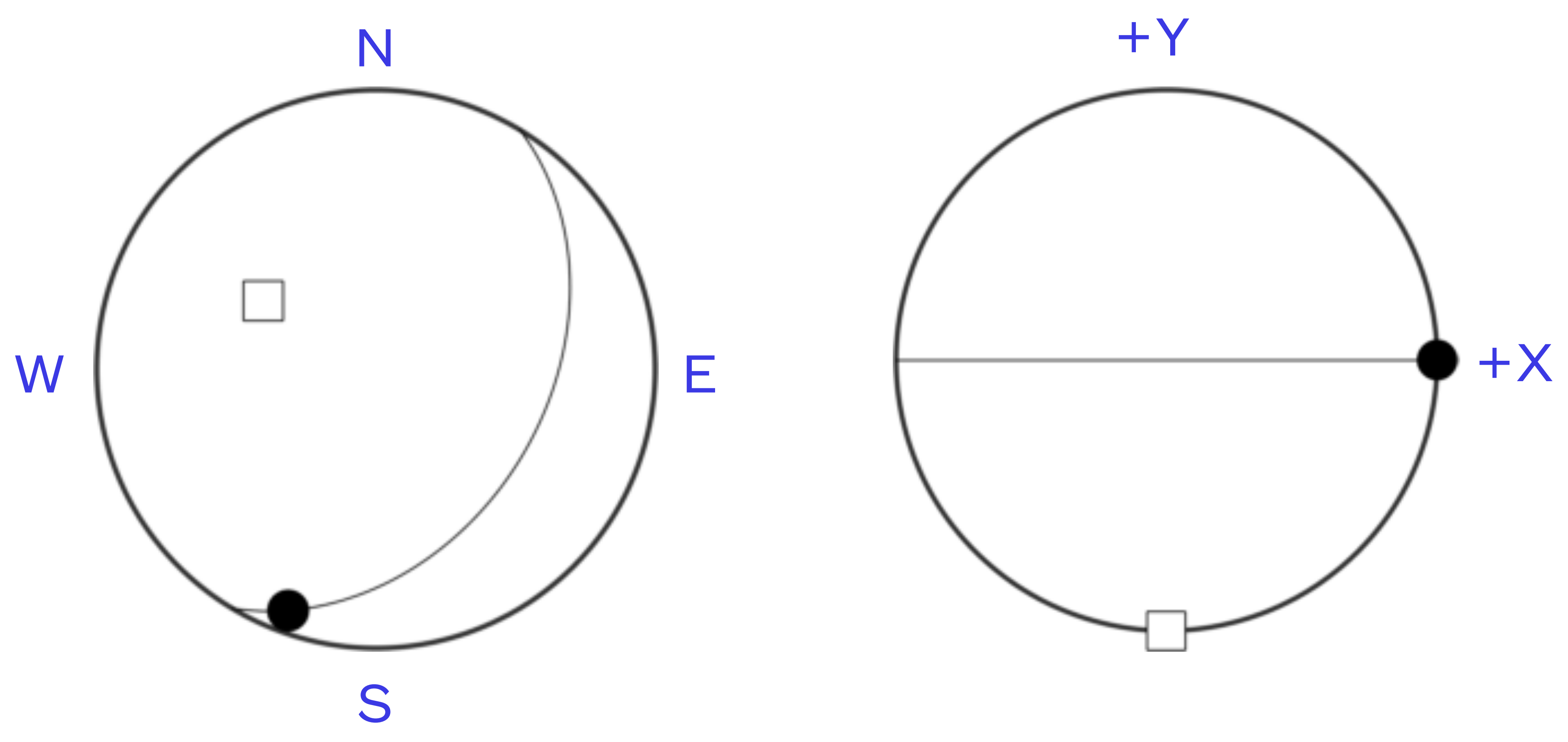
Field data in MTEX [geographic reference frame]

Initial considerations

- Data and plotting conventions:
  - field data (e.g., right-hand-rule for strike+dip)
  - plotting in MTEX (e.g., ‘xAxisDirection’,'east')



Convert field data to MTEX objects

- Field direction —> vector3d
- L-S fabric —> orientation/rotation
- Scripts online to help: https://github.com/zmichels/Fabrica
- Also generally useful: “Structural Geology Algorithms” (Allmendinger et al., 2012)

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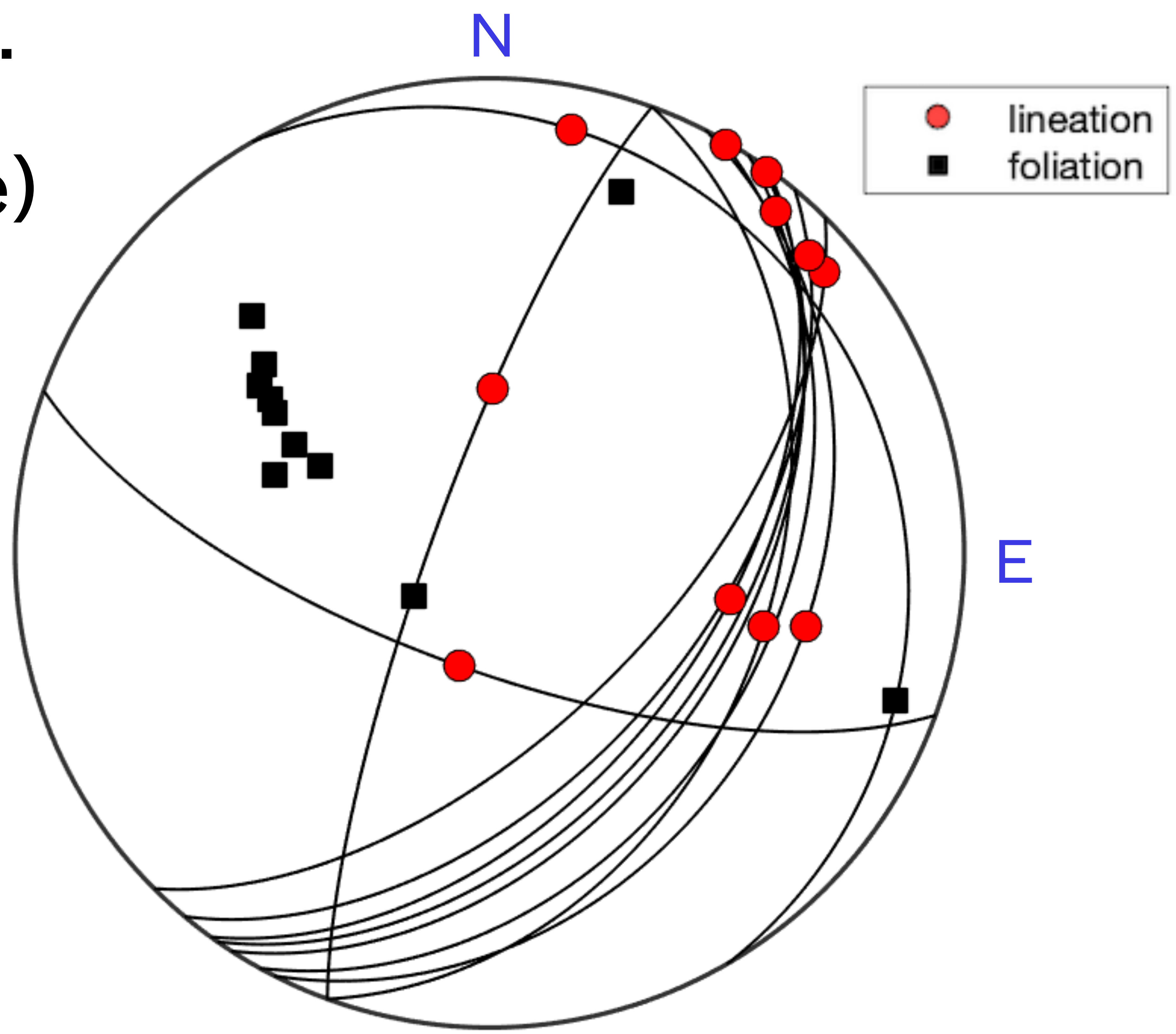
Field data in MTEX [geographic reference frame]

Directions (vectors)

- Individual measurements (e.g., trend+plunge, or strike+dip)
    - lineations, foliation poles, strain axes, etc…
- compute geometric relationships (e.g., angle)



Ellipsoids (orientations / rotations)

- Combinations of measurements
- Ex: fabric ellipsoid (lineation + foliation)

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Field data in MTEX [geographic reference frame]

Why bother with MTEX when other software for structural geology?

- Full-fabric orientation vs. separate directions
  - maintain orthogonal relationship between fabric elements (mean, mode, etc.)
  - define rotations between fabric orientations
- Analyses/workflows are scriptable, repeatable, sharable
- Potentially all analysis in one software (micro-data + field data)
- Very flexible and customizable
- Great support and discussion community

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Field data in MTEX [geographic reference frame]

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Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures

SDT2or() is a function available at my GitHub repository and provides an example of how to compute vectors/directions, fabric orientations, and rotations between "specimen" and "geographic" reference frames.

https://github.com/zmichels/Fabrica

```
[ fabOr, fabRot, strikeV, poleV, linV ]  =  SDT2or( strike, dip, trend )
```


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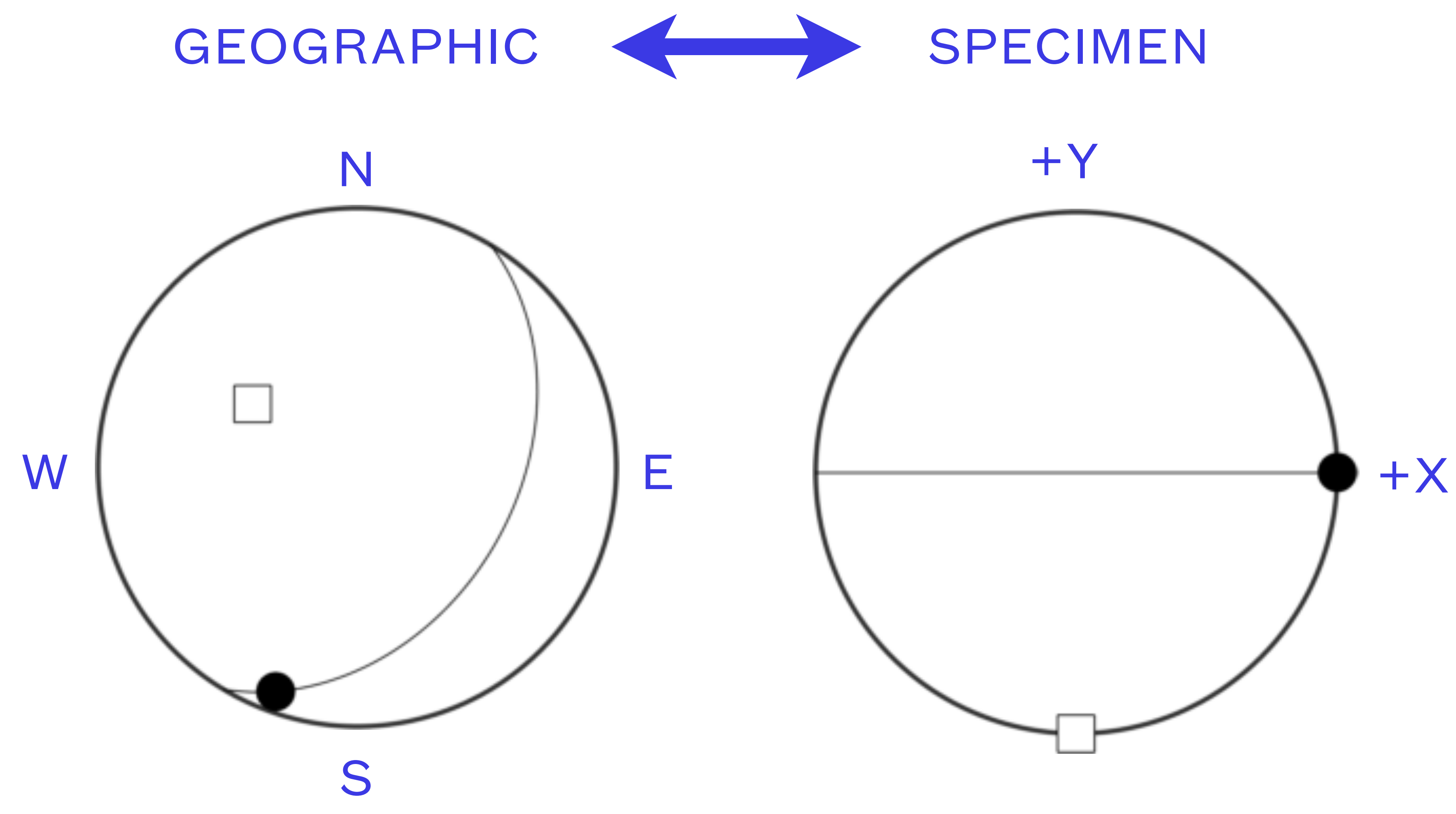
Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures



Rotation to geographic → fabRot

Foliation pole direction → poleV

[fabOr, fabRot, strikeV, poleV, linV] = SDT2or(strike, dip, trend)

Fabric orientation → fabOr

Strike direction → strikeV

Lineation direction → linV

Right-hand rule → strike, dip

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Field data in MTEX

[geographic reference frame]

Fabric analysis of field-scale structures

	A	B	C
1	strike	dip	trend
2	110	70	15
3	200	80	1
4	330	15	11
5	20	40	105
6	33	45	220
7	45	60	230
8	35	47	36
9	36	50	101
10	29	39	30
11	27	33	103
12	40	52	227
13			

Command Window

```
>> T = readtable('fakeFieldFabric.xlsx')

T =

  11×3 table

    strike    dip    trend
    ______    ___    _____

     110      70       15
     200      80        1
     330      15       11
      20      40      105
      33      45      220
      45      60      230
      35      47       36
      36      50      101
      29      39       30
      27      33      103
      40      52      227

>> [fabOr, fabRot, strikeV, poleV, linV] = SDT2or(T.strike,T.dip,T.trend);
>>
```


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Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures

Workspace

Name ▲	Value
fabOr	1x11 orientation
fabRot	1x11 rotation
linV	11x1 vector3d
poleV	11x1 vector3d
strikeV	11x1 vector3d
T	11x3 table

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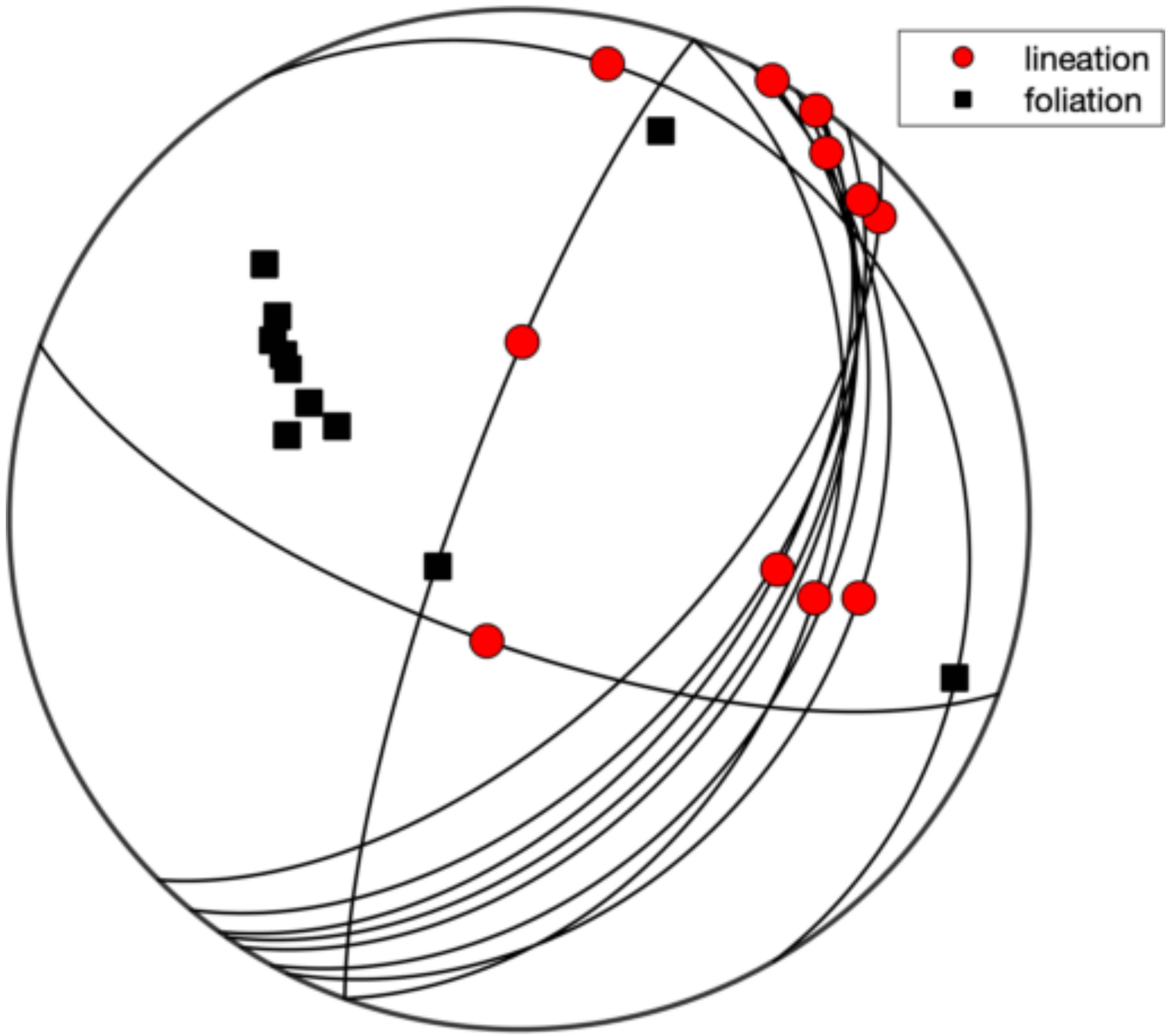
Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures



A **preferred direction/orientation**

What is the best way to do that in MTEX?

- advantage of analyzing the pairs of lineation+foliations together, with each pair represented by a single orientation.
- MTEX calcDensity() function is very useful, whether vectors or orientations (or other data for that matter)

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Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures

Separate Analysis

lineation and foliation directions analyzed separately

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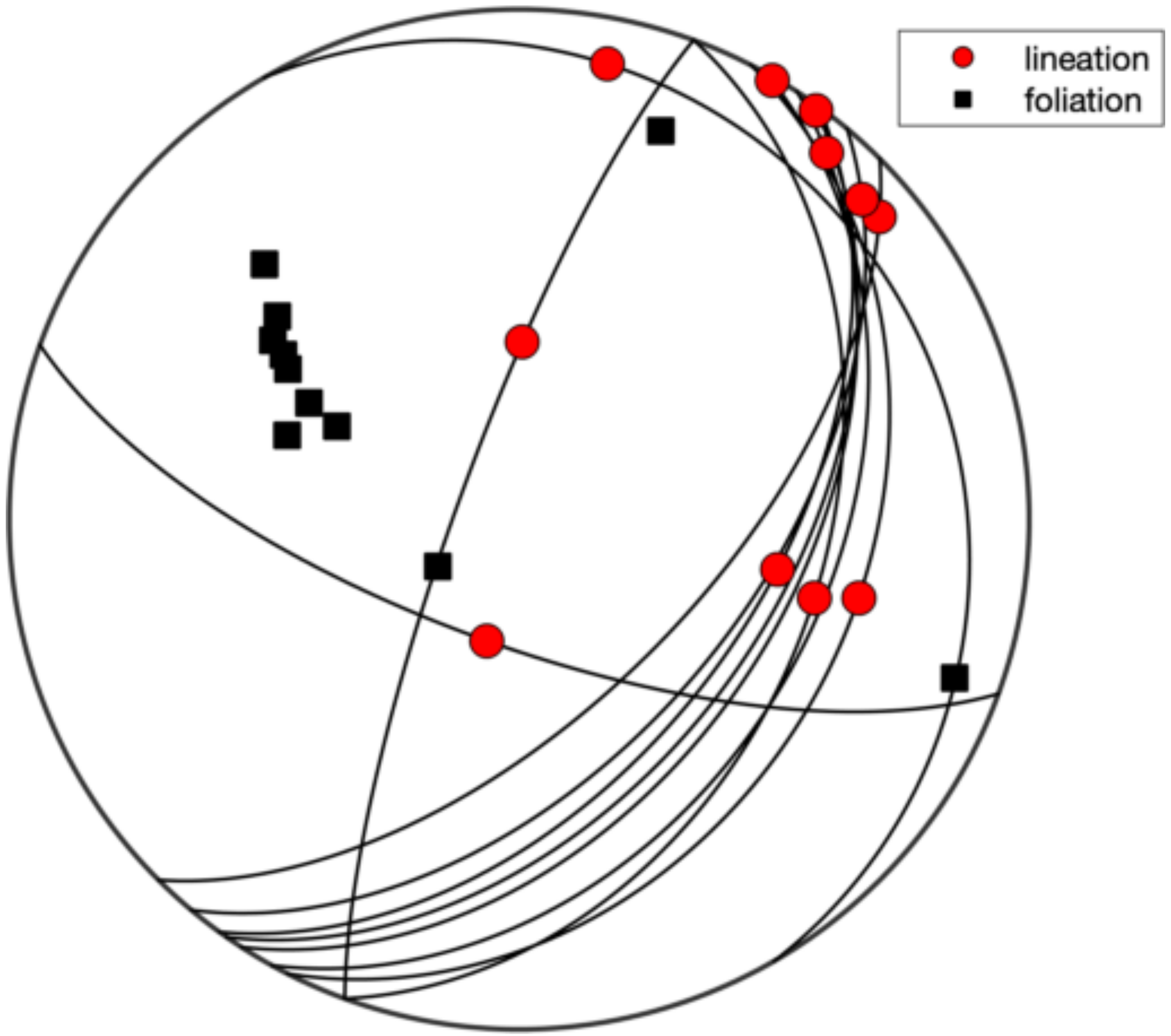
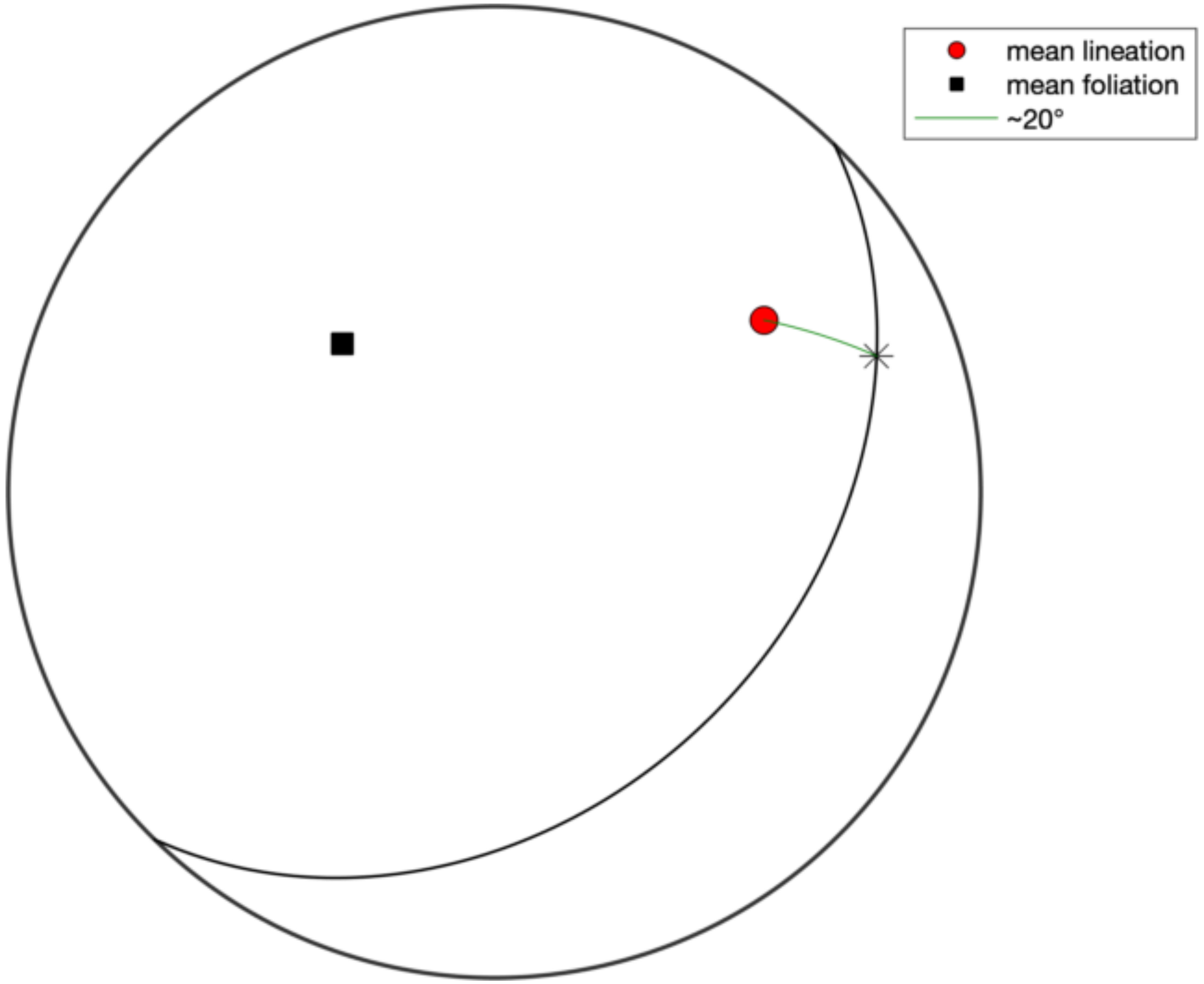
Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures



The mean lineation does not lie within the plane of the mean foliation.



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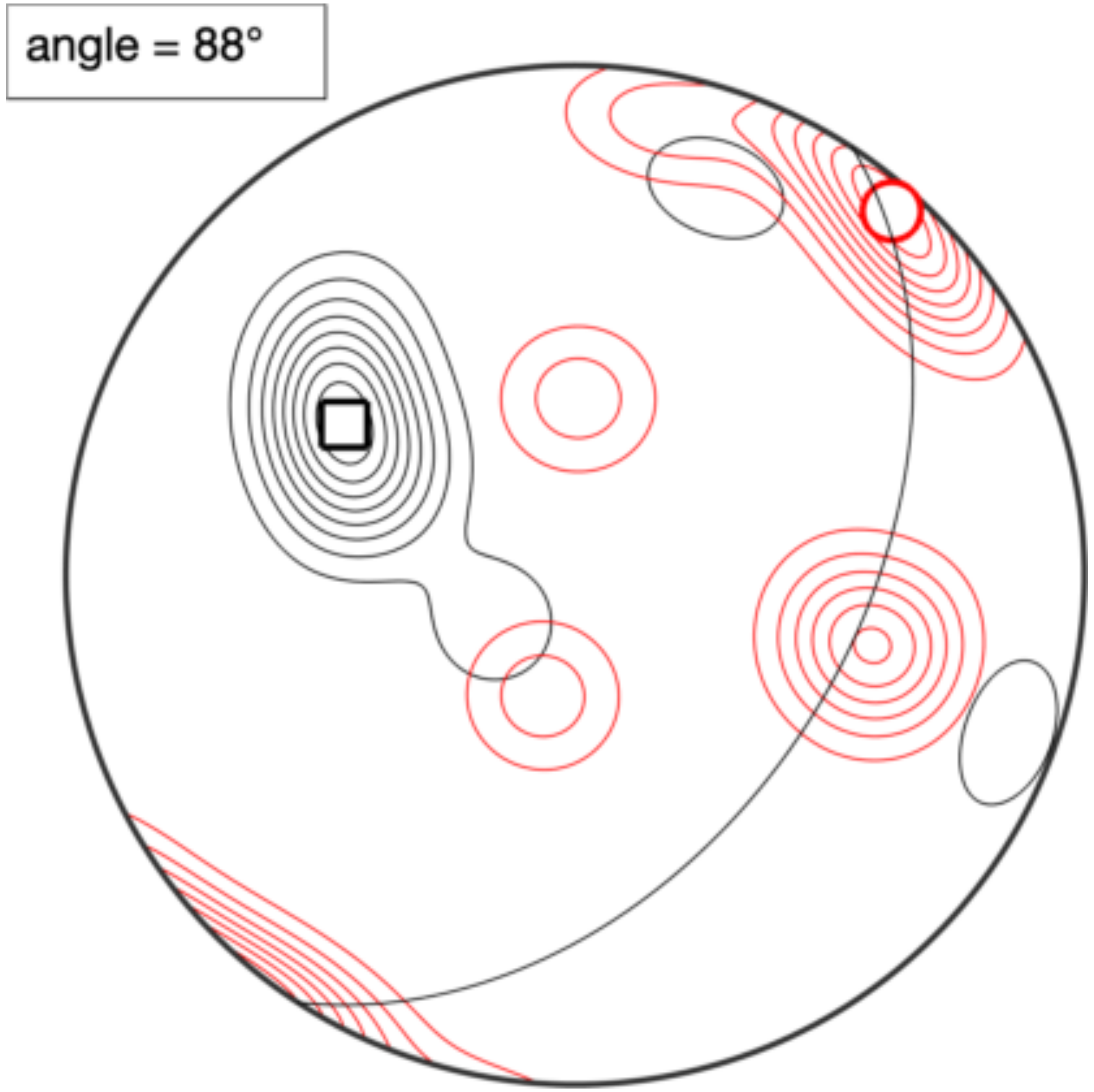
Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures



Perhaps a preferred orientation from direction densities, instead. [Use calcDensity()]

When applied to the foliation and lineation separately, this approach yields nearly (but not) perpendicular vectors – the preferred lineation direction does not lie in the preferred foliation plane (2° off).

Instead... lets try analyzing foliation+lineation pairs *together* by representing each pair as an orientation/rotation. The output of the SDT2or() function includes such a representation.

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Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures

Combined Analysis

lineation and foliation directions analyzed *together*

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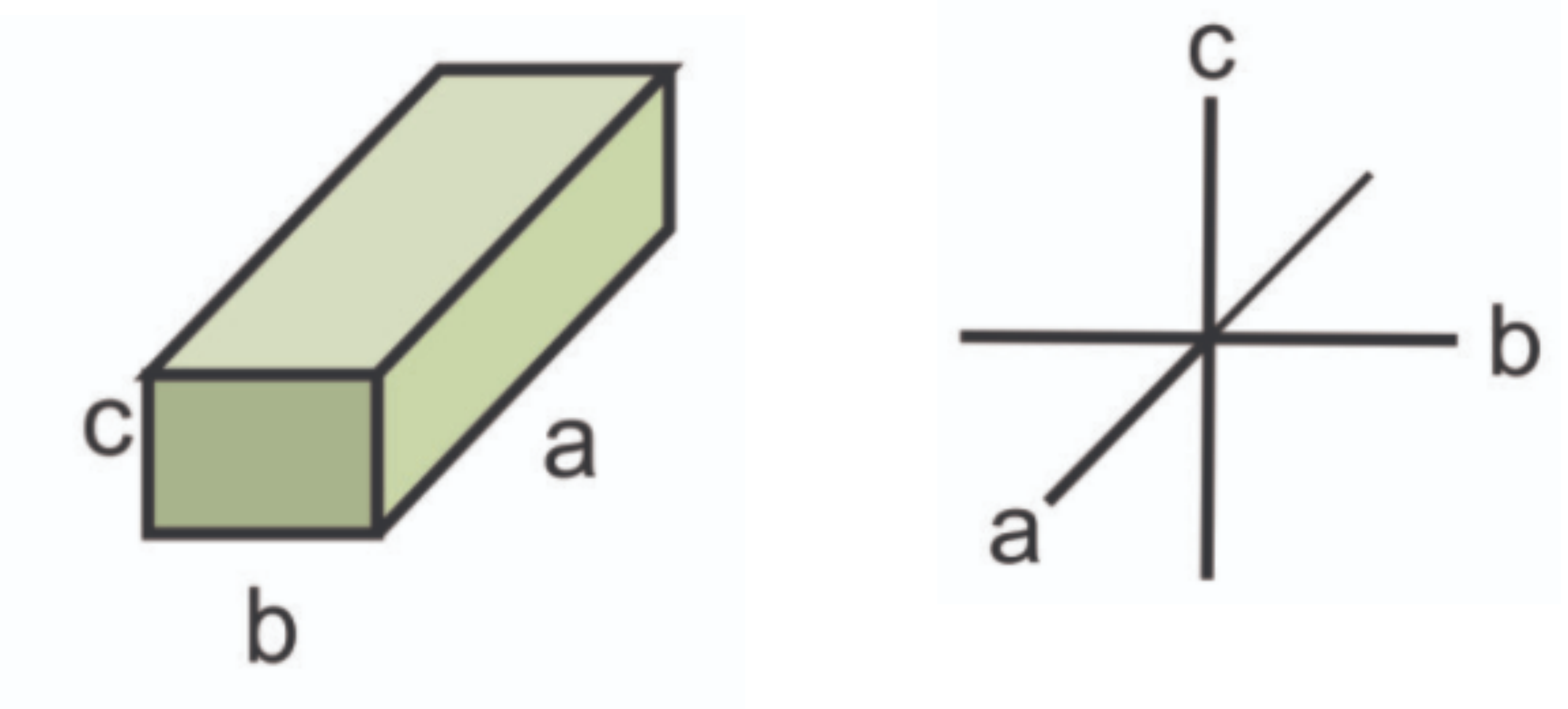
Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures orientational representation of fabric

Orthorhombic symmetry



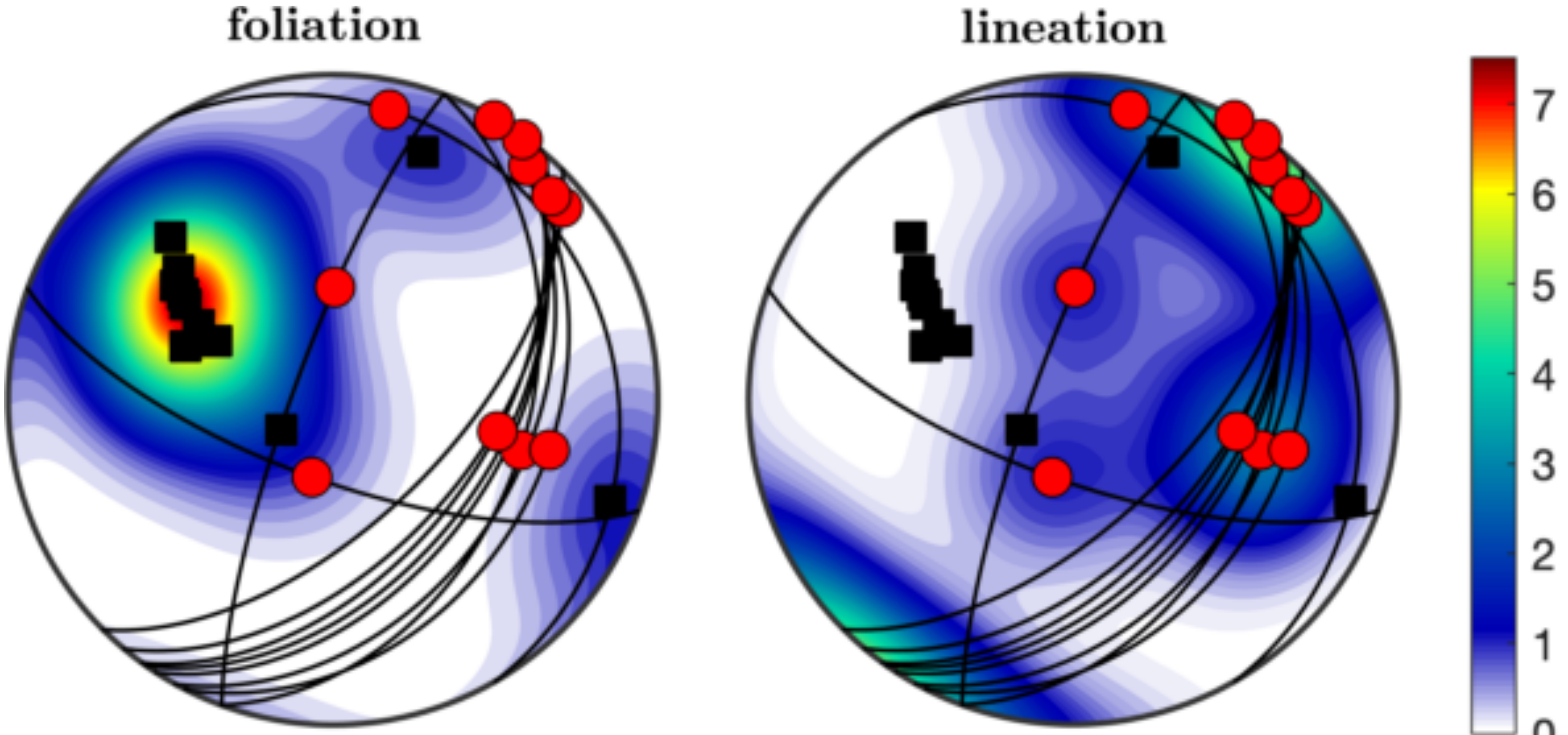
$a \neq b \neq c$

all angles 90°

Instead of lattice planes/directions, we substitute principal axes of the fabric ellipsoid (e.g., *X*, *Y*, *Z*)

Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures orientational representation of fabric



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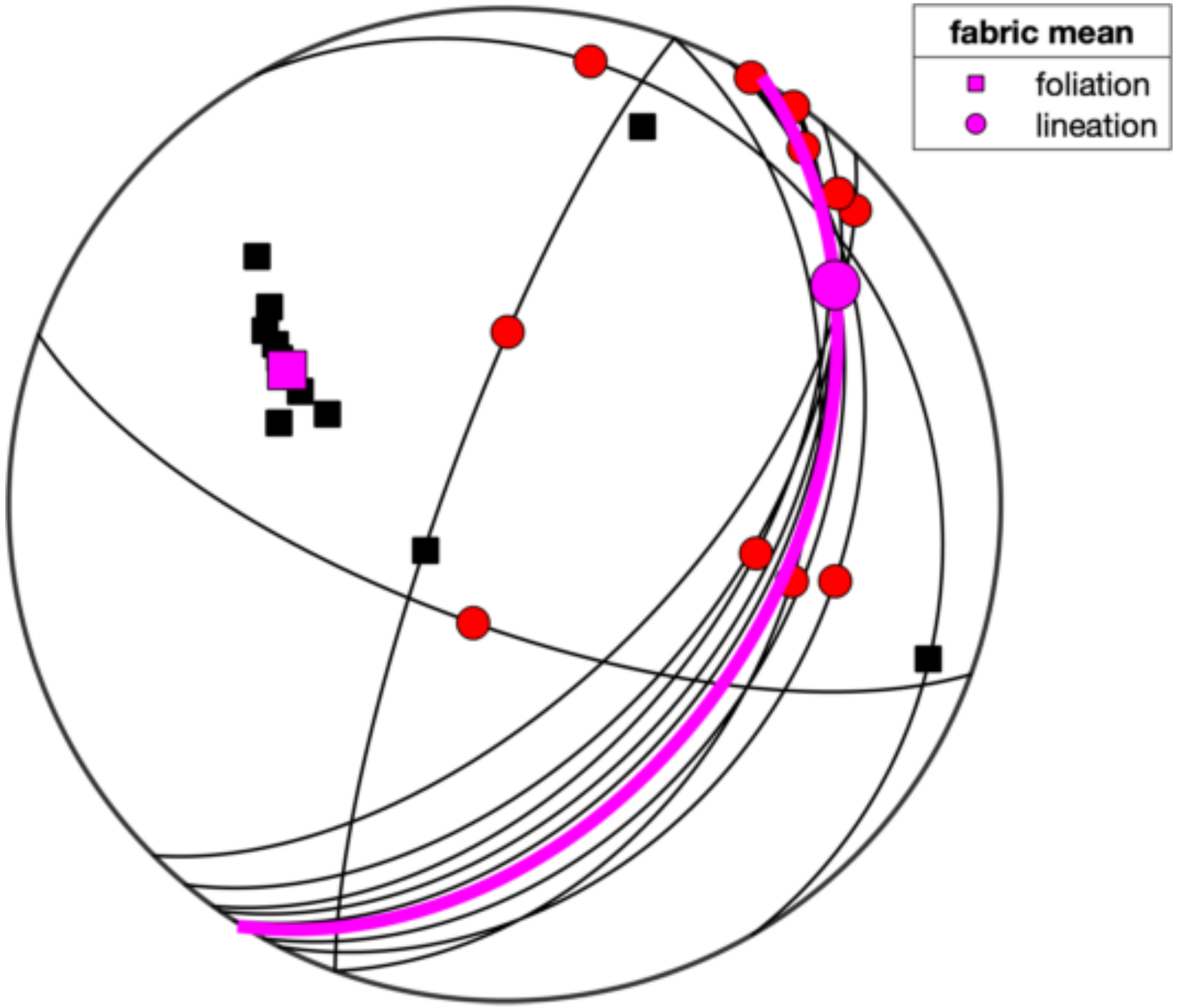
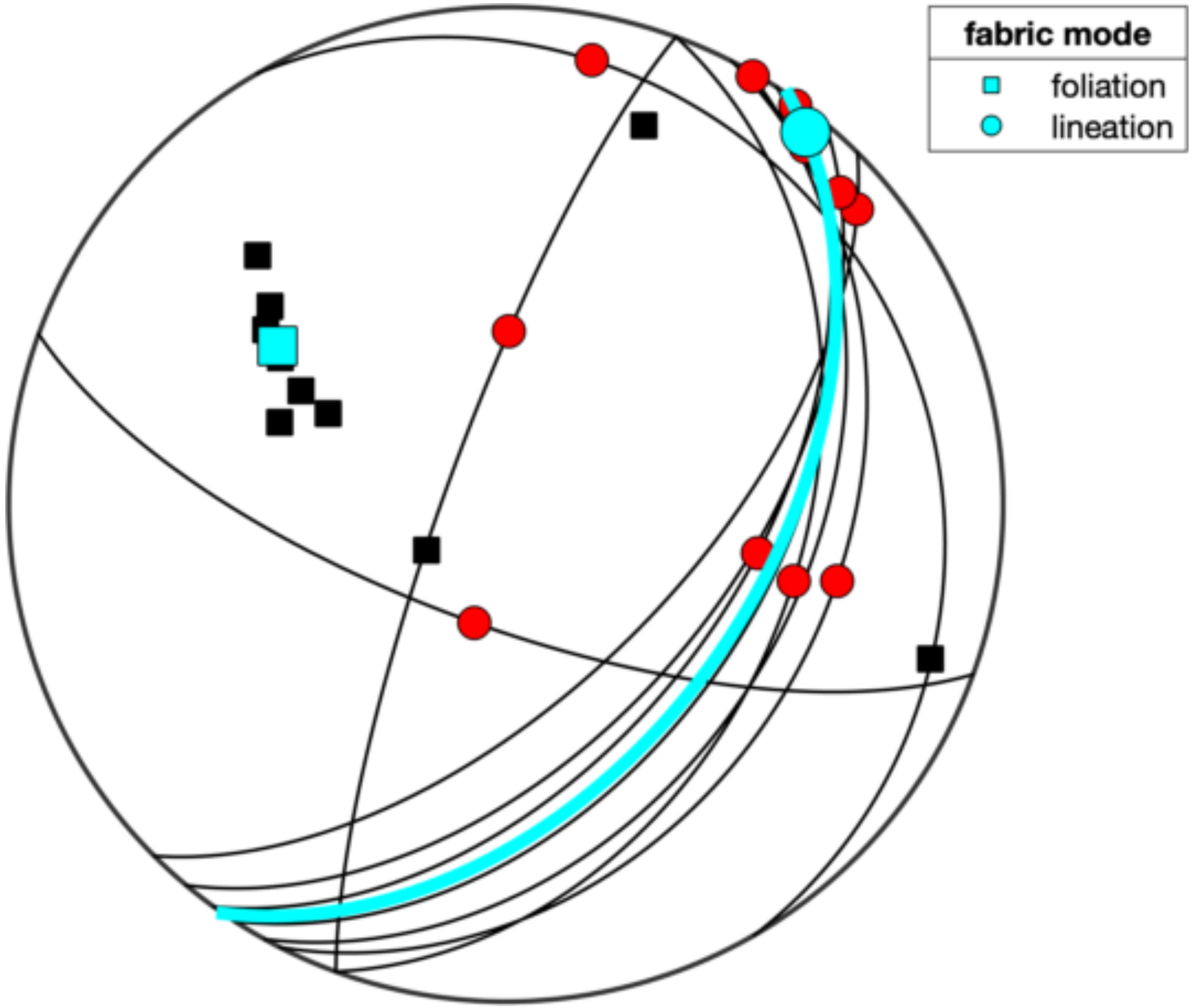
Field data in MTEX [geographic reference frame]

Fabric analysis of field-scale structures

Lineation always lies in the foliation plane





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Rotating Data

specimen vs geographic

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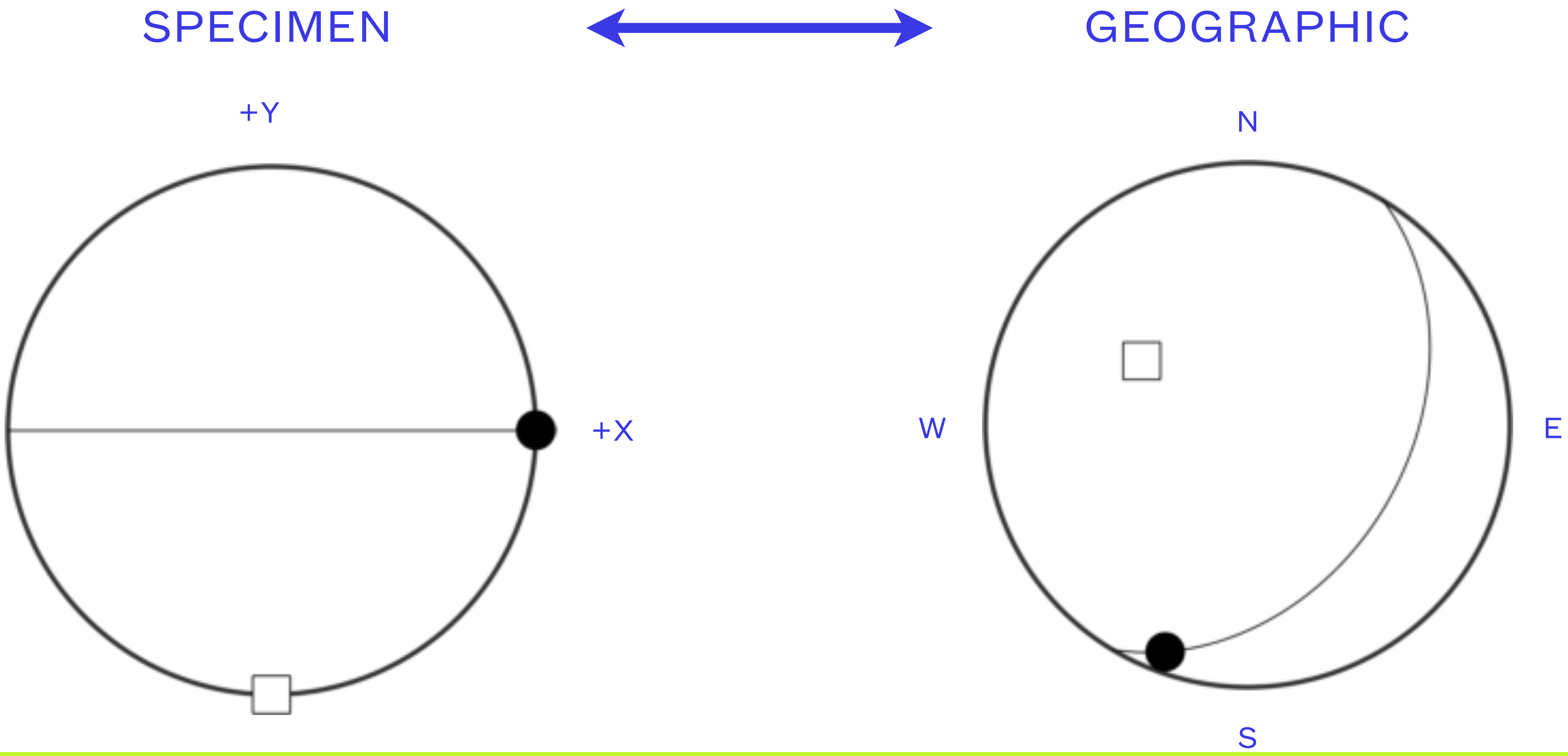
Field data in MTEX [geographic reference frame]

Relating microstructures to field structures

[specimen-to-geographic rotations]



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Field data in MTEX [geographic reference frame]

Relating microstructures to field structures

[specimen-to-geographic rotations]

SPECIMEN ⟷ GEOGRAPHIC

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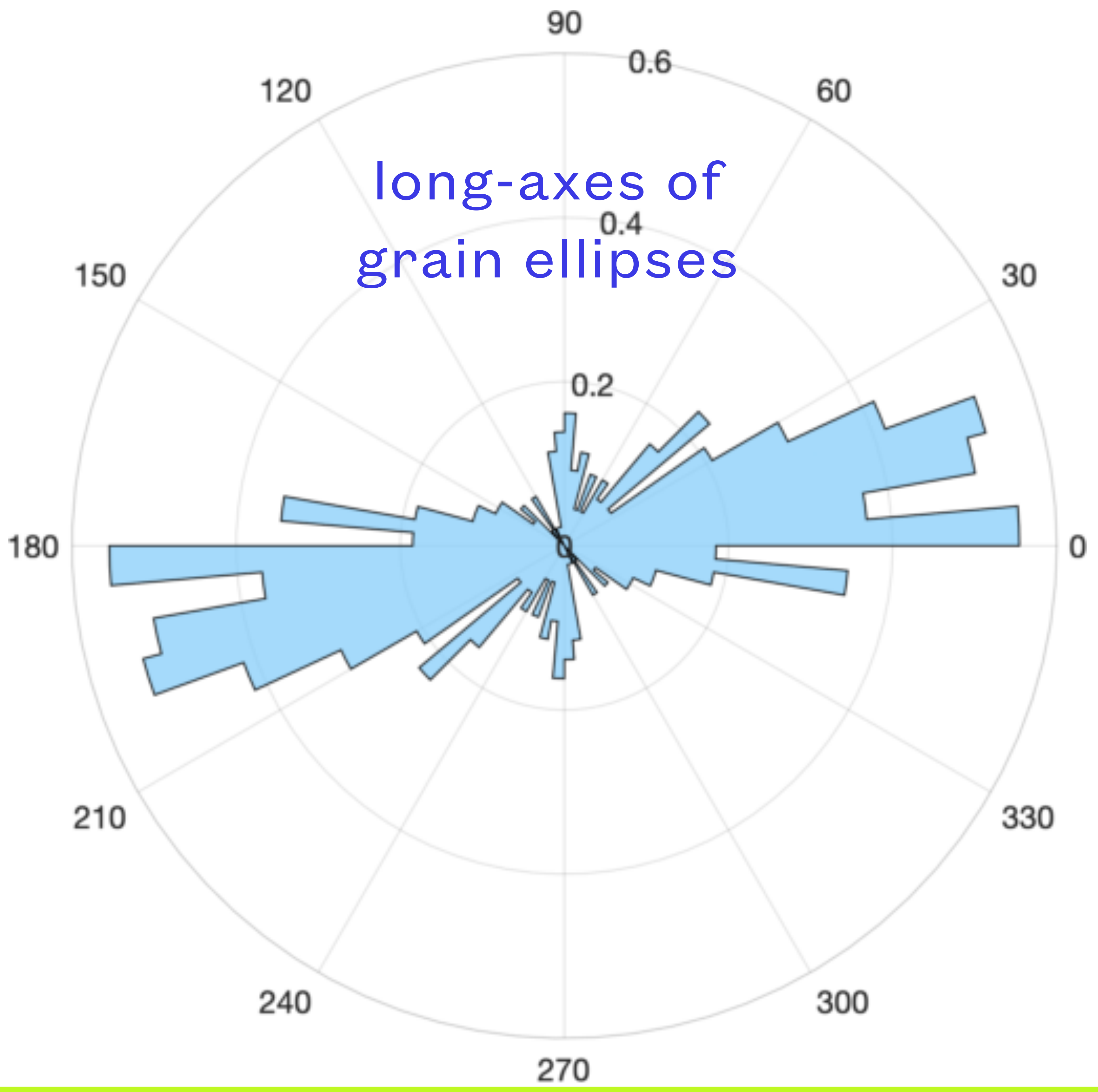
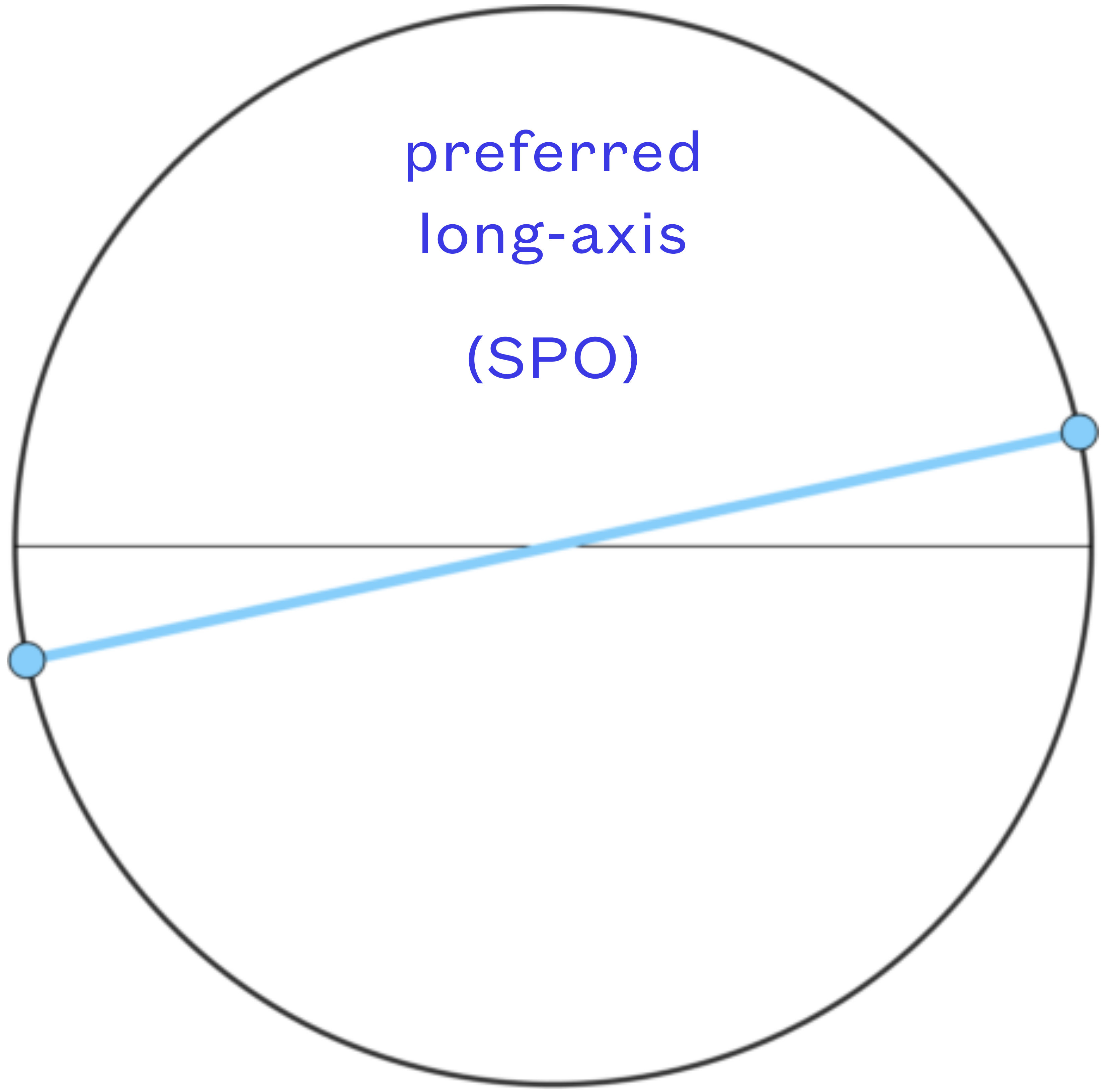
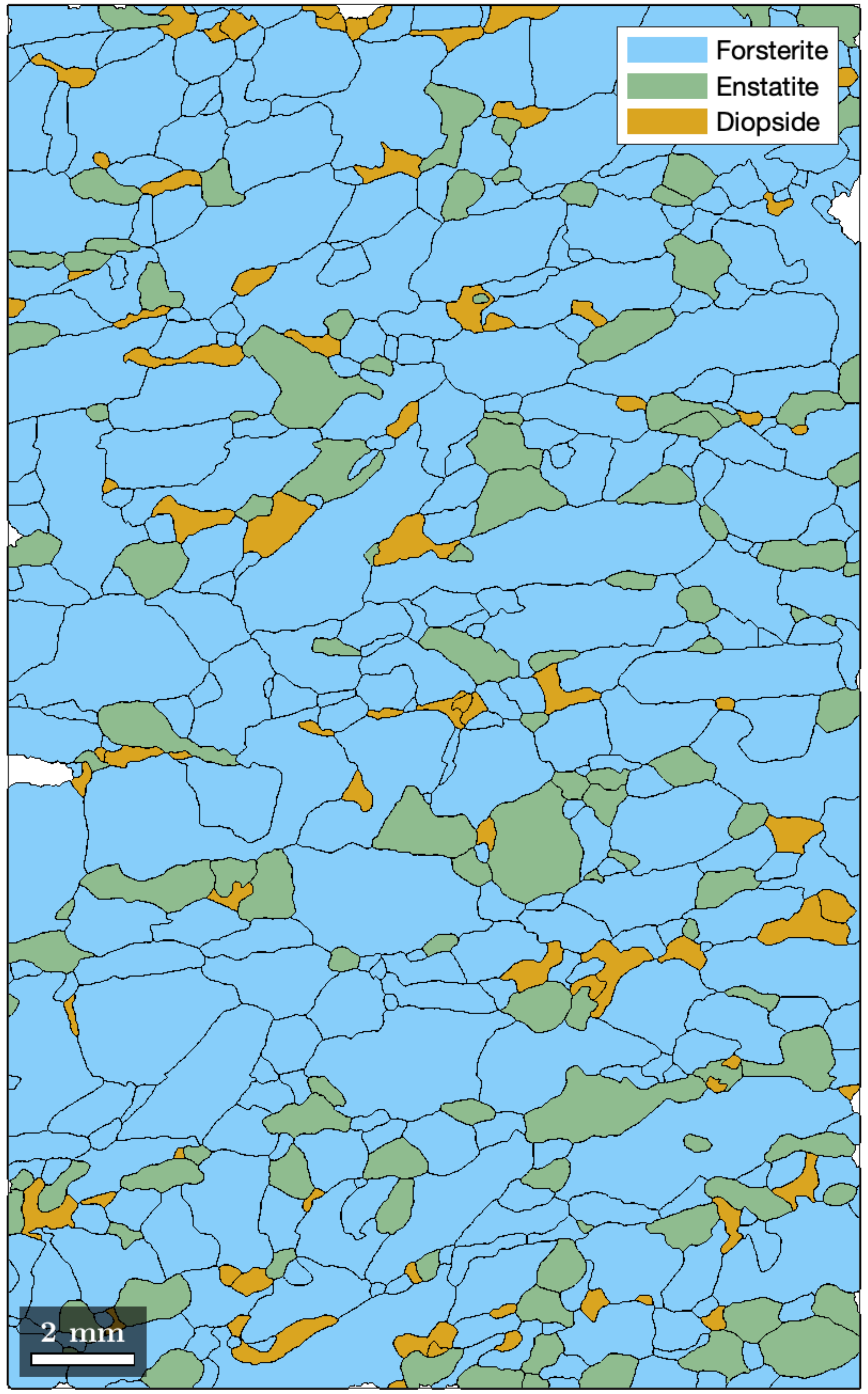
Field data in MTEX [geographic reference frame]

Relating microstructures to field structures

[specimen-to-geographic rotations]







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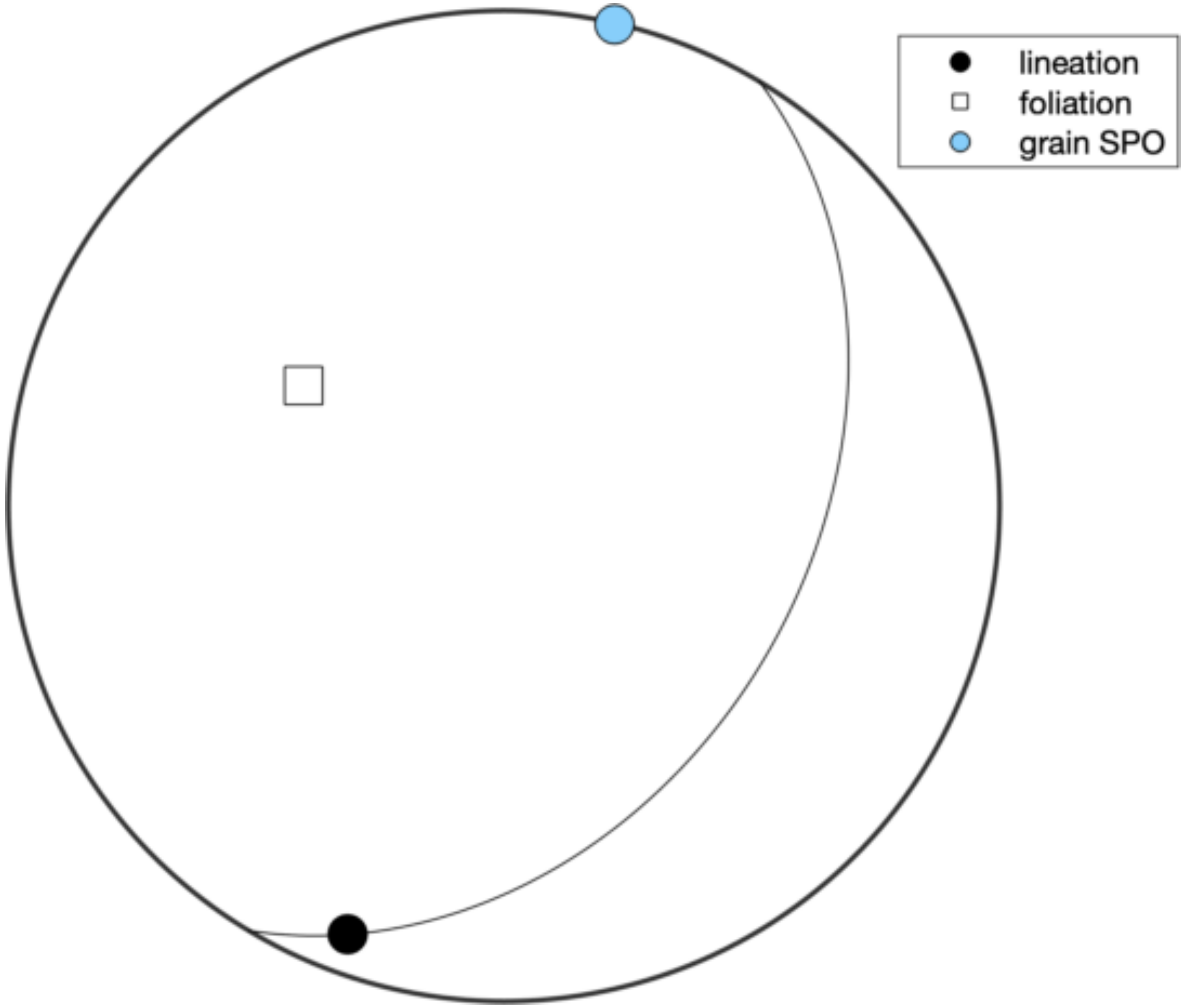
Field data in MTEX [geographic reference frame]

Relating microstructures to field structures

[specimen-to-geographic rotations]

The geographic reference frame can be very useful. It provides a unifying framework to define other relevant reference frames.



Example: First rotate to geographic, then relative to a shear zone boundary

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Field data in MTEX [geographic reference frame]

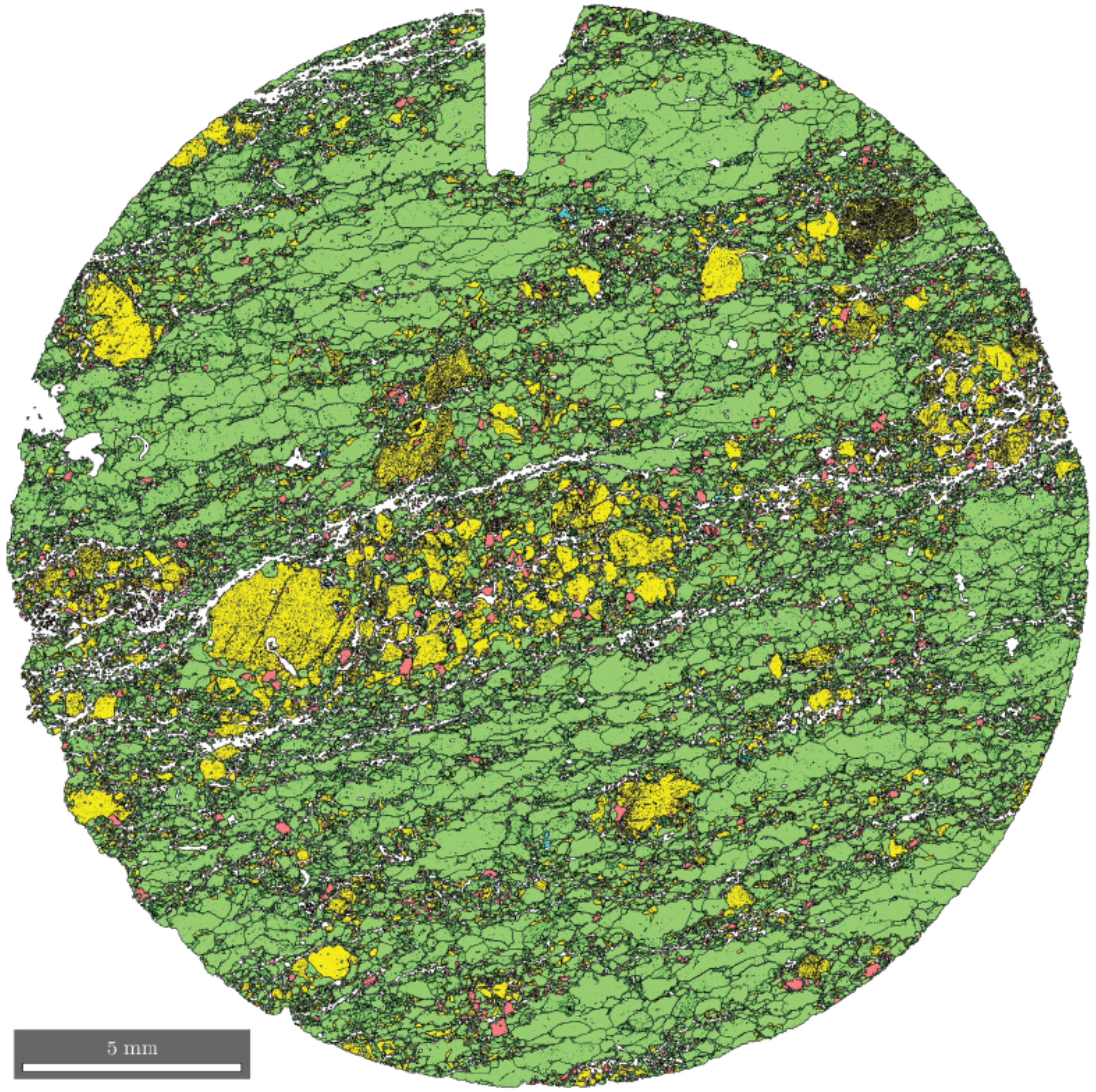
Relating microstructures to field structures

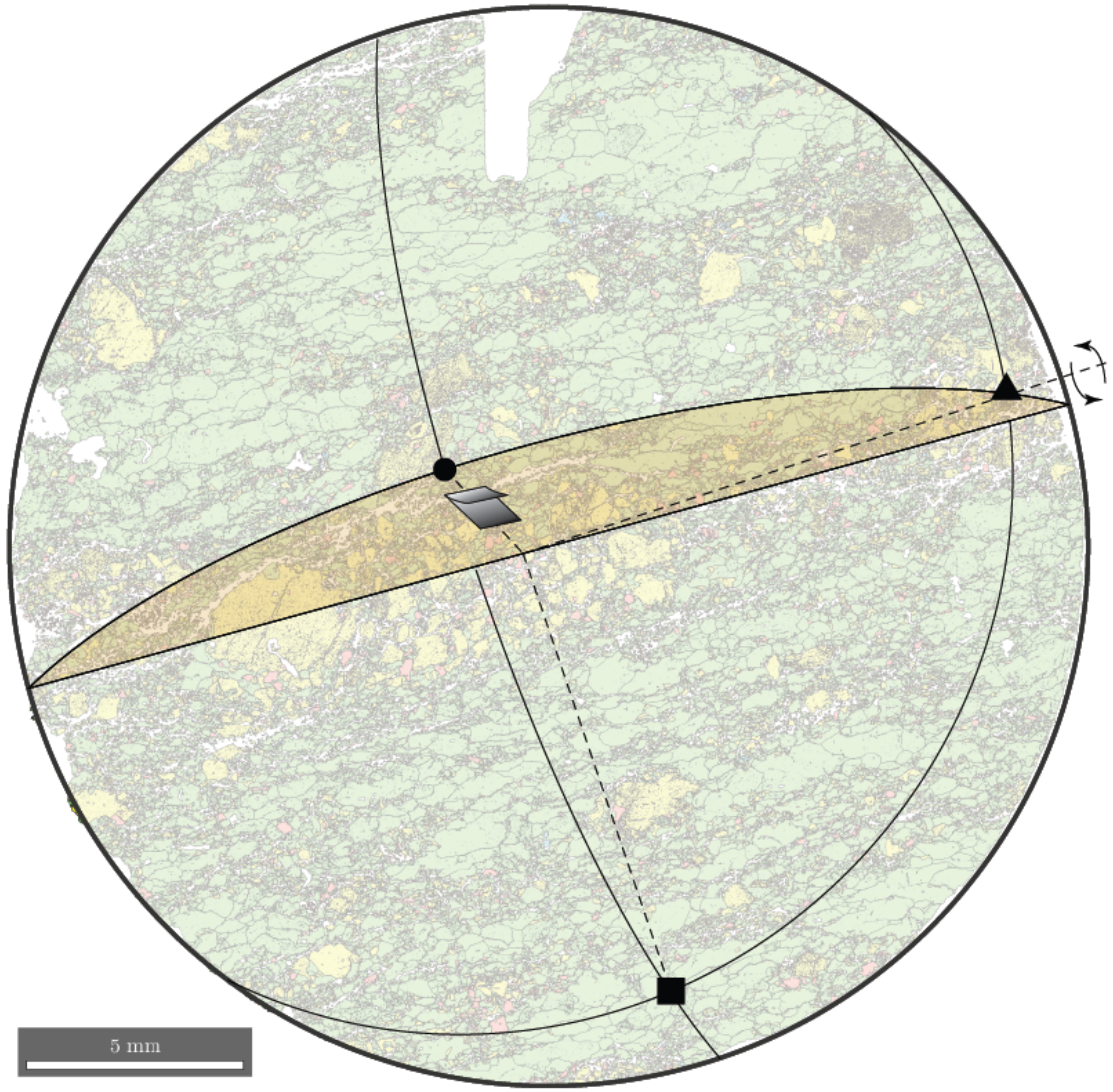
[linking reference frames]

Drill core:

Red Mountain, NZ

The geographic orientation of the core and the fabric link the fabric to the EBSD map.





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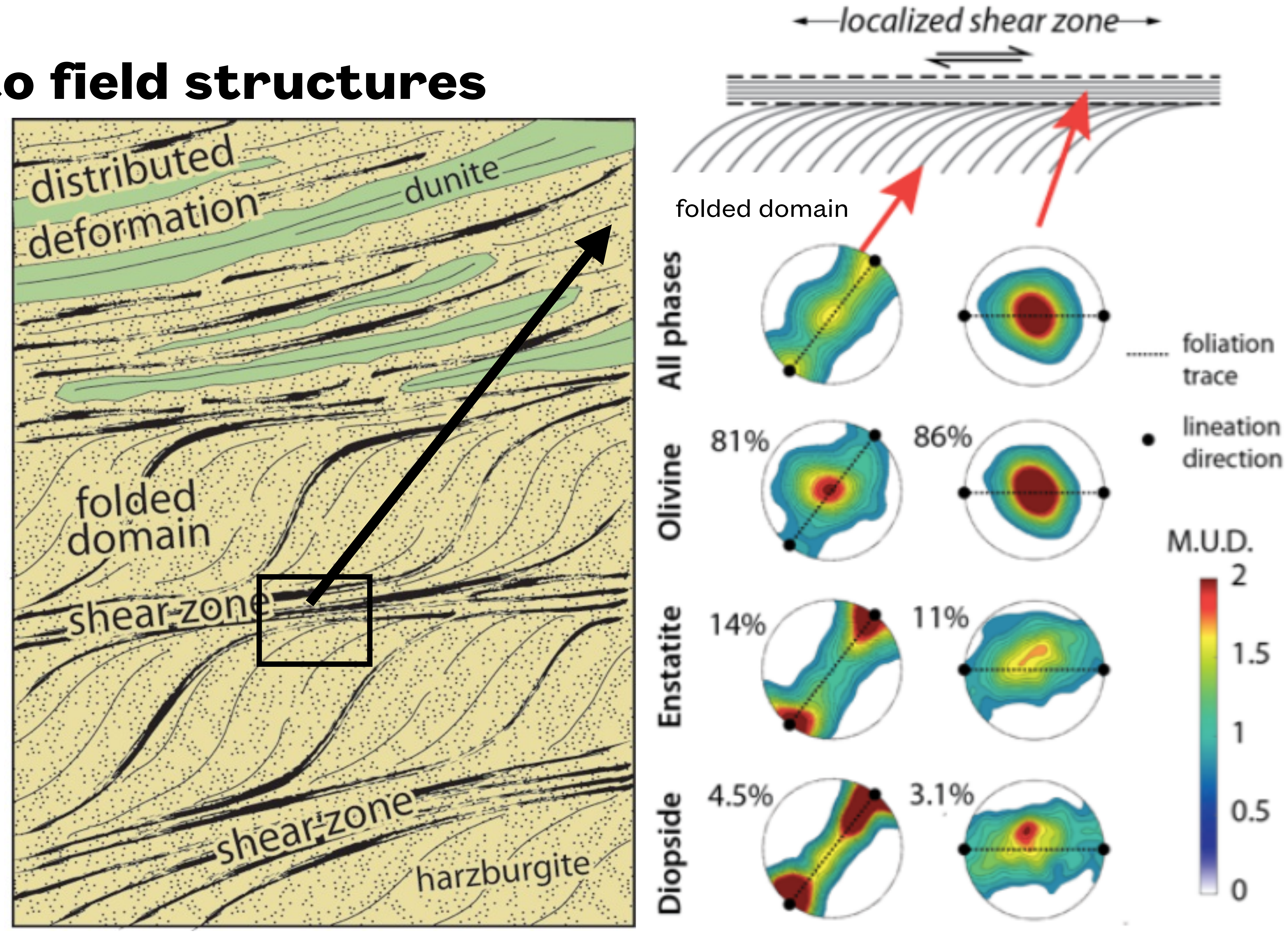
Field data in MTEX [geographic reference frame]

Relating microstructures to field structures

[linking reference frames]

Reorient/rotate any data to a common structural or kinematic reference frame.



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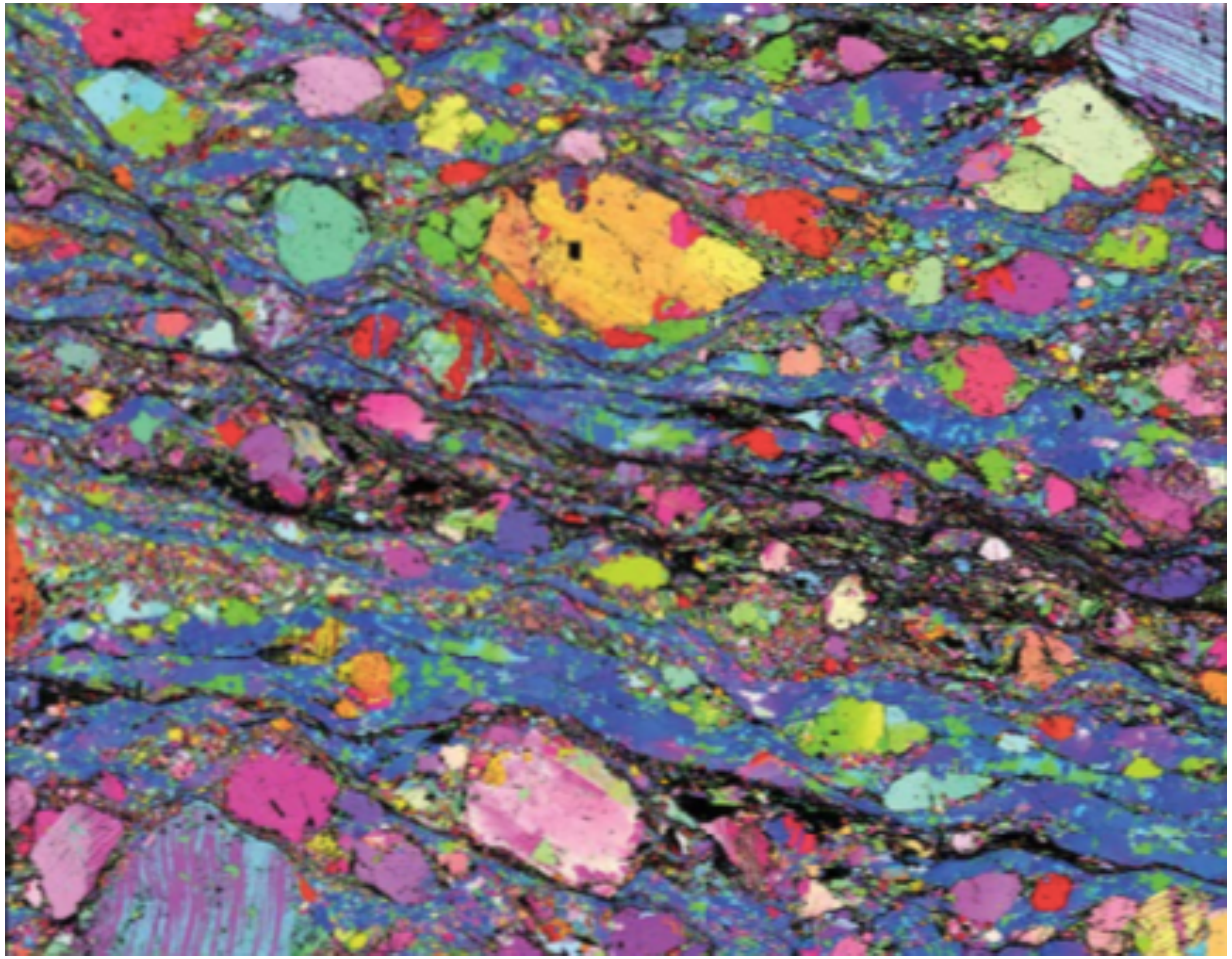
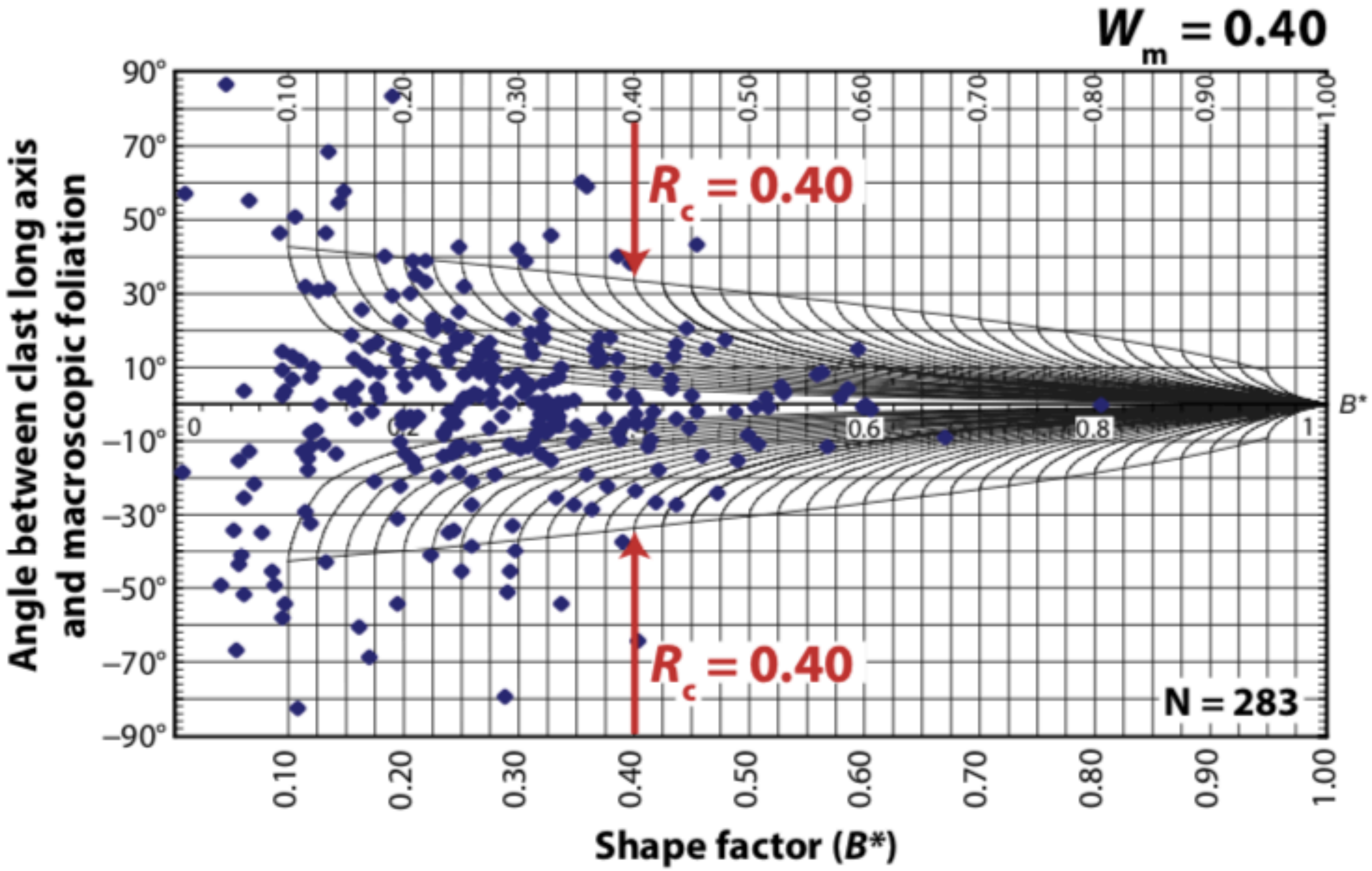
Kruckenberg et al. (2019)

Rotating the orientation of the flow apophyses back to geographic coordinates, we constrain the paleo tectonic convergence vector trending ~142-160° and plunging ~3-10°.

Field data in MTEX [geographic reference frame]

MTEX + EBSD + Matlab





Kruckenberg et al. (2019)

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Combining Datasets

appending properties of EBSD and grain2D

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Interpolating datasets together

EBSD for microstructure + other datasets

- An example combining overlapping EBSD and CL maps
  - Thank you to Jennifer Taylor (U of MN)
- Workflow:
  - Crop CL image and EBSD map to identical region
  - Use a gridded interpolant to resample/downsample the CL image at all xy-coordinates of points in the EBSD dataset
    - result is one CL value per EBSD data point
  - Compute grains using the ebsd orientations
  - Compute mean CL value per grain
  - Compare various grain-scale features with mean CL value

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Interpolating datasets together

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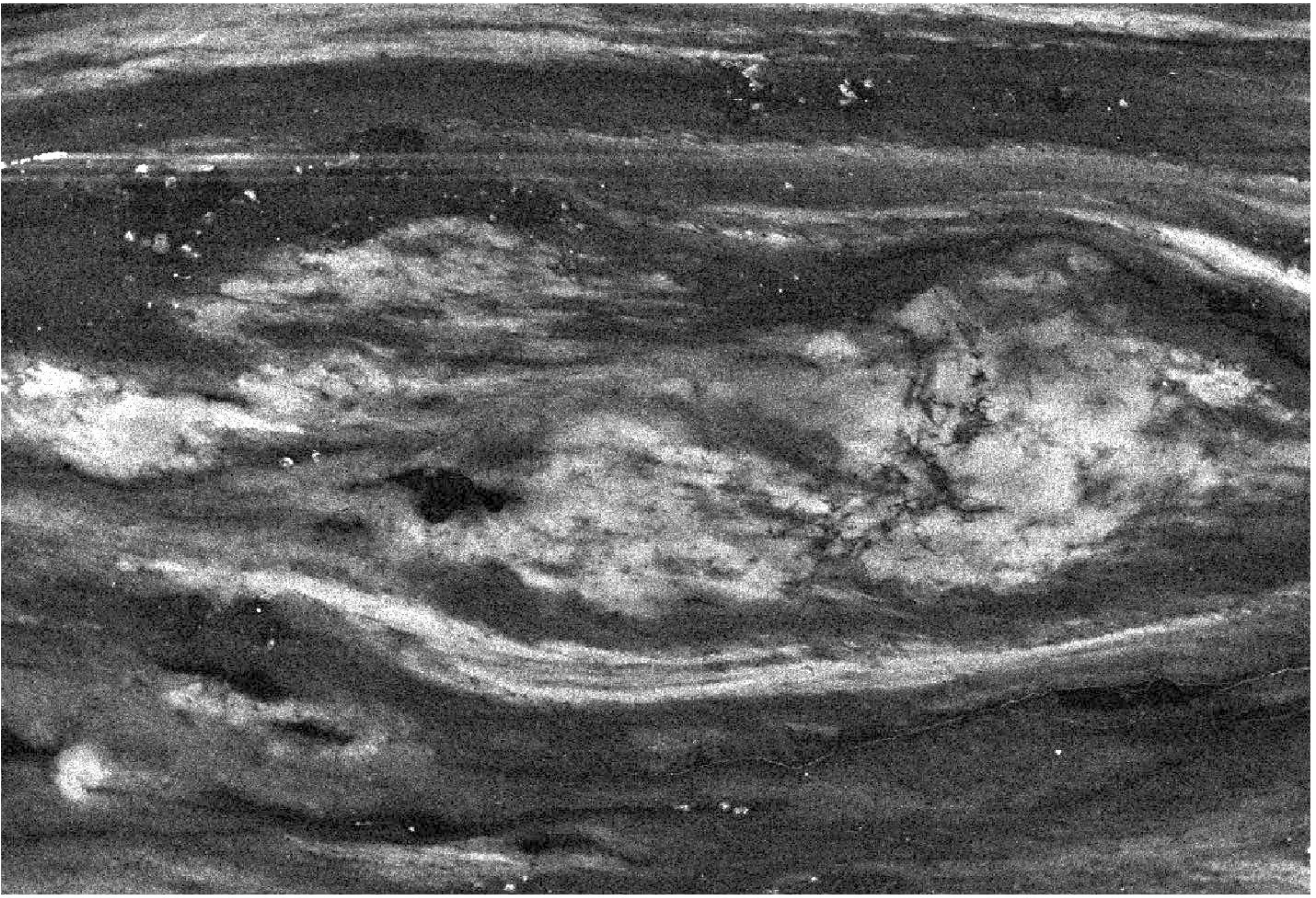
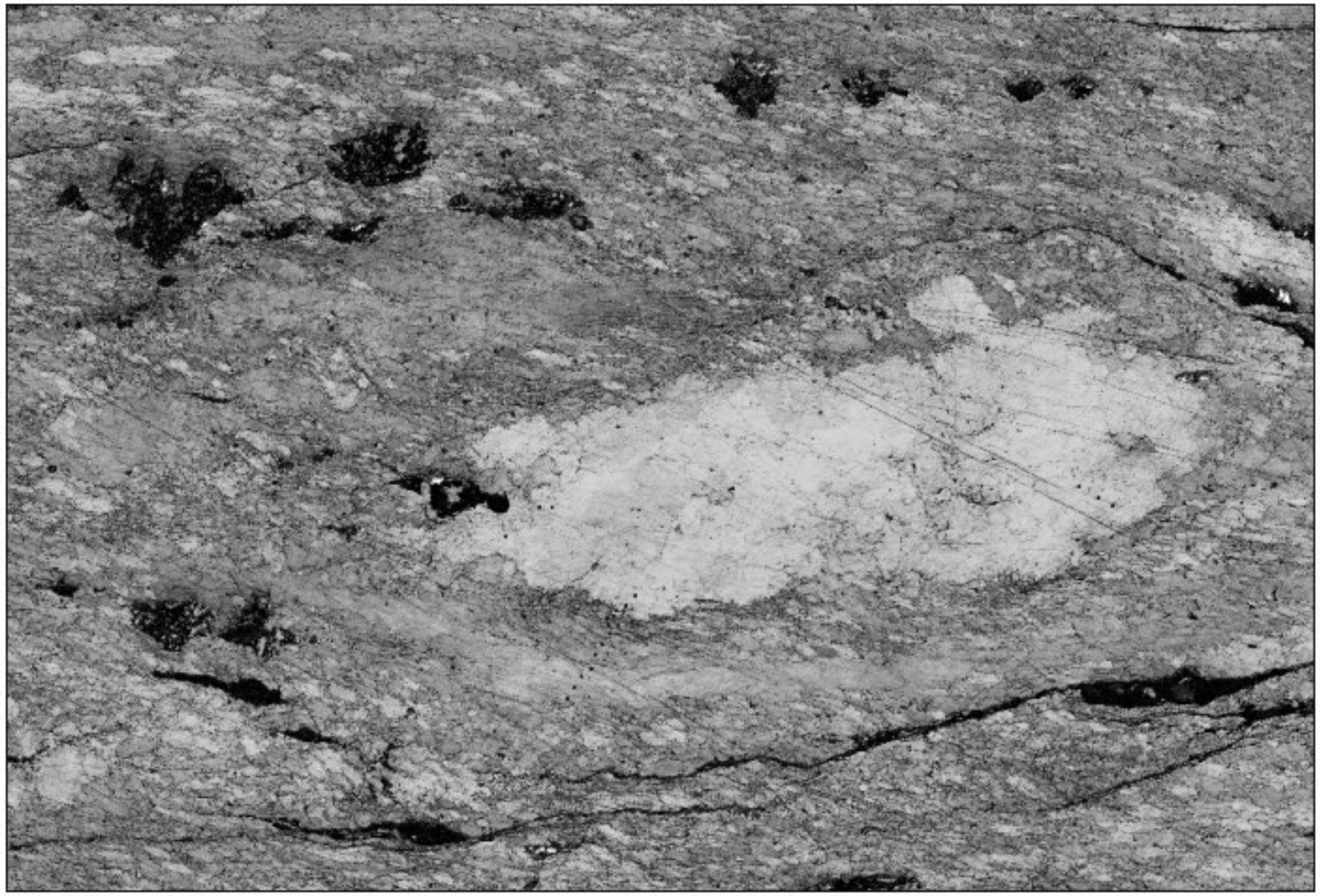
Interpolating datasets together

Cathodoluminescence



Band Contrast (EBSD)



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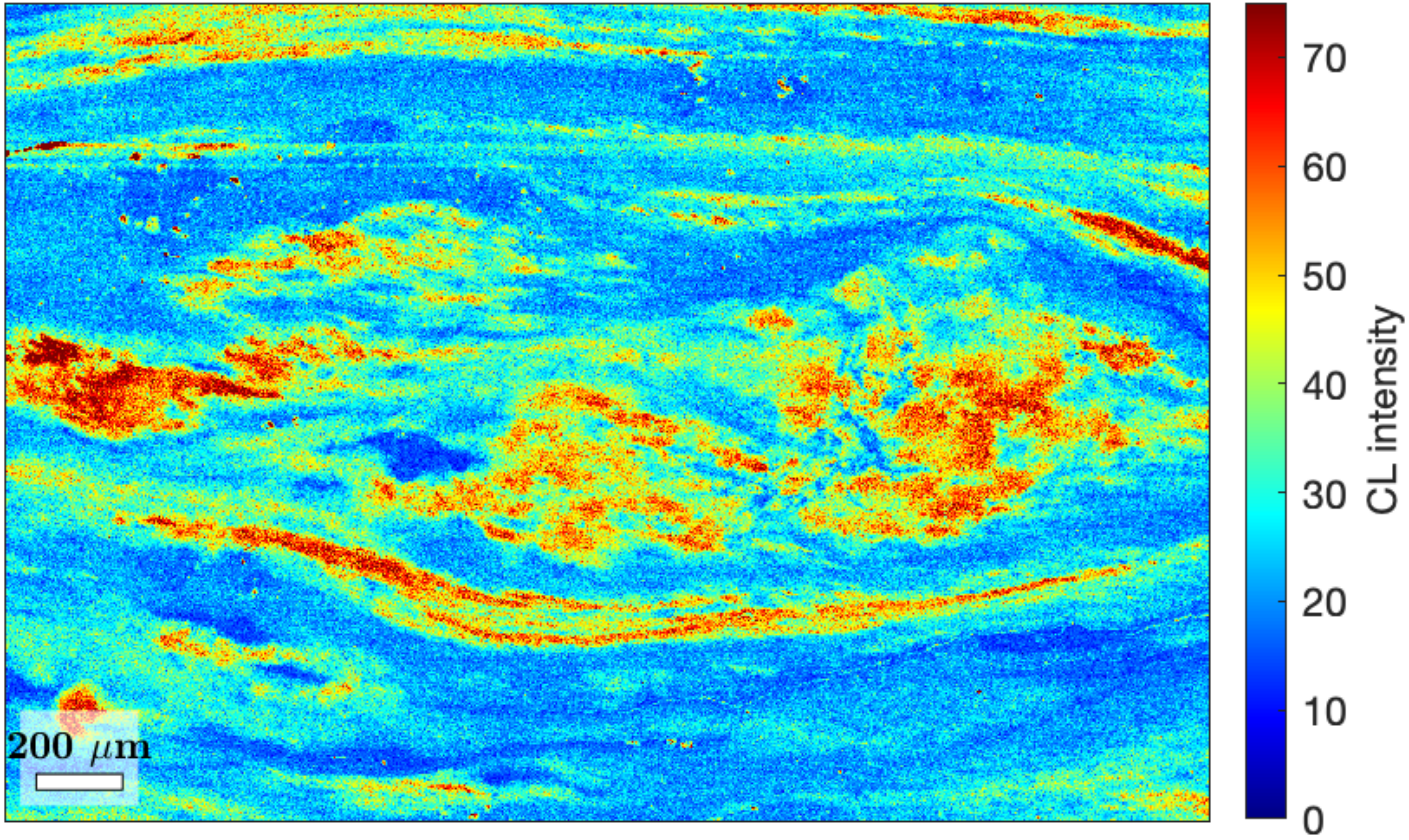
Interpolating datasets together



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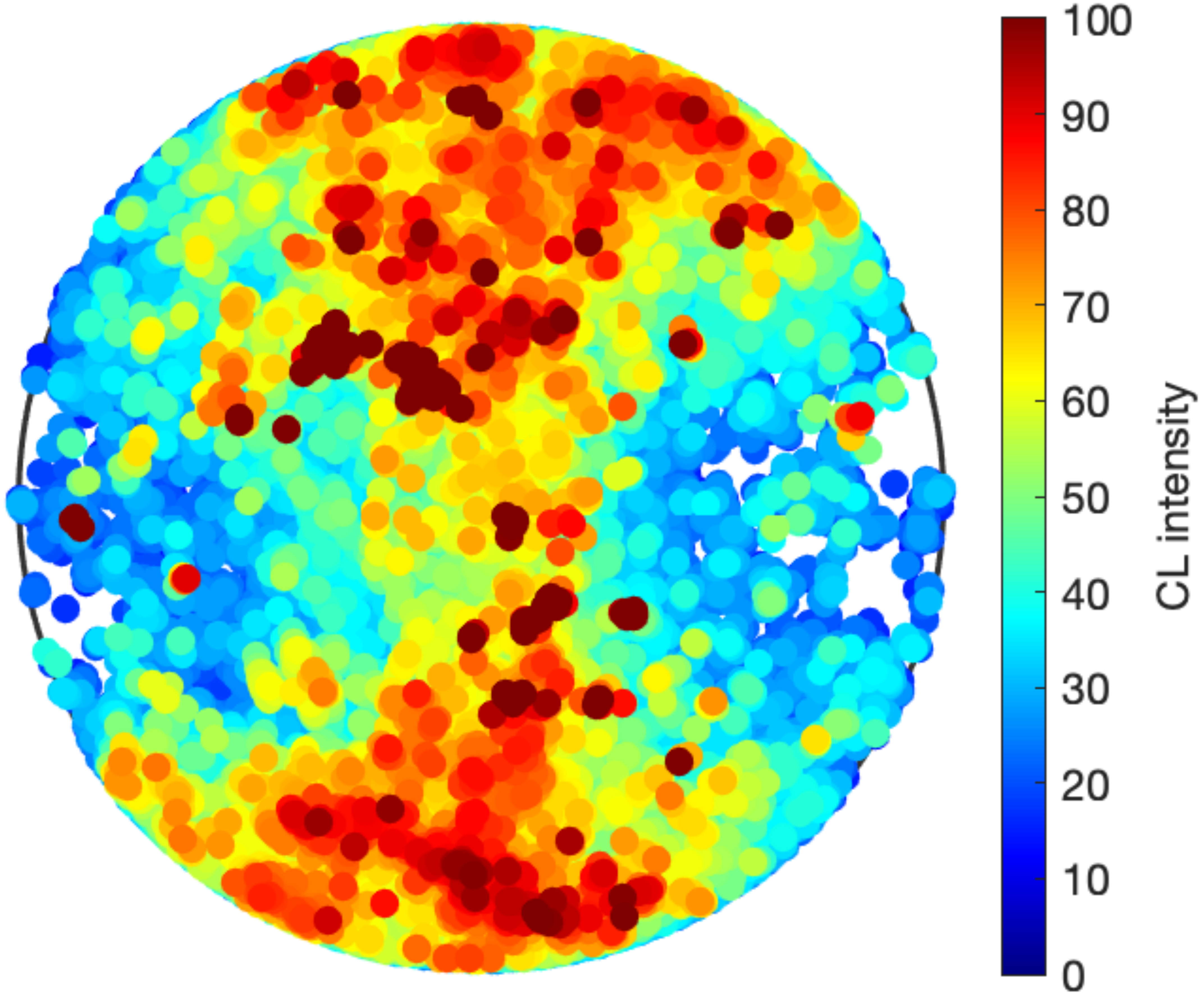
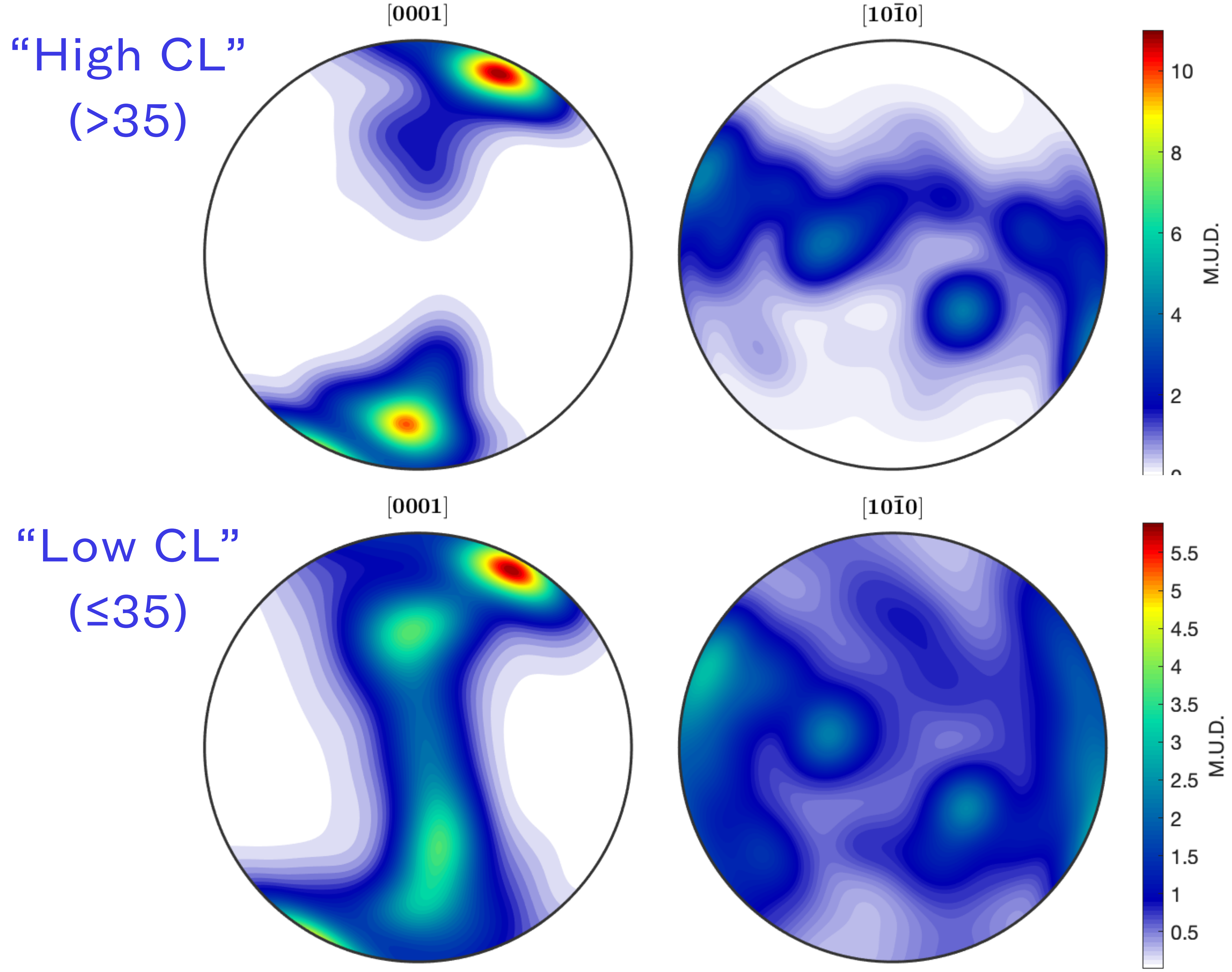
Interpolating datasets together

Quartz c-axes
colored by CL value



Quartz pole figures
separated by CL threshold



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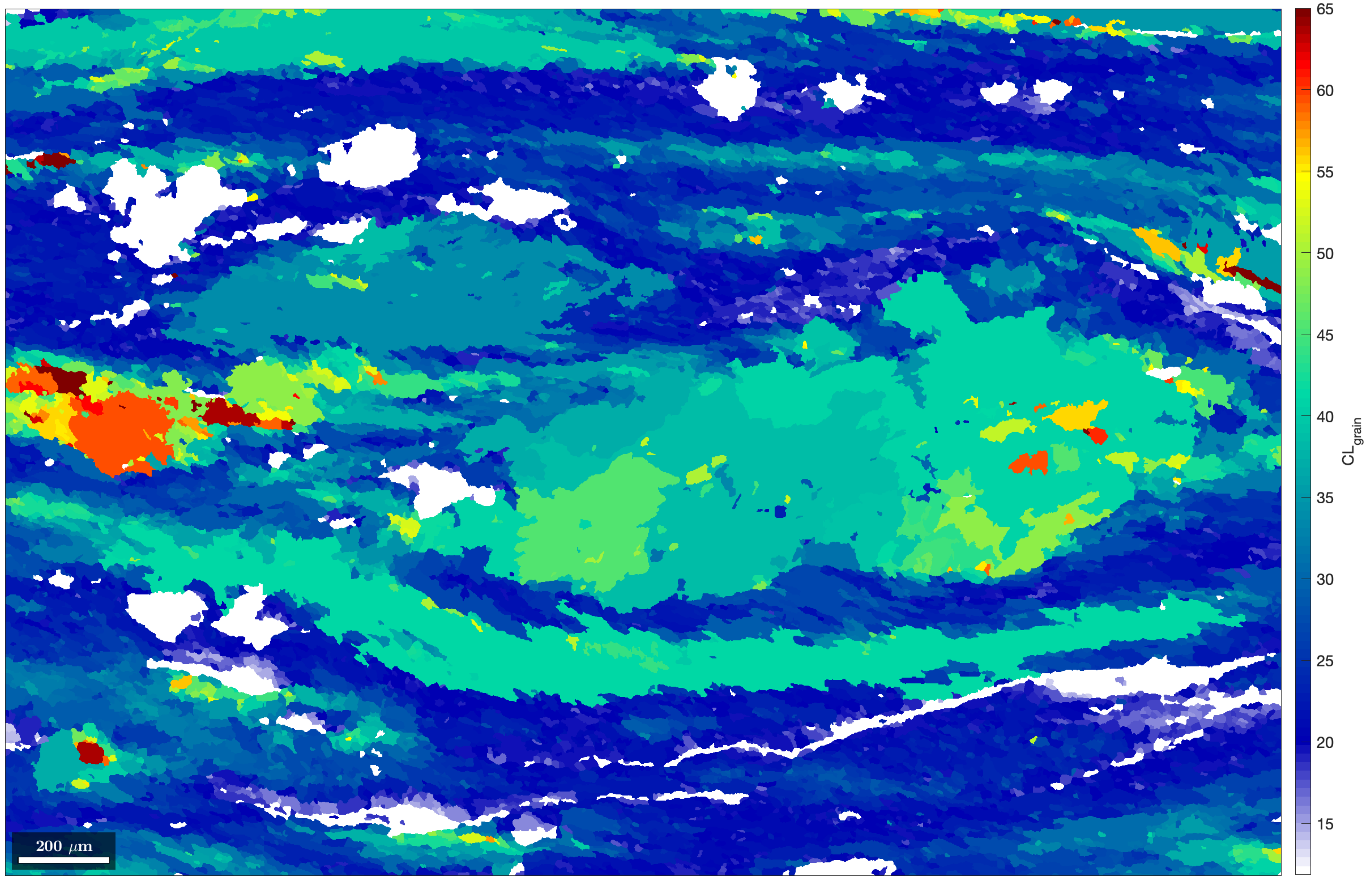
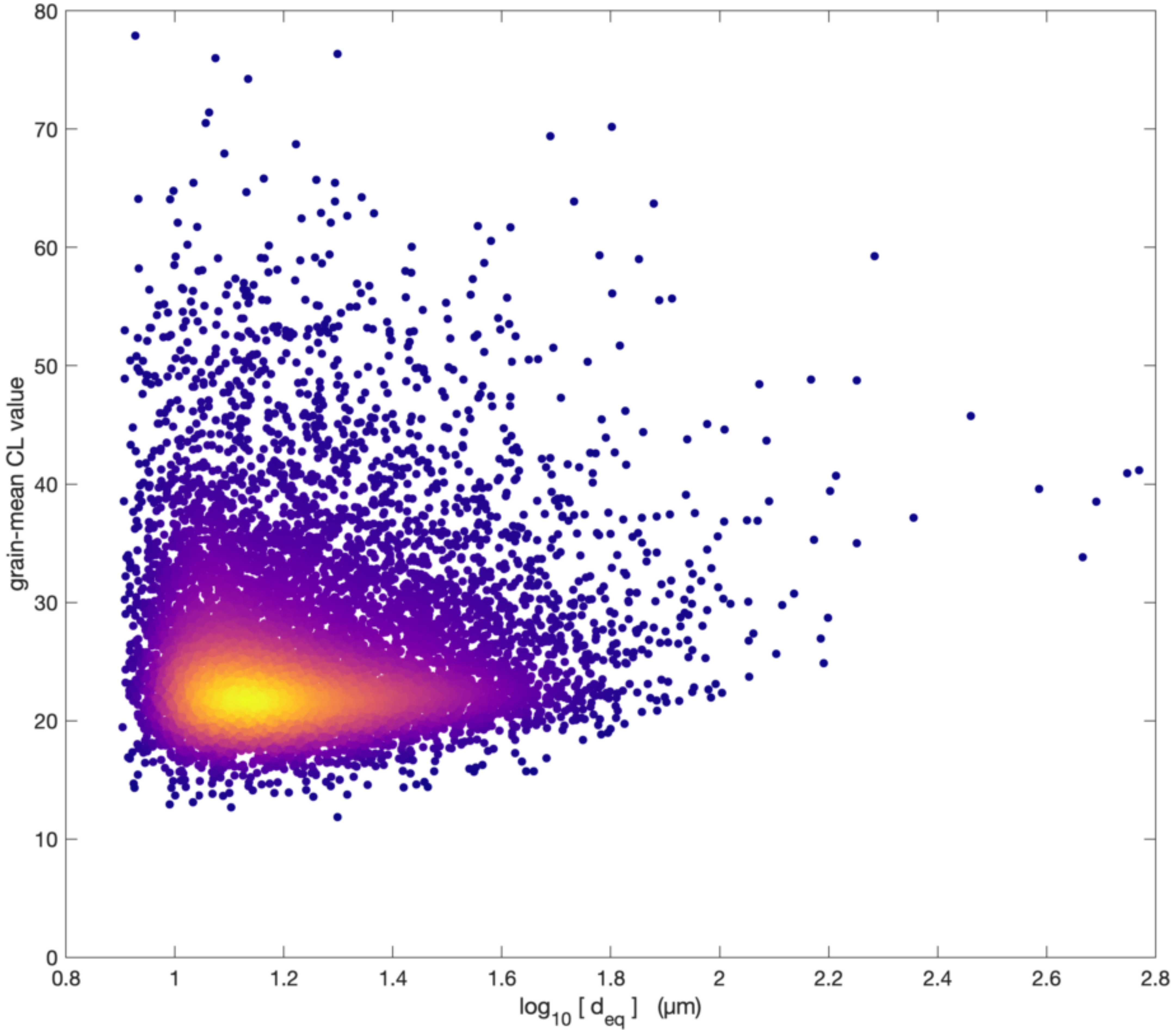
Interpolating datasets together

grain-mean CL value



mean-CL vs. diameter



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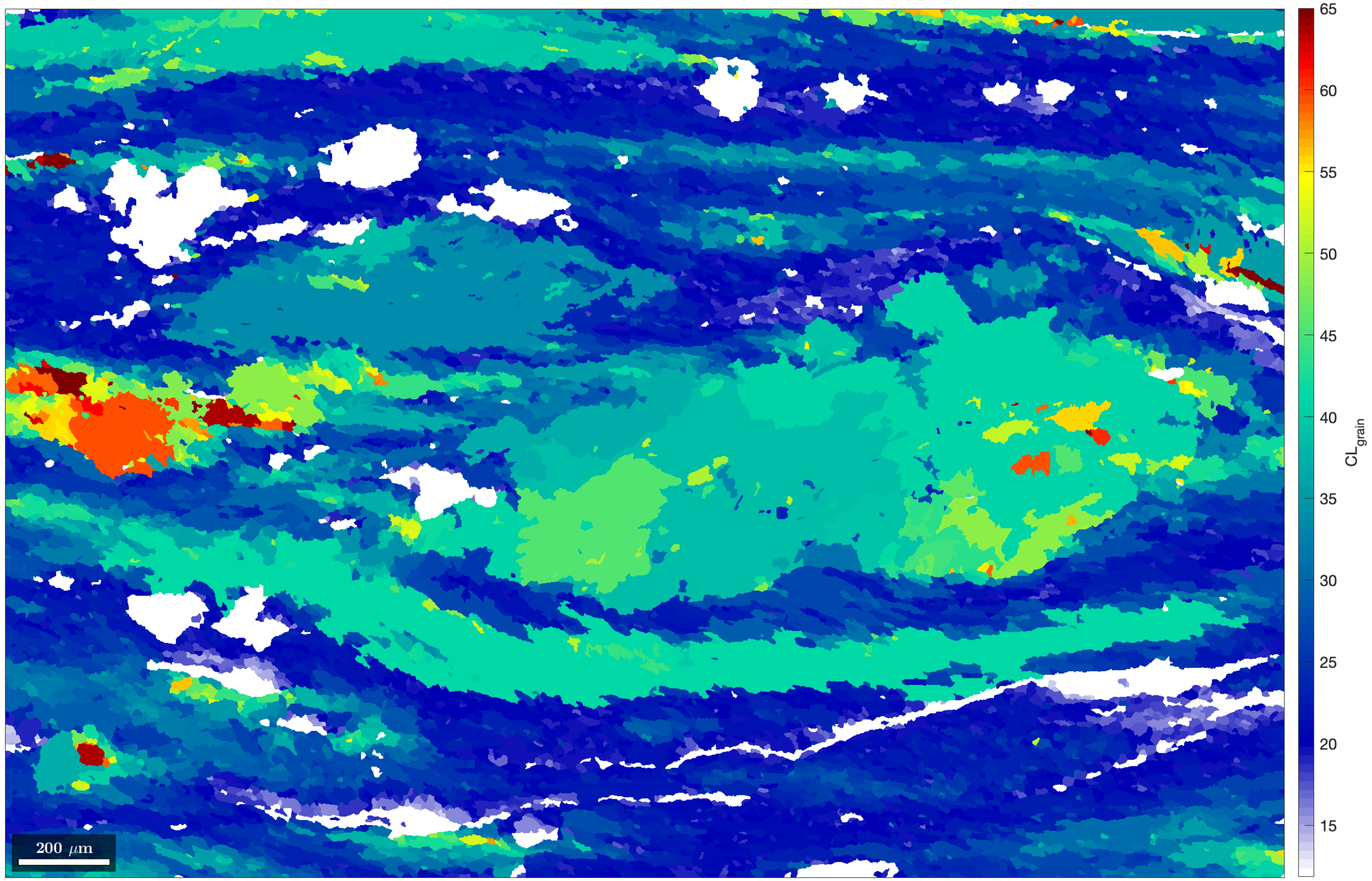
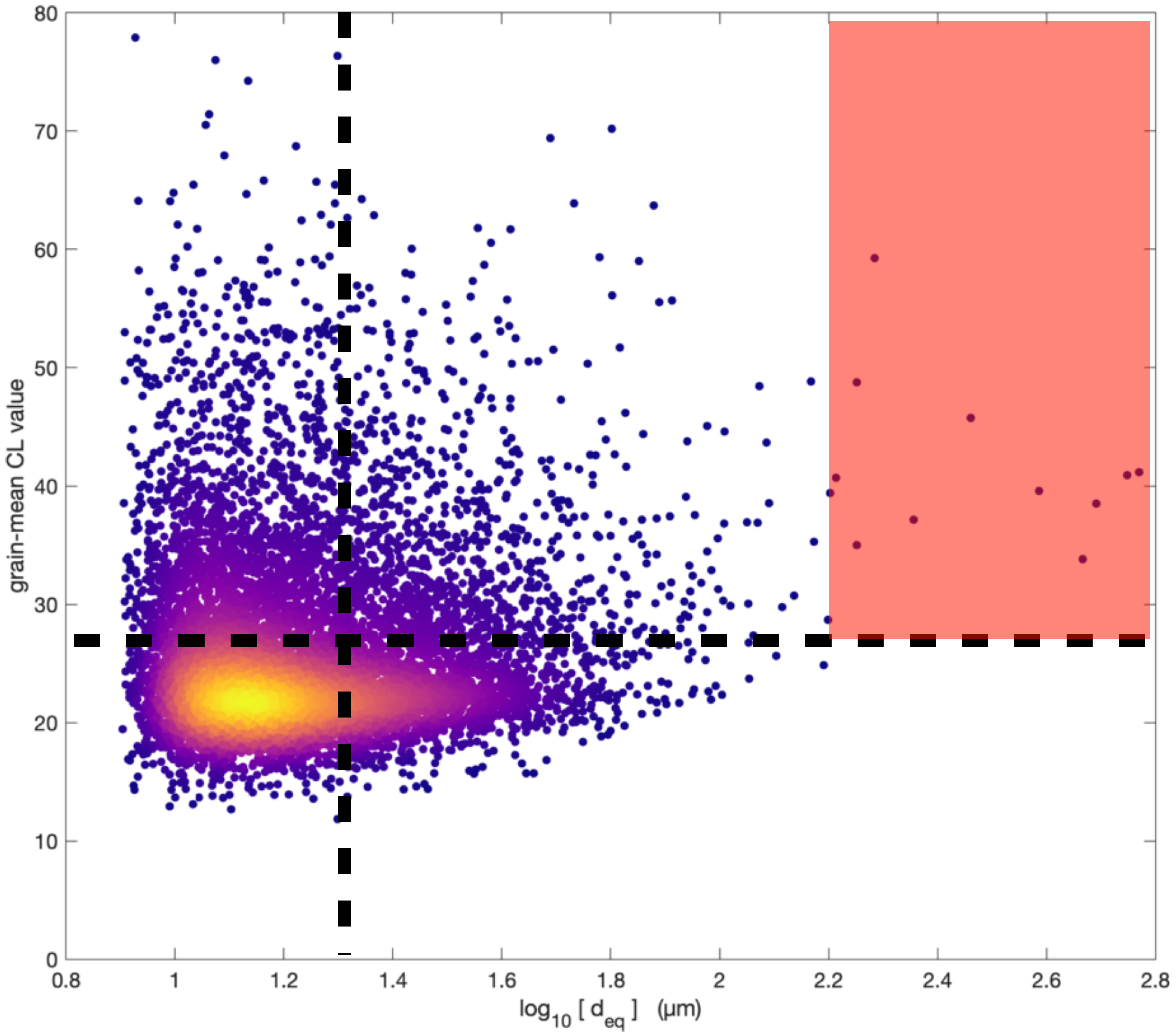
Interpolating datasets together

grain-mean CL value



mean-CL vs. diameter



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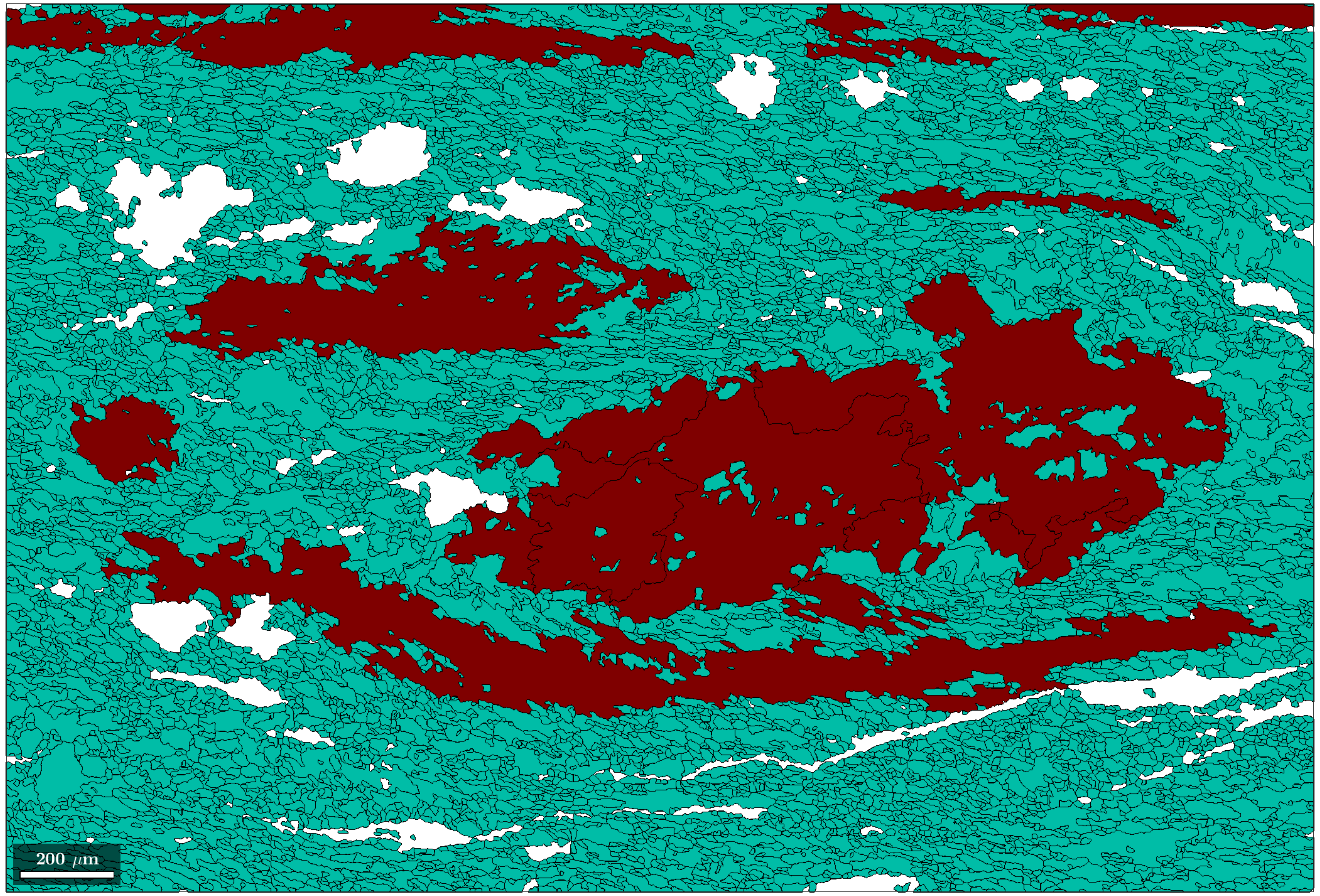
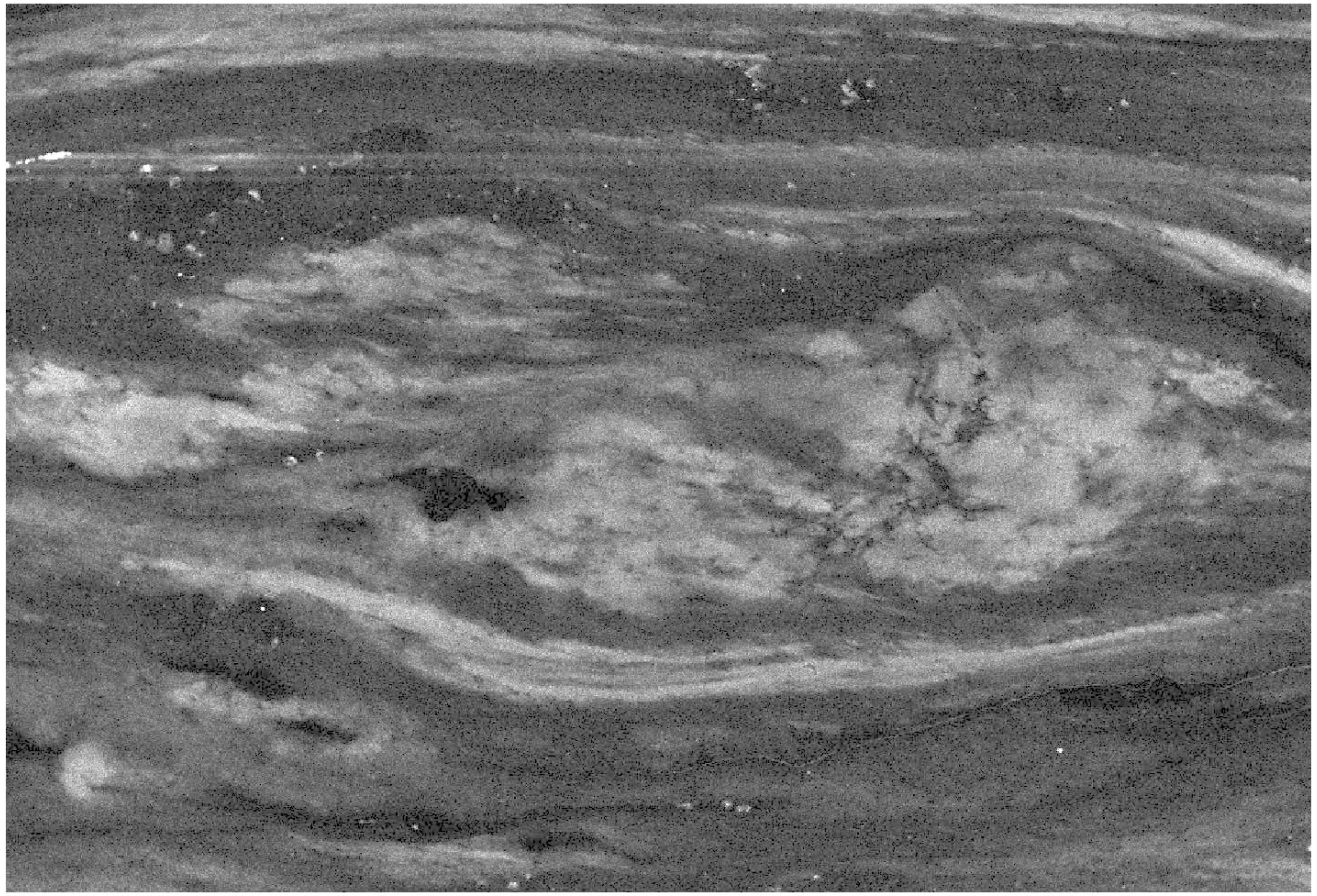
Interpolating datasets together

grains d ≥ 150 μm



original CL map



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Intragranular misorientation analysis

Grain Reference Orientation Deviation (a.k.a, Mis2Mean in MTEX)

- misorientation relative to grain's mean orientation
- great for spatial plots to visualize intragranular distortion
- not ideal for slip-system analysis because no spatial connection

Boundary misorientations

- neighbor-to-neighbor misorientation
- misorientations across discrete boundaries
    - plot axes distributions in crystal reference frame
        - infer slip systems?
    - plot axes in specimen reference frame
        - infer slip kinematics?

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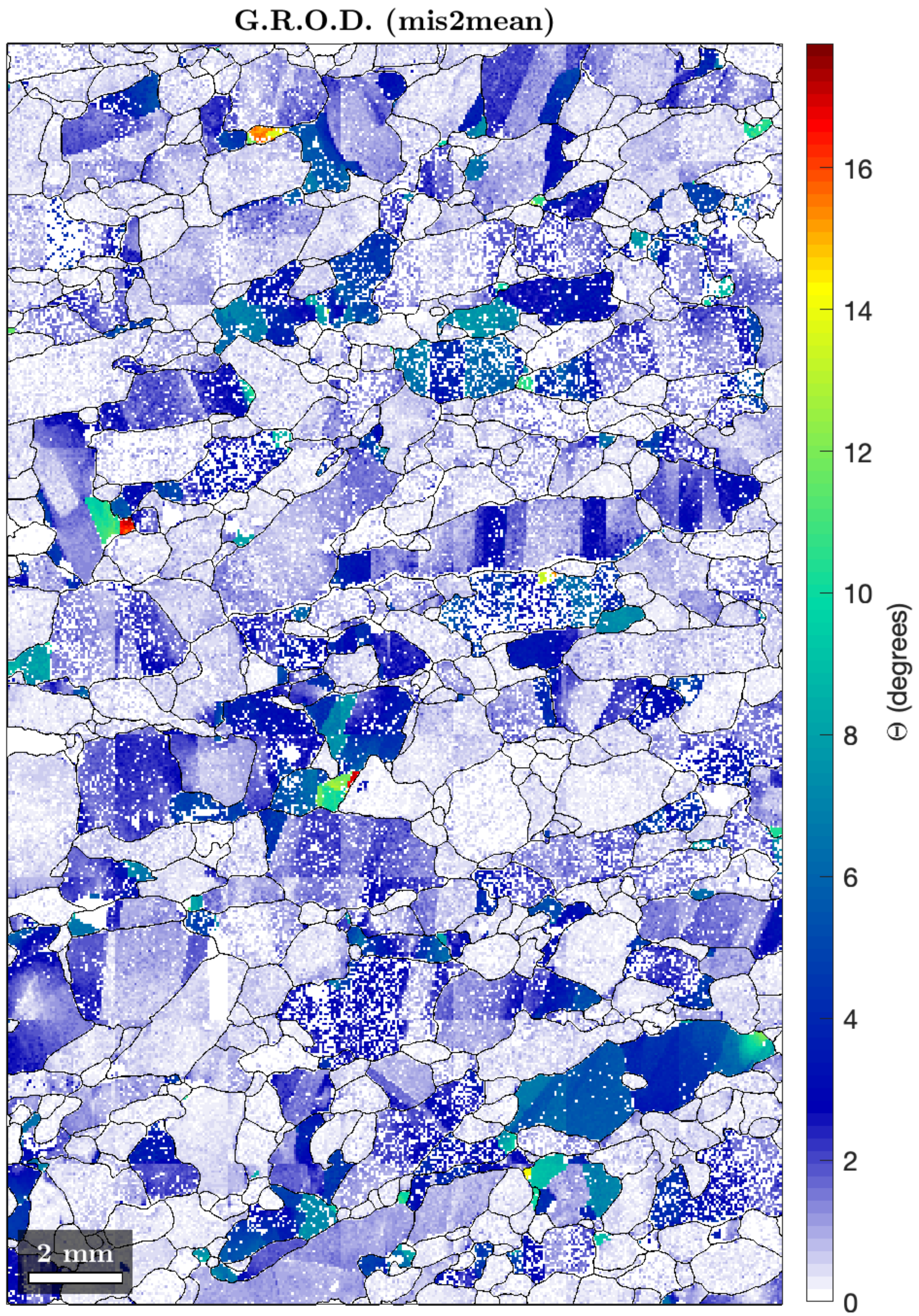
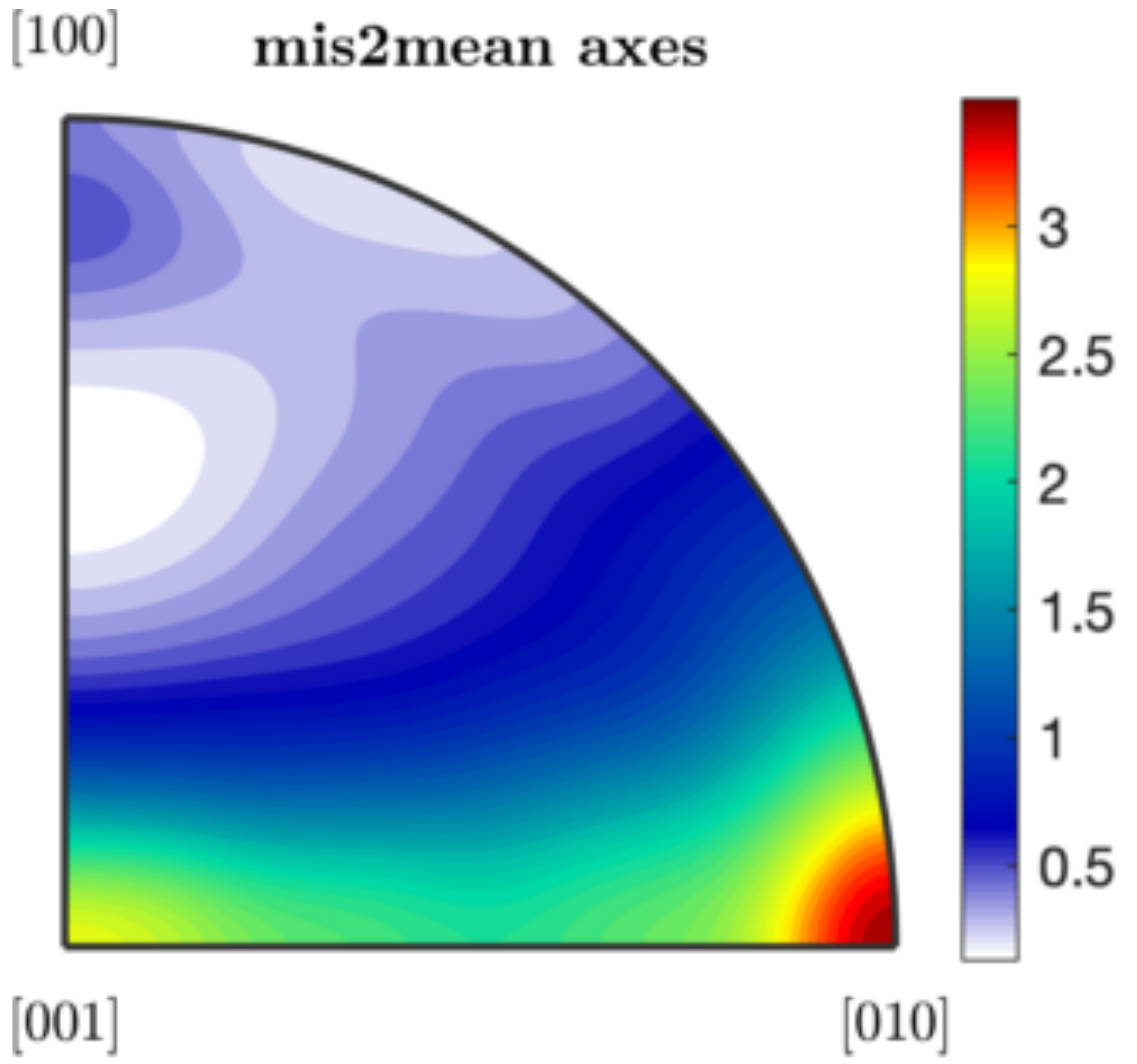
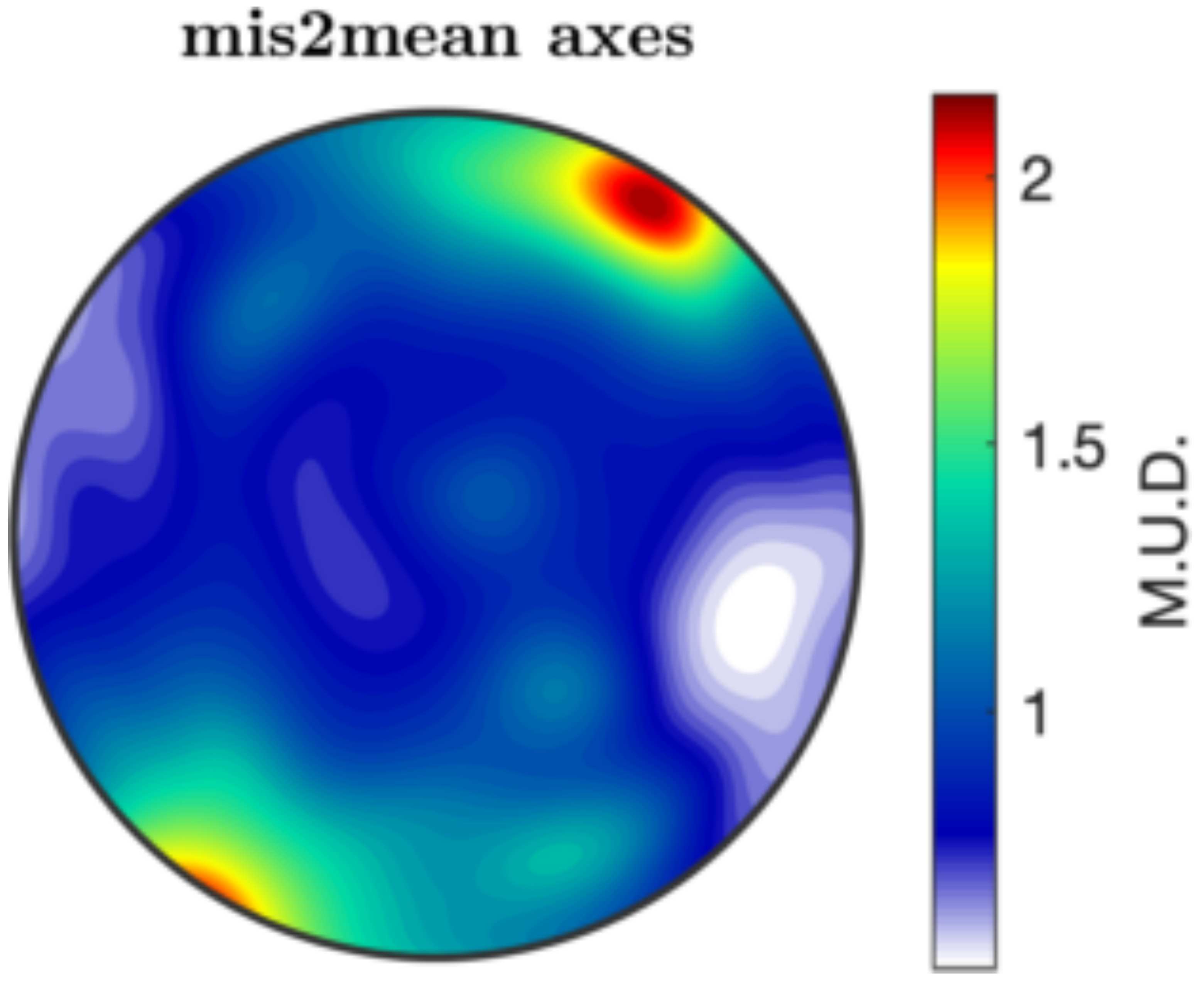
Intragranular misorientation analysis



crystal reference frame



specimen reference frame



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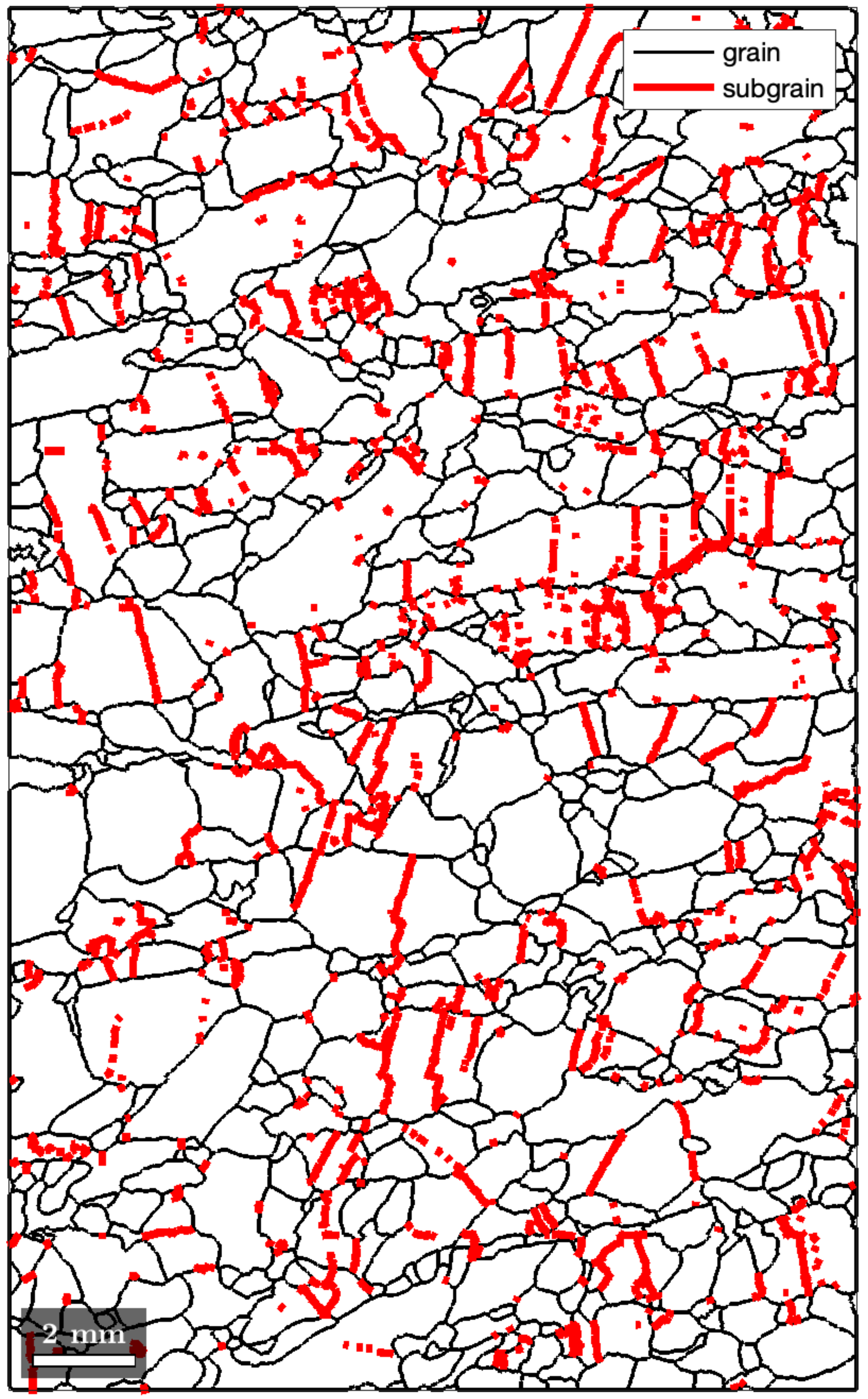

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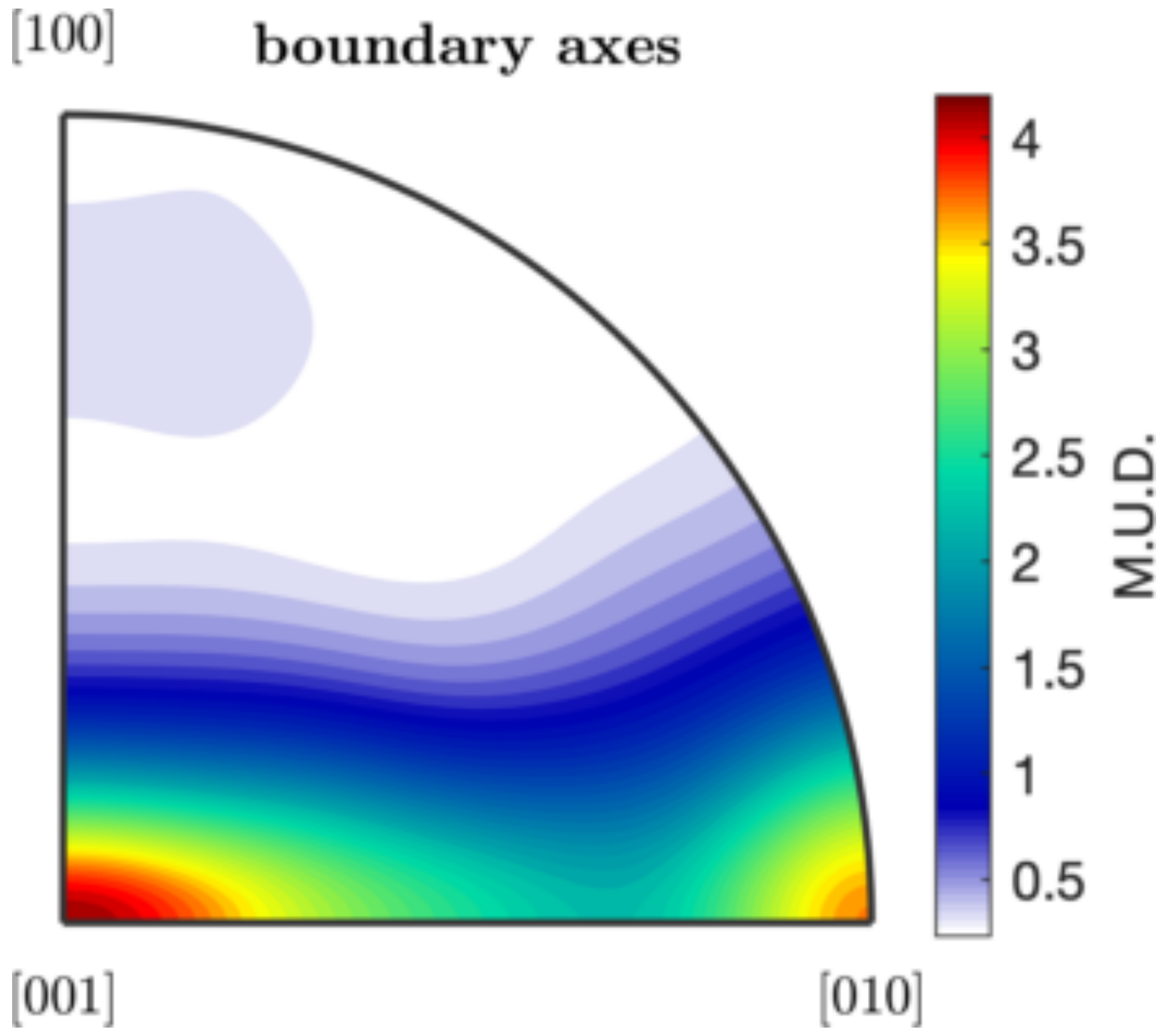

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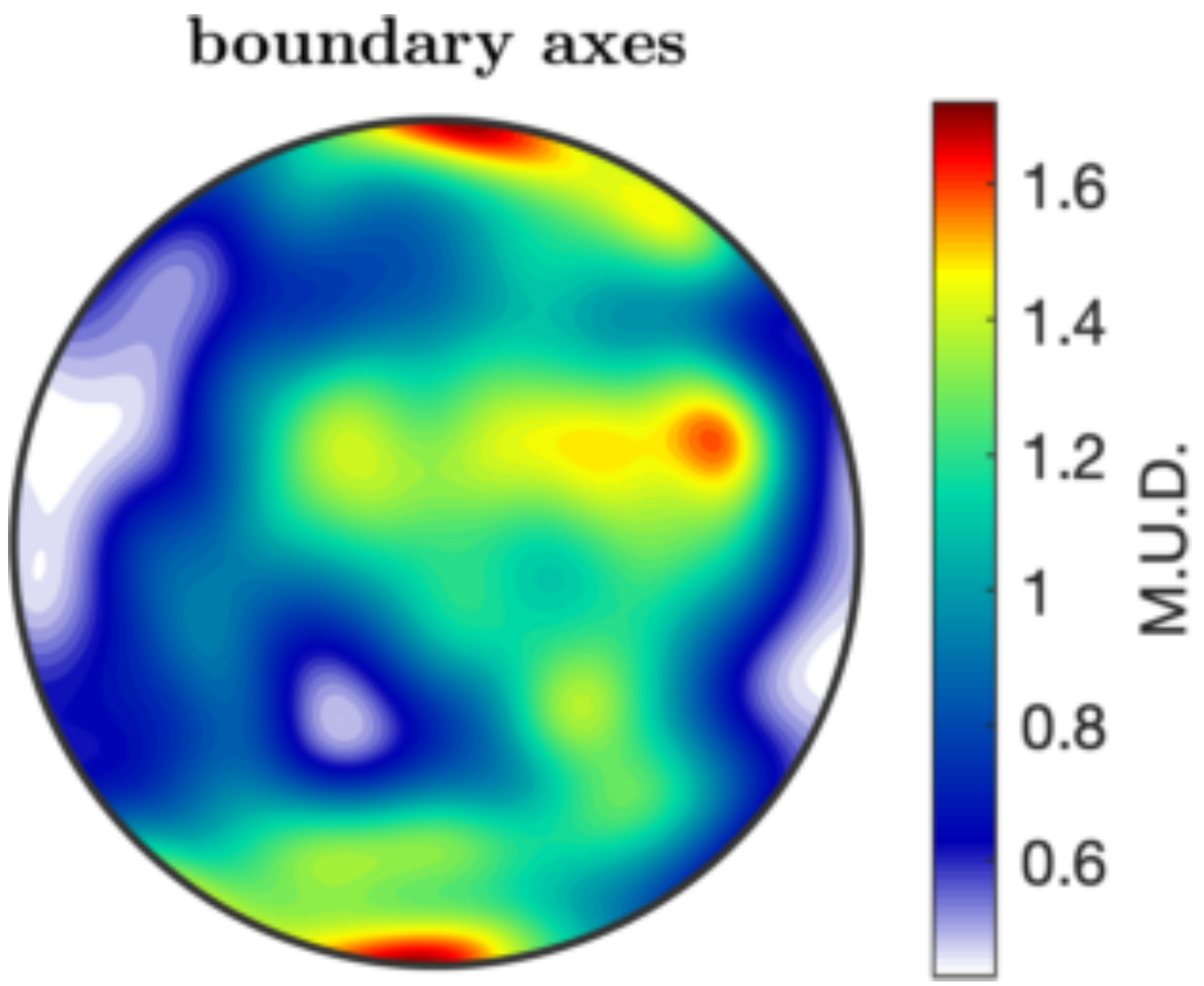

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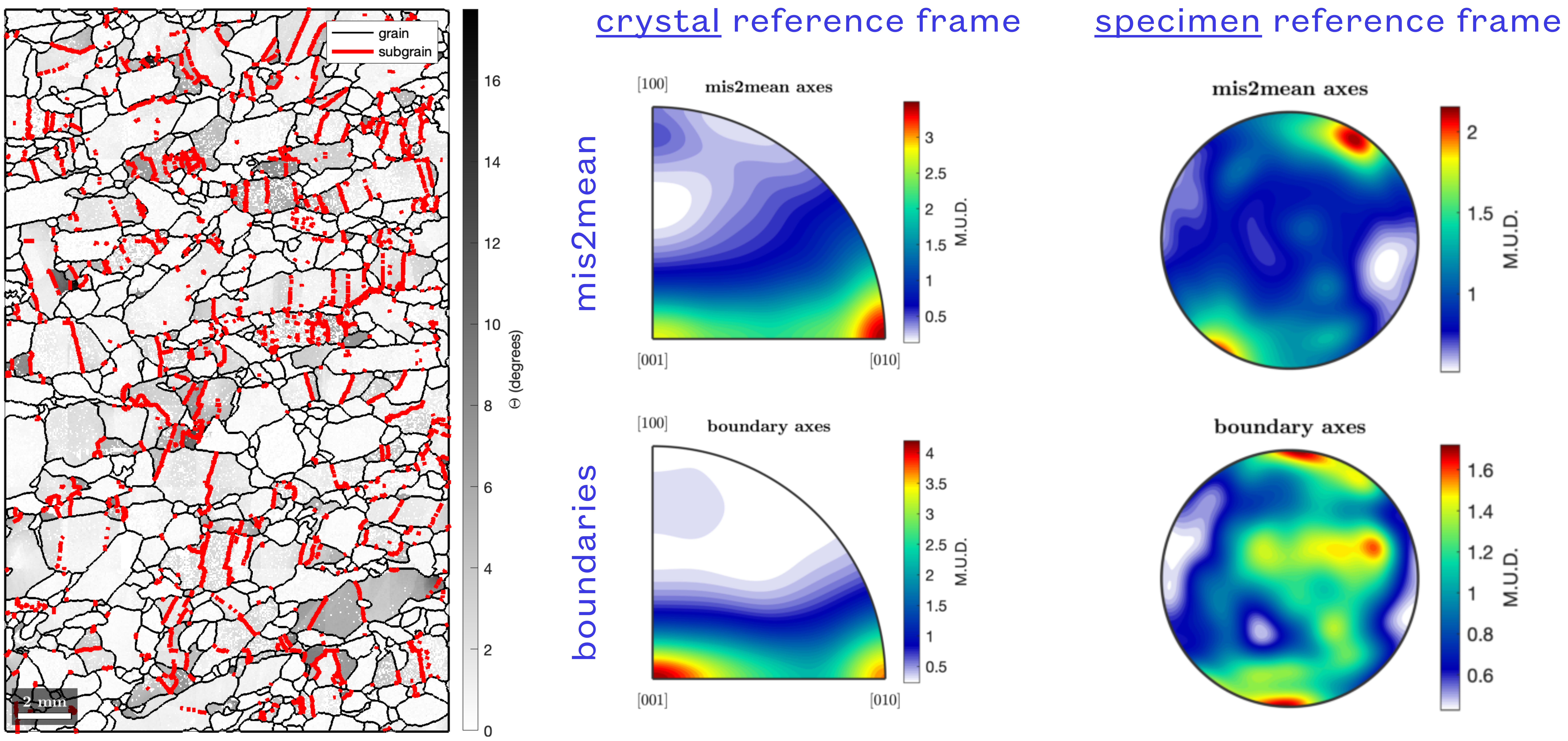

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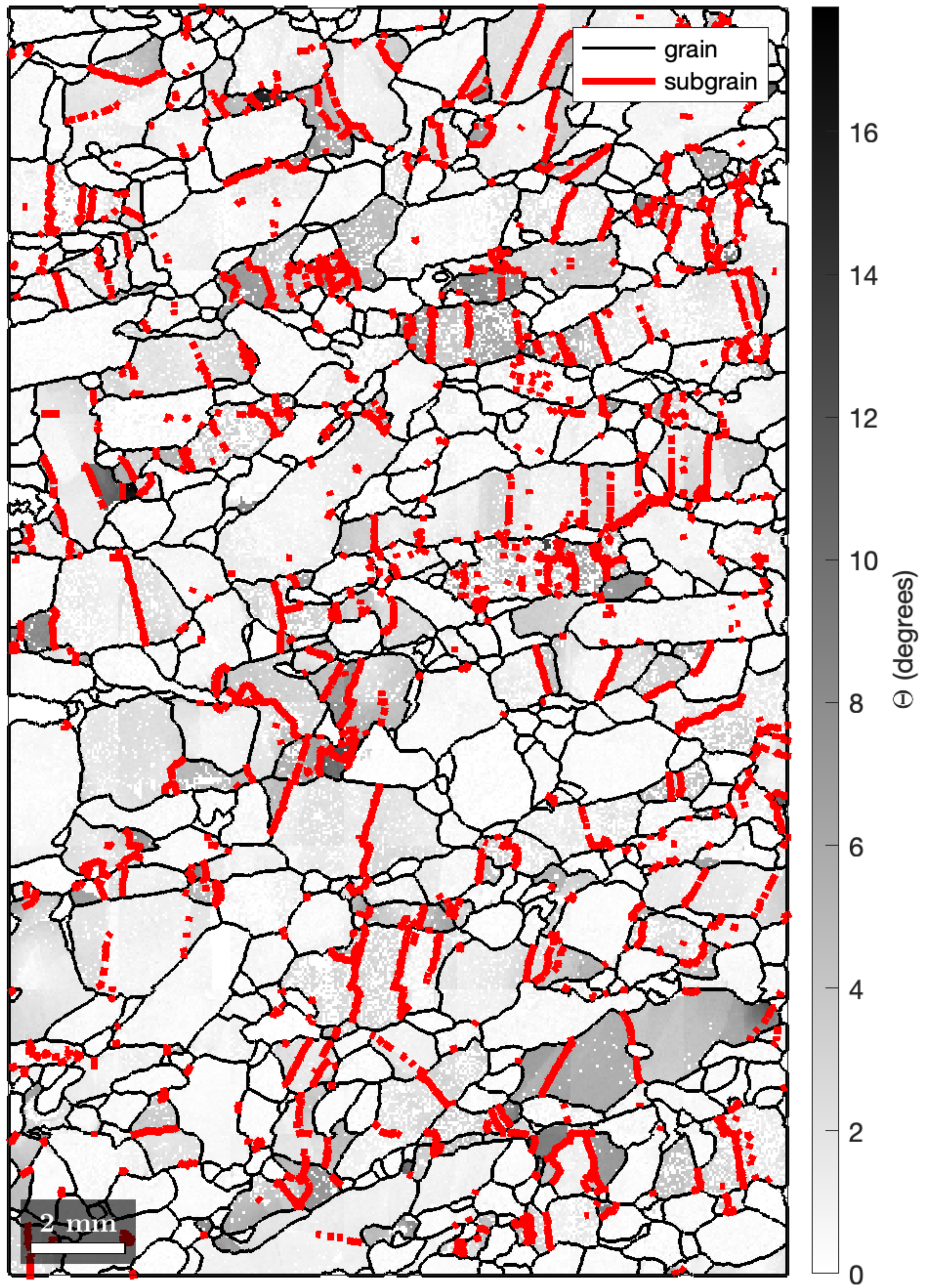

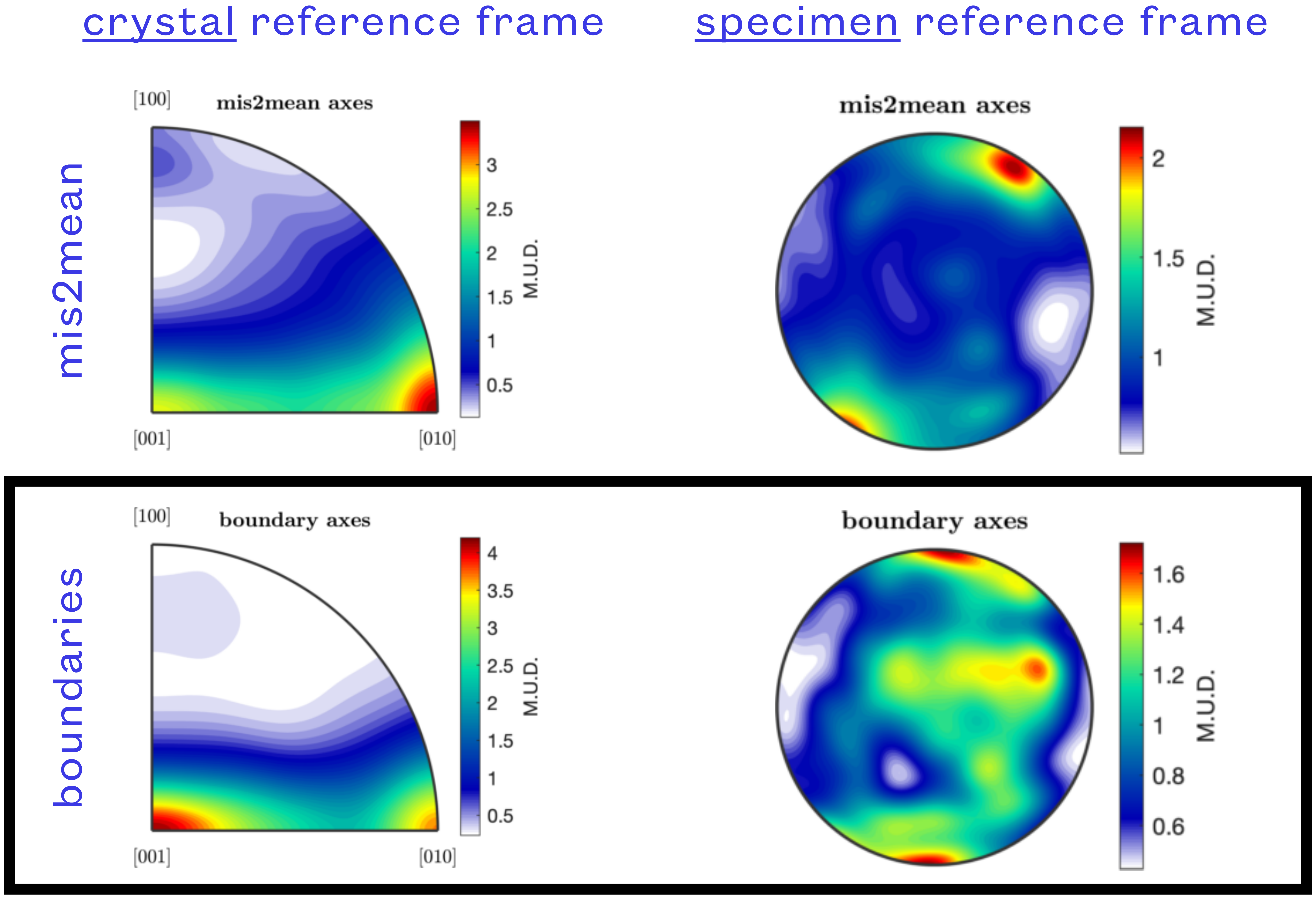

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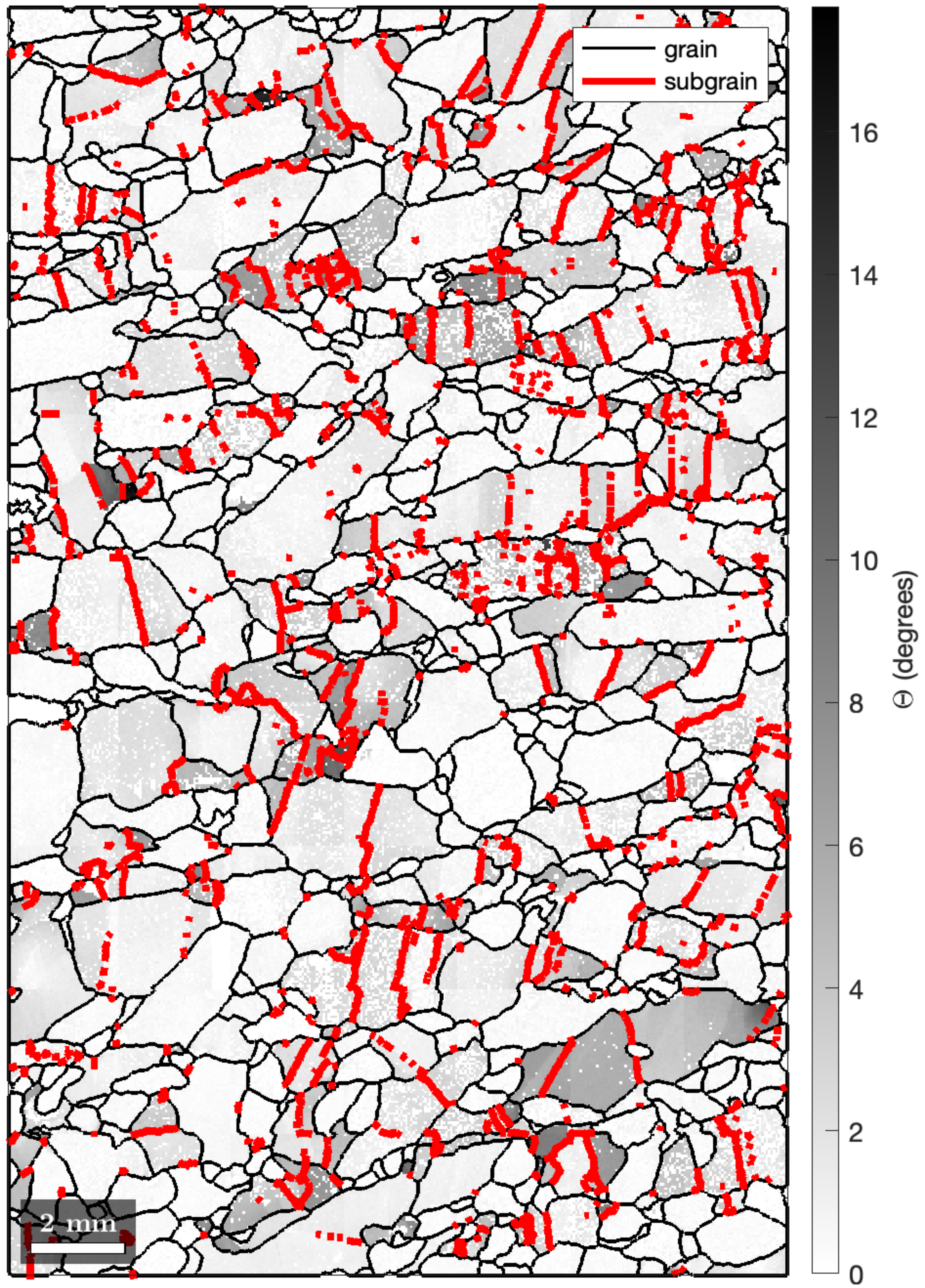
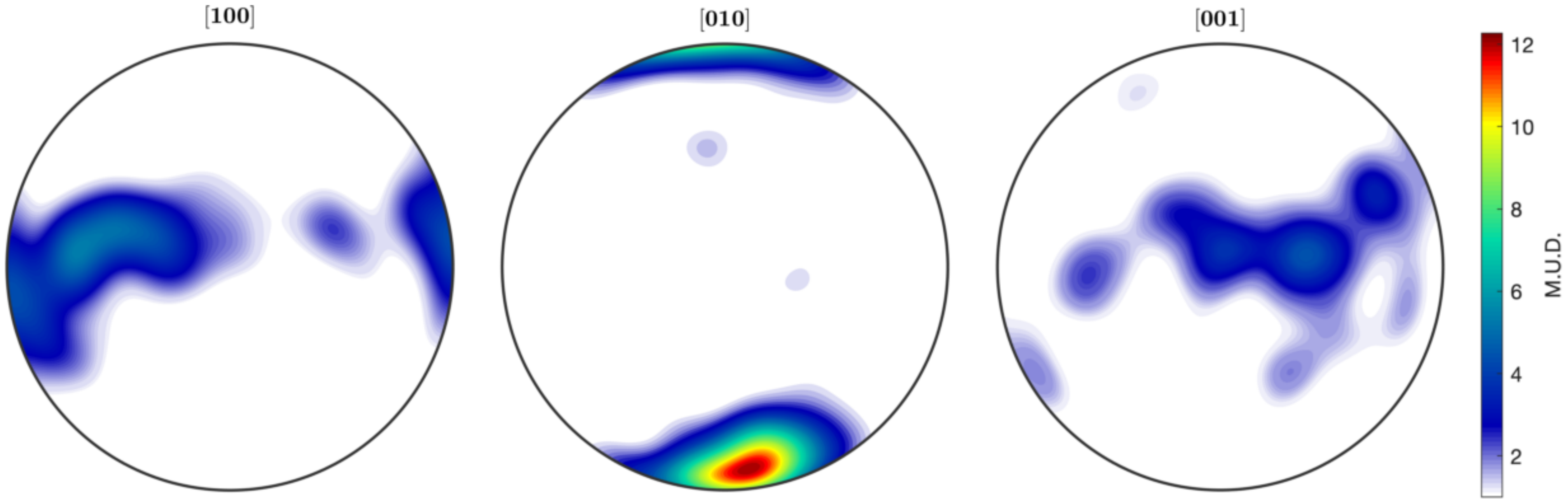
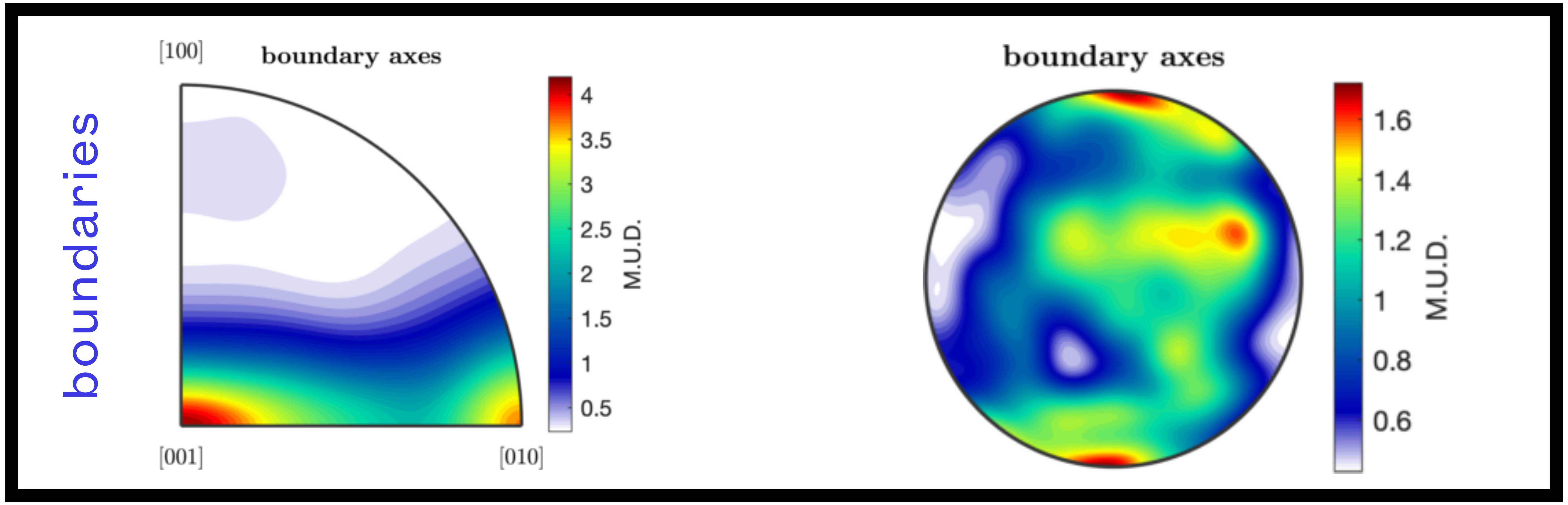
Intragranular misorientation analysis







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Summary

- MTEX can be used for plotting field structural data
  - Matlab-centric workflow for microstructure and field structure
  - Analyze fabric ellipsoids as orientations
- Rotating data is easy using MTEX, but you must be careful.
- Define and rotate to custom reference frames (i.e. geographic or kinematic)
- Combining other datasets with EBSD data in MTEX permits unique custom analyses
  - Ex: Define grains from EBSD data, then compute grain average value

- github.com/zmichels/MTEX_Workshop_2021

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