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Relationship between inhomogeneous deformation and local texture in zirconium from multiscale image correlation

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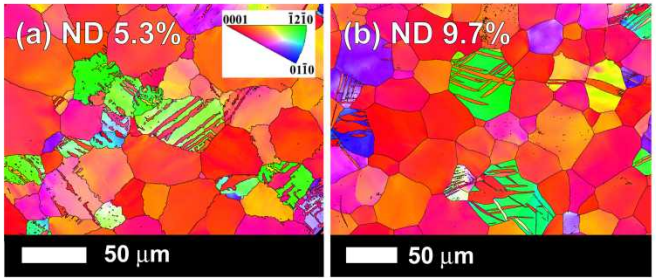
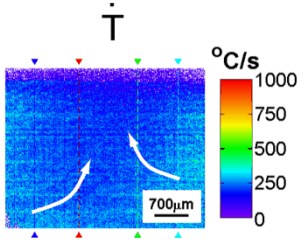
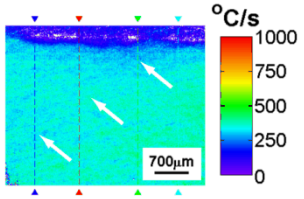
Motivation

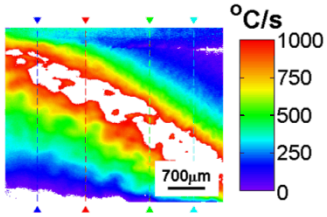
Compression along basal orientation has enough nonbasal grains to cause spatial variation in prismatic Schmid factor.

?







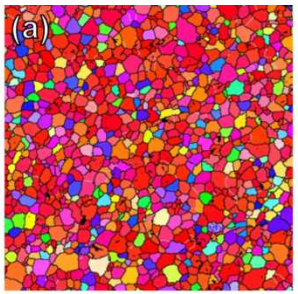


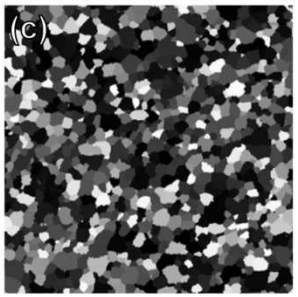
At moderate strains, post-mortem microscopy confirms that …*in situ* thermal fields unstable, ogeneous ssion of heating.

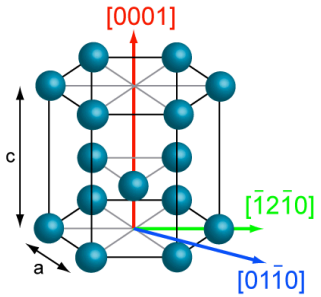
Is there a correlation between texture and microscale localization at small strains?

ORIENTATION MAP

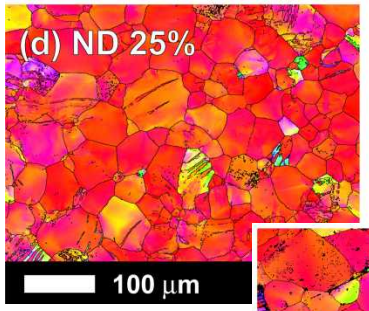
SCHMID FACTOR

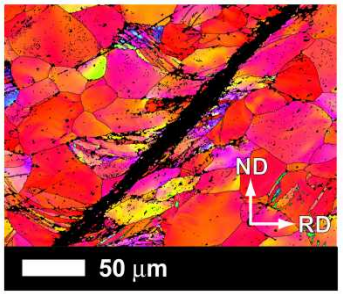






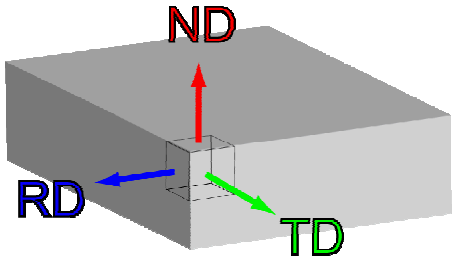
At large strains, the banded patterns visible at moderate strains reduce to one dominant shear band.

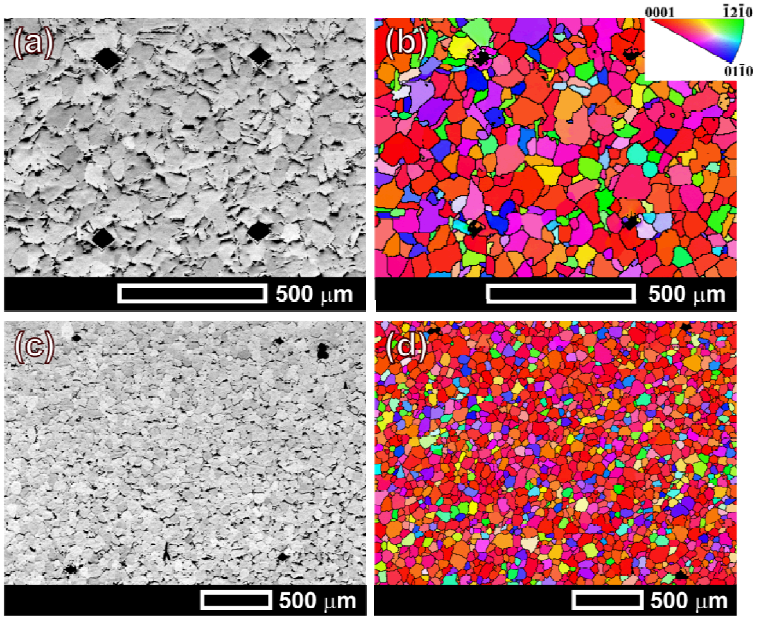




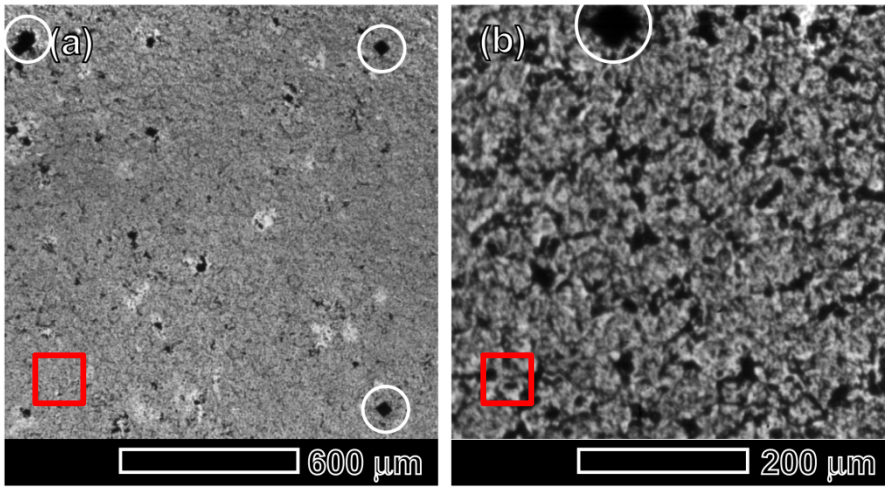
Limited number of slip systems and differences in activation stress result in "hard" and "soft" orientations (basal vs. nonbasal).

Experimental Method





- Etch grain structure of 8 mm cube sample
- Mark surface with microindenter
- Measure grain orientations in region of interest

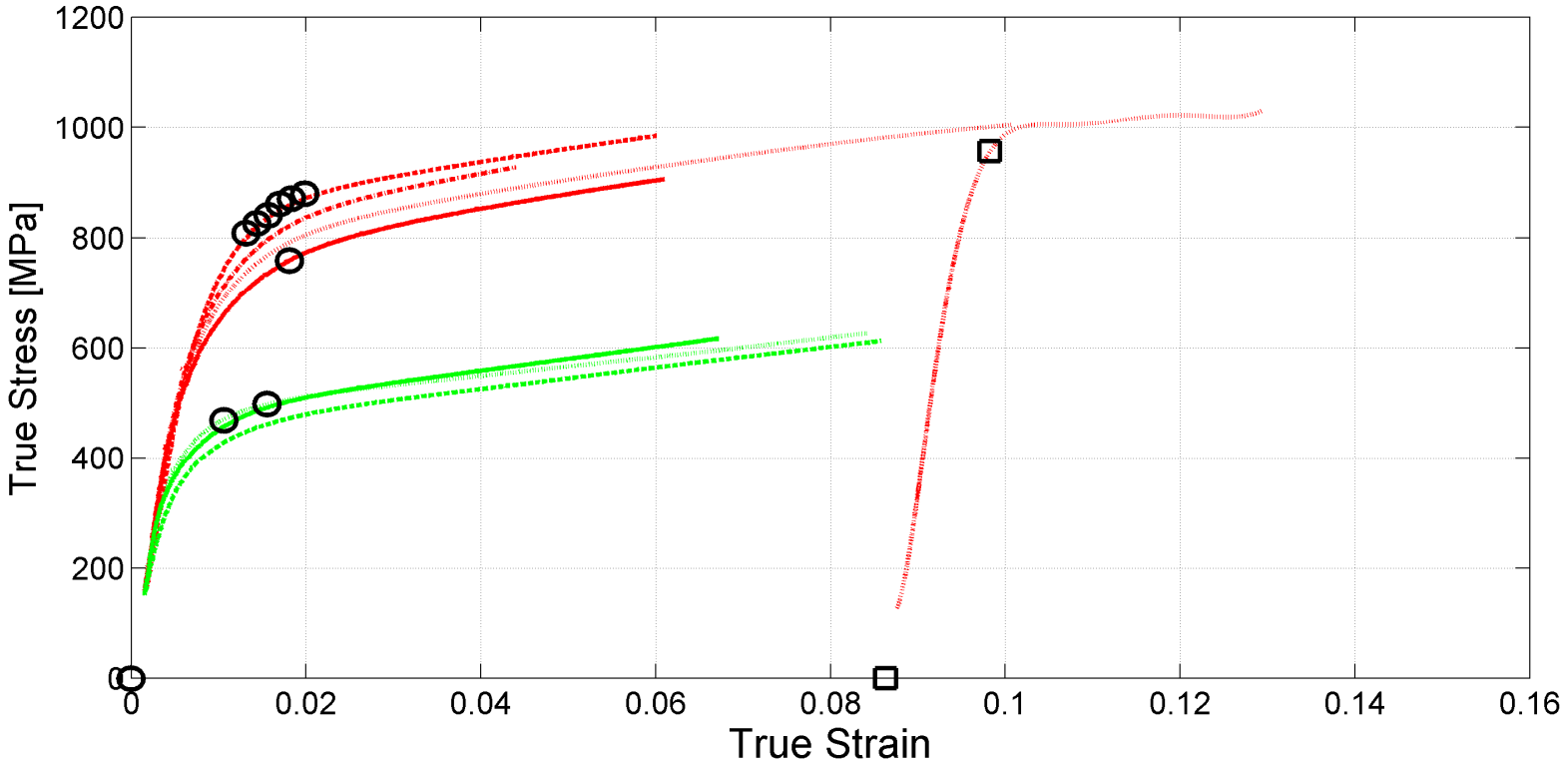


3.6 μm/pixel
"mesoscale"

1.2 μm/pixel
"microscale"

- Speckle pattern from 1 μm Si particles
- Compression at strain rate of 1 /s
- DIC subset size varies between 50 and 150 μm depending on magnification

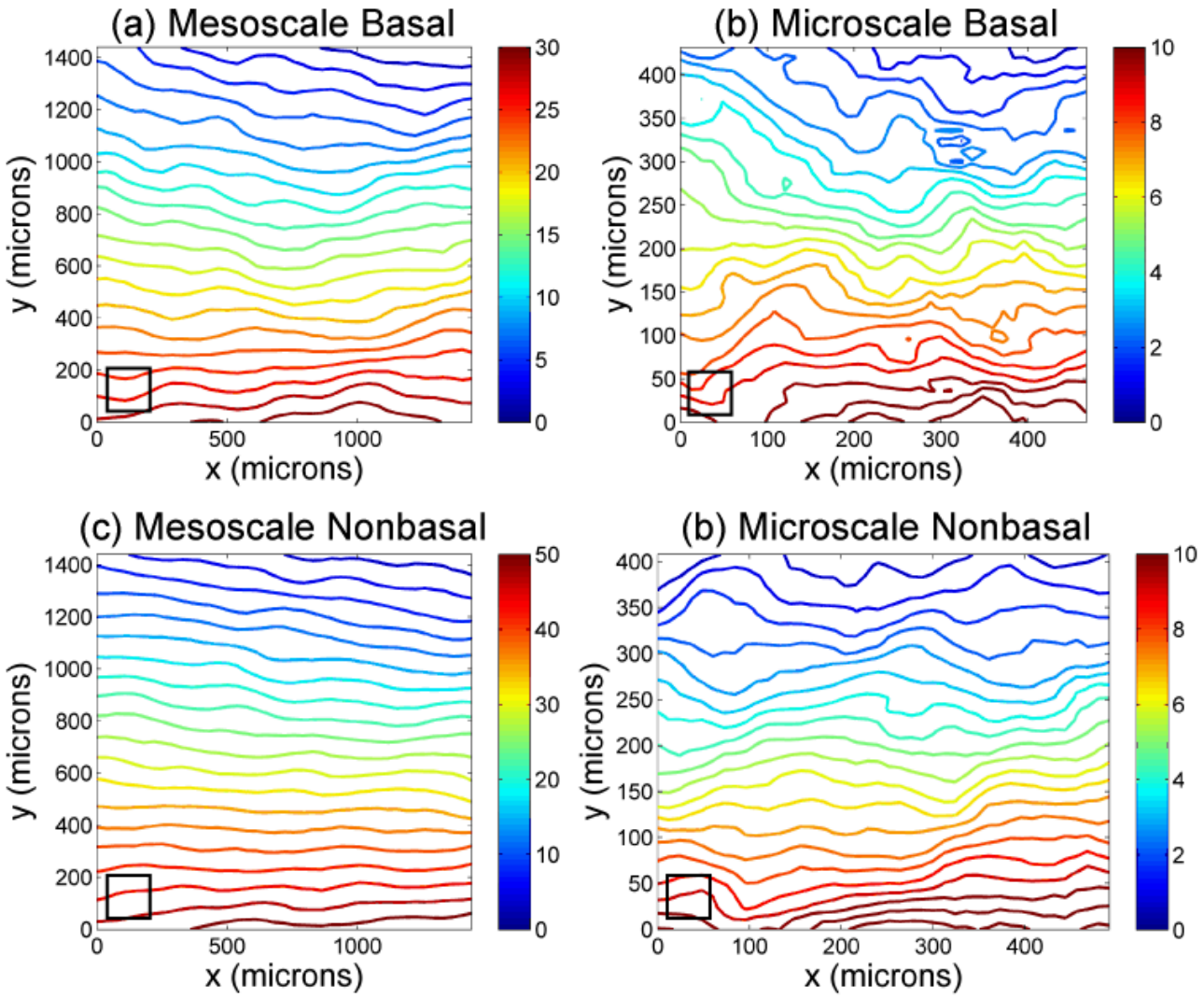
Mechanical Response



- Symbols indicate strains for which correlations were performed
- One basal oriented sample was re-loaded for a second DIC measurement

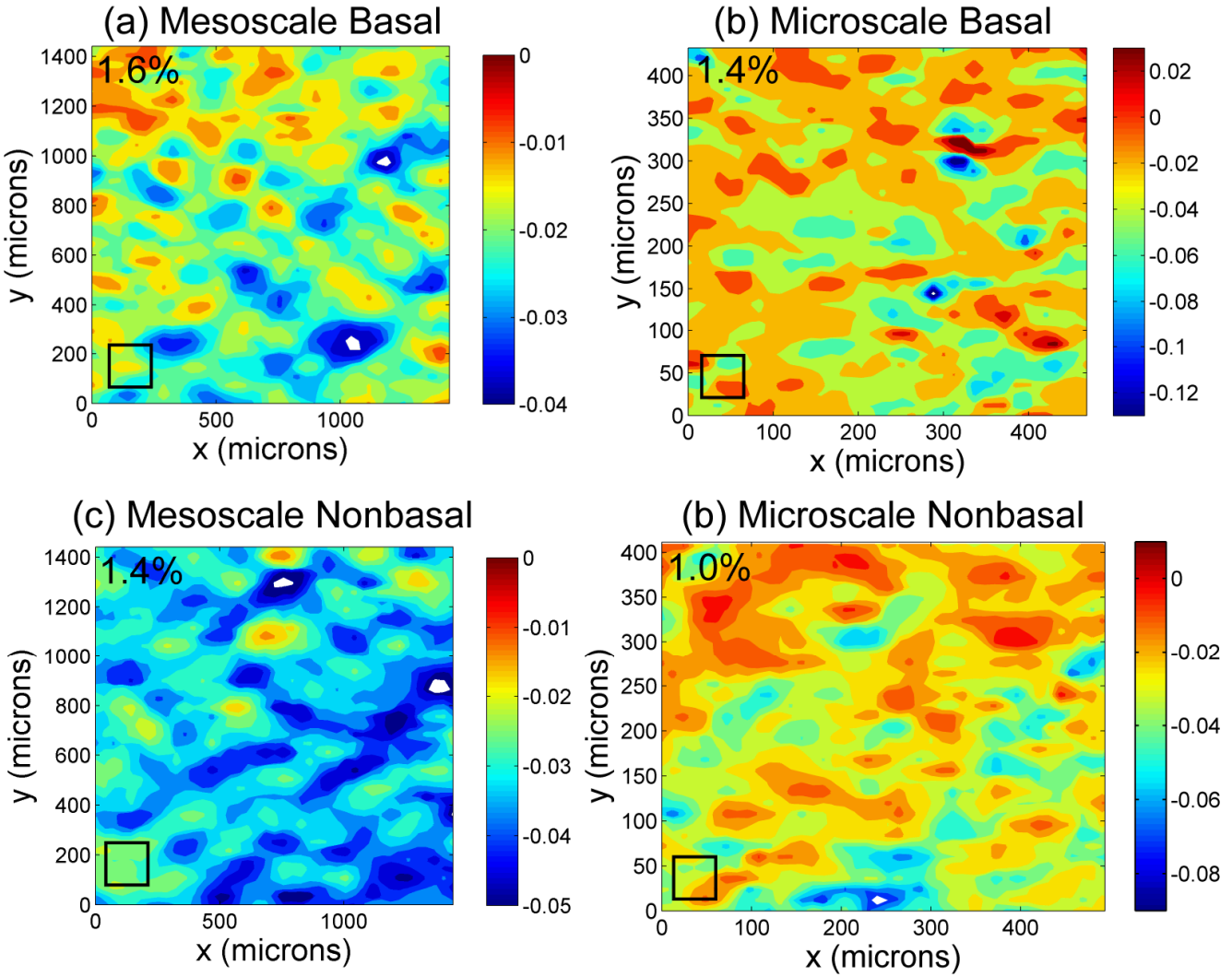
DIC Displacements

- In general, basal texture shows greater inhomogeneity in displacement field than nonbasal texture.
- Microscale experiments *appear* more inhomogeneous due to increased resolution of method.



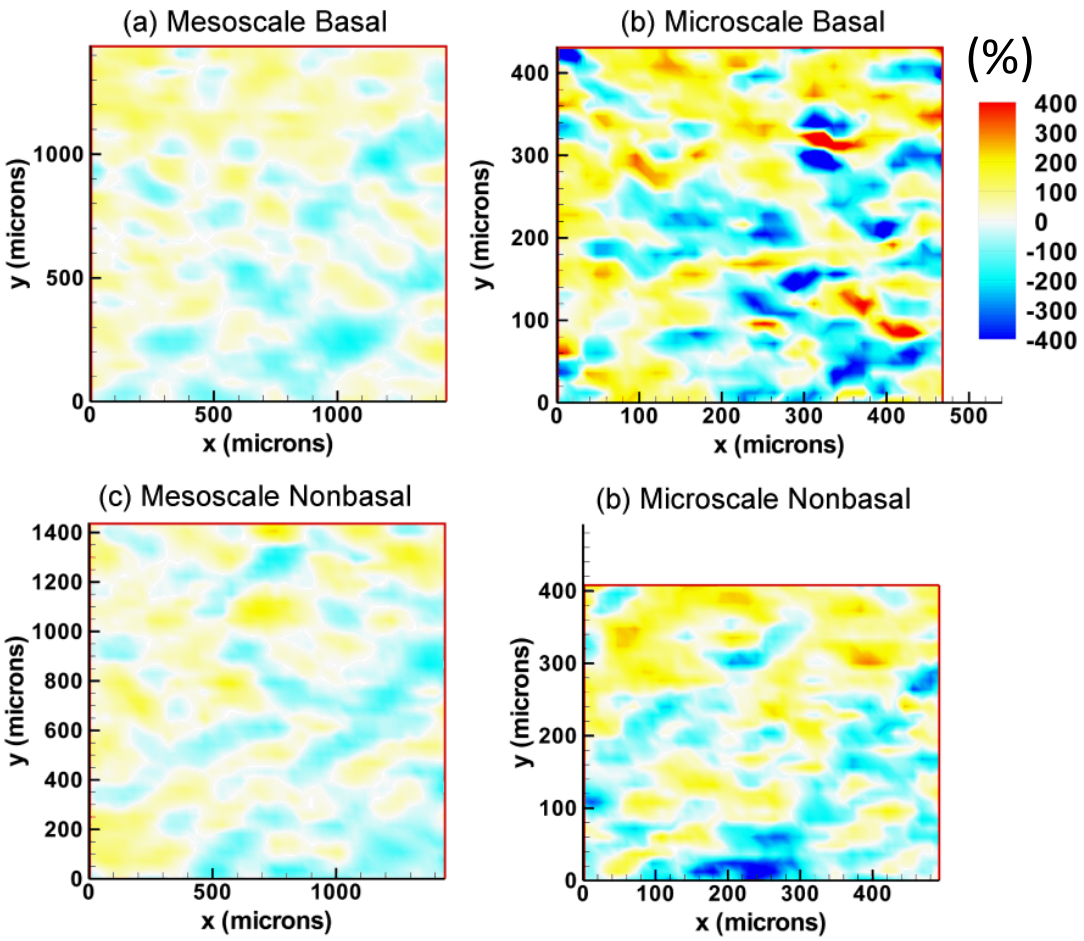
DIC Axial Strains

- Trends are repeated axial strain plots
- Bands of deformation more apparent from mesoscale view in both basal and nonbasal orientations
- Local strain values deviate significantly from bulk value.



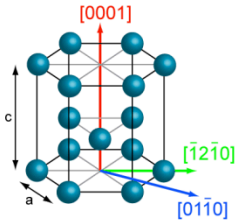
Axial Strain Deviation

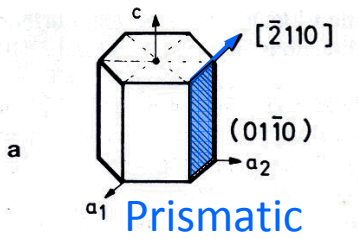
- Strain deviation ($\Delta\varepsilon_{yy}$) is calculated as percent difference from average strain value.
- Mesoscale deviation plots do not show any qualitative difference between textures.
- Microscale experiment for basal textured specimen shows largest deviations within the correlation window.

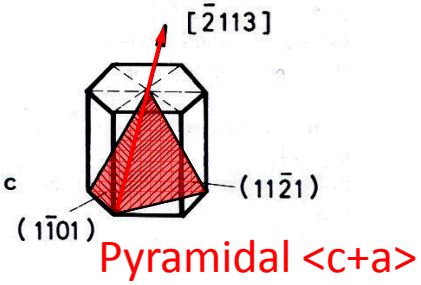


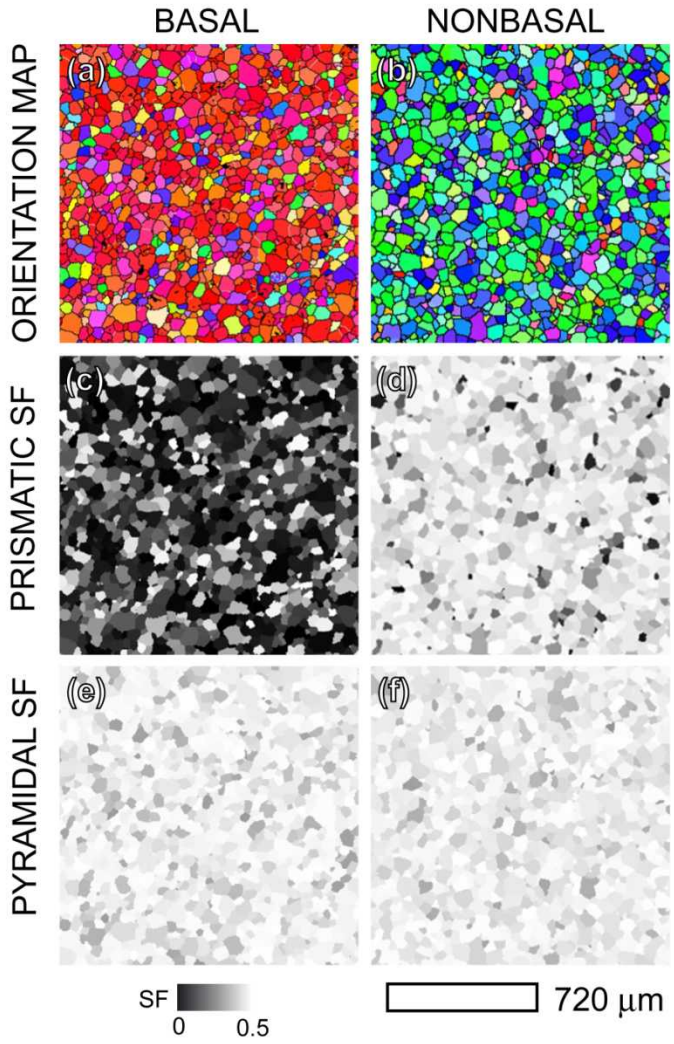
Correlating Texture with Strain

- Strain maps are already quantitative in nature
- *Qualitative* comparison can be made with orientation maps
- *Quantitative* comparison can be made with maps of Schmid factors
- Prismatic and pyramidal slip systems are chosen due to the small strain values
- The most heterogeneous distribution of Schmid factors appears in the basal oriented prismatic map









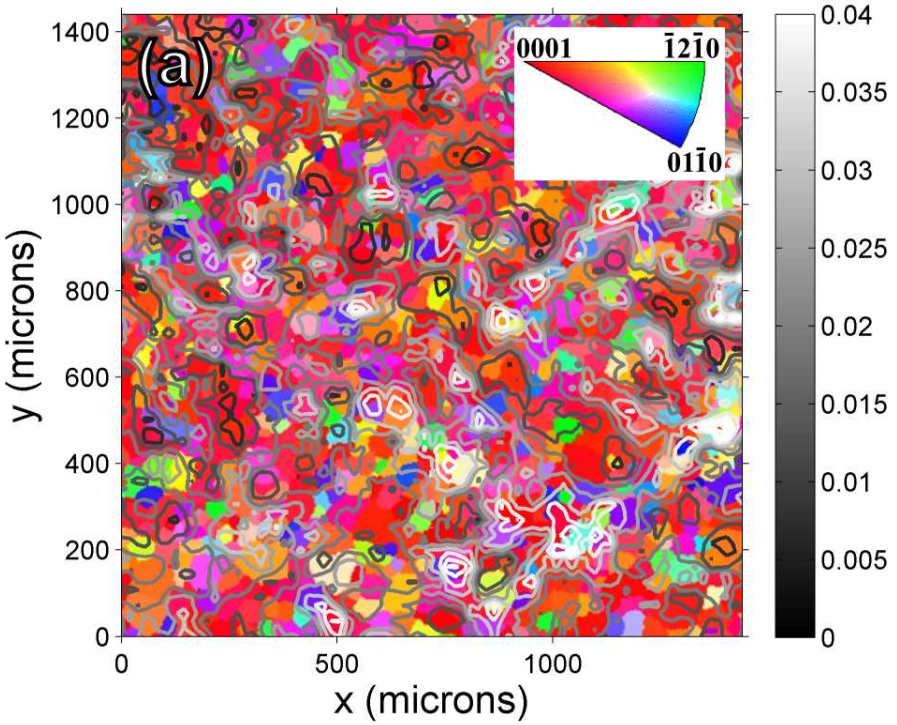
Spearman Rank Correlation

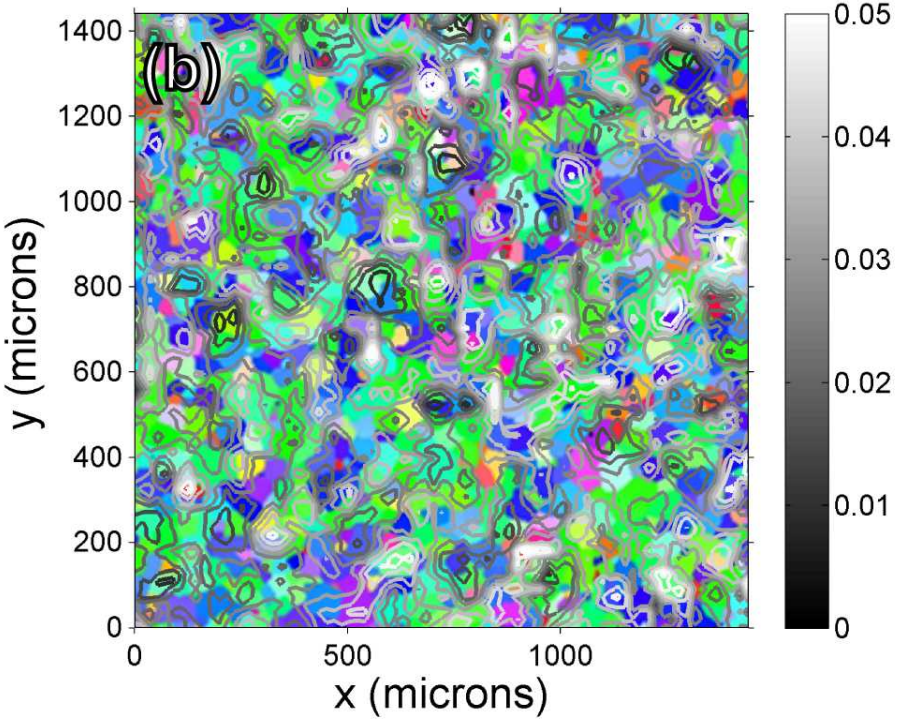
- Given two data sets *A* and *B* with unknown probability distributions
- The Spearman rank correlation coefficient, r_s, is a statistical measure of how strong the correlation is between data sets (0→no correlation, 1→perfect correlation)

$$r_s = \frac{\sum_m \sum_n \left(A_{mn} - \bar{A}\right)\left(B_{mn} - \bar{B}\right)}{\sqrt{\left(\sum_m \sum_n \left(A_{mn} - \bar{A}\right)^2\right)\left(\sum_m \sum_n \left(B_{mn} - \bar{B}\right)^2\right)}}$$

- Small P-values represent a high degree of confidence
- Correlate maximum shear strain (γ_{max}) with Schmid factor
  - γ_{max} uses axial, transverse and shear components

Effect of Grain Orientation on γ_{max}





- Visible bands of deformation
- Basal texture shows strains concentrate over nonbasal oriented grains.

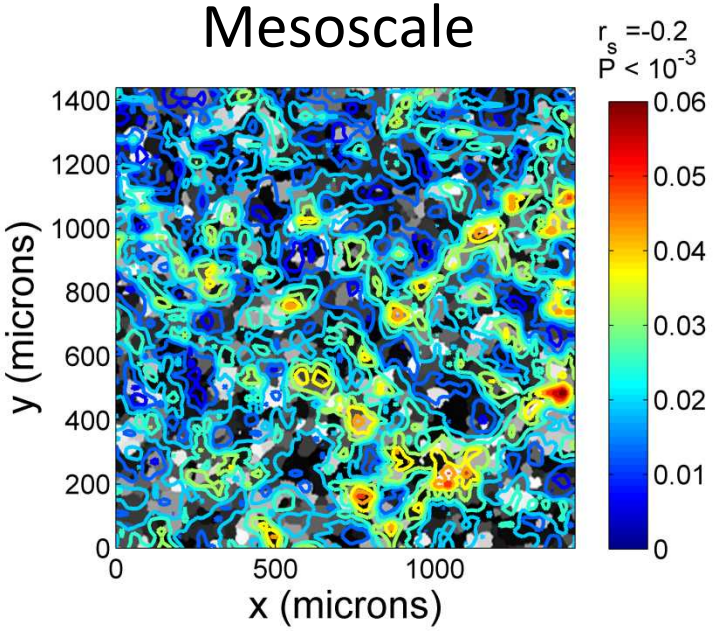
- Nonbasal texture shows some strain concentration over (-12-10) oriented grains (green).

Correlation Between Prismatic SF and γ_{max}

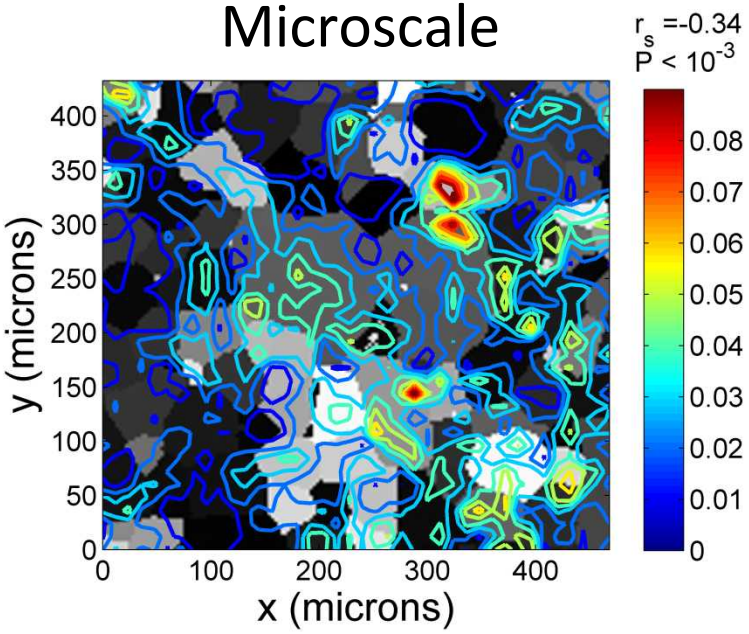
Basal

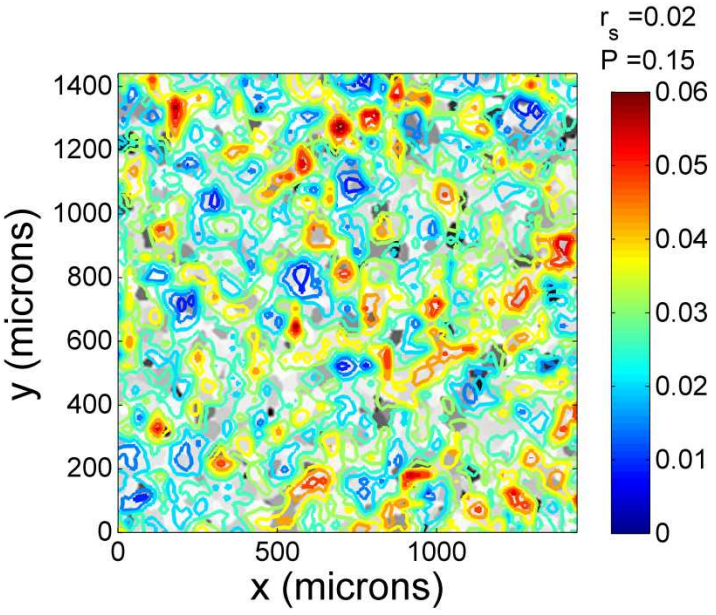
Nonbasal

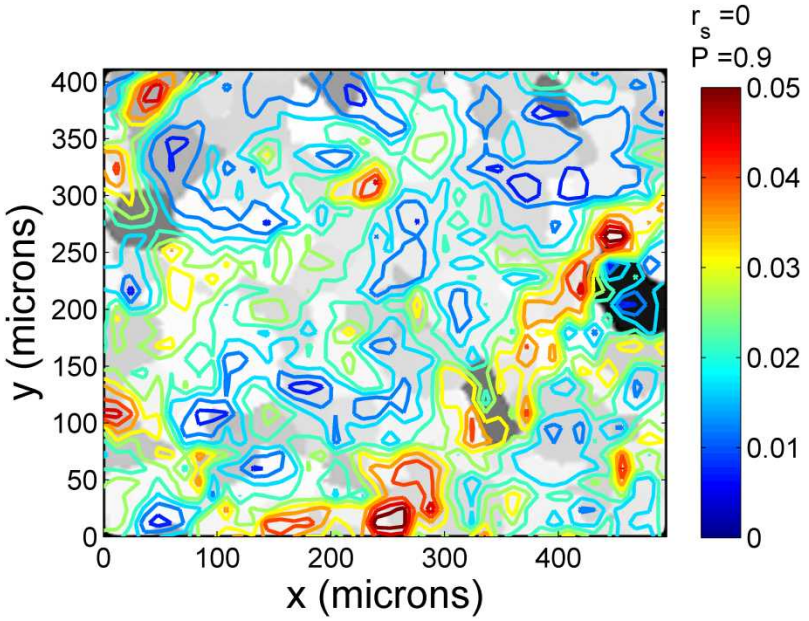
Mesoscale



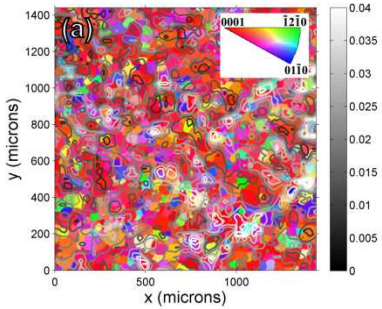
Microscale

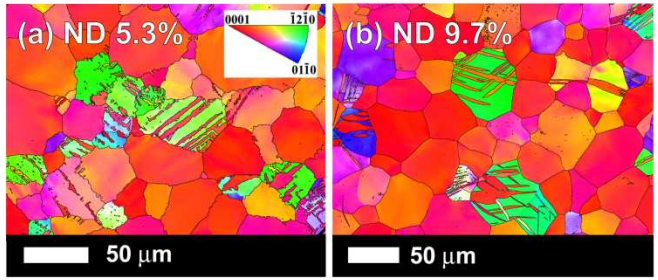


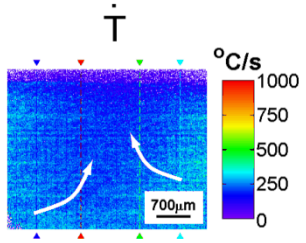


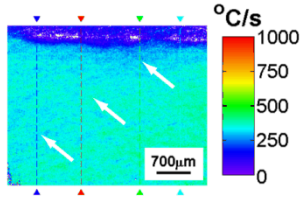


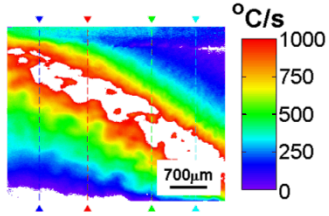
Summary

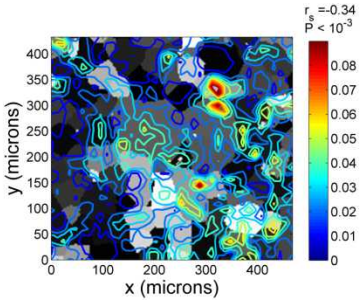






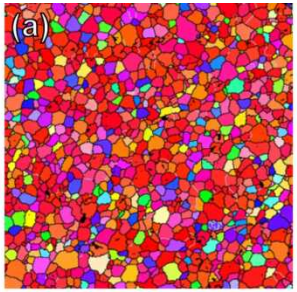




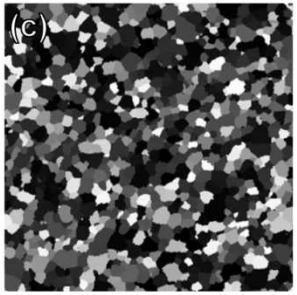


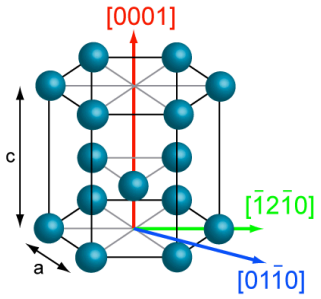
- Strain localization appears at bulk strains less than 2%
- Deformation bands concentrate over nonbasal (soft) grains
- Correlation of .34 between prismatic Schmid factor and maximum shear strain

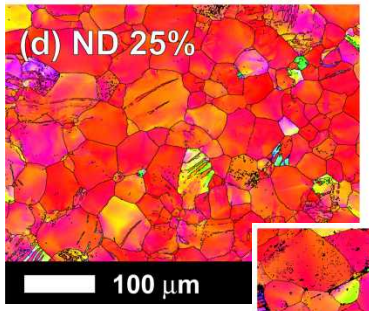
ORIENTATION MAP

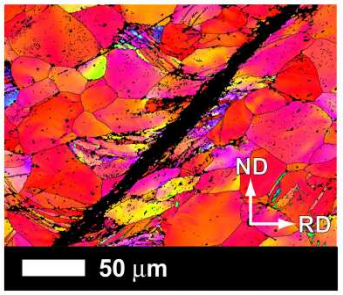


SCHMID FACTOR





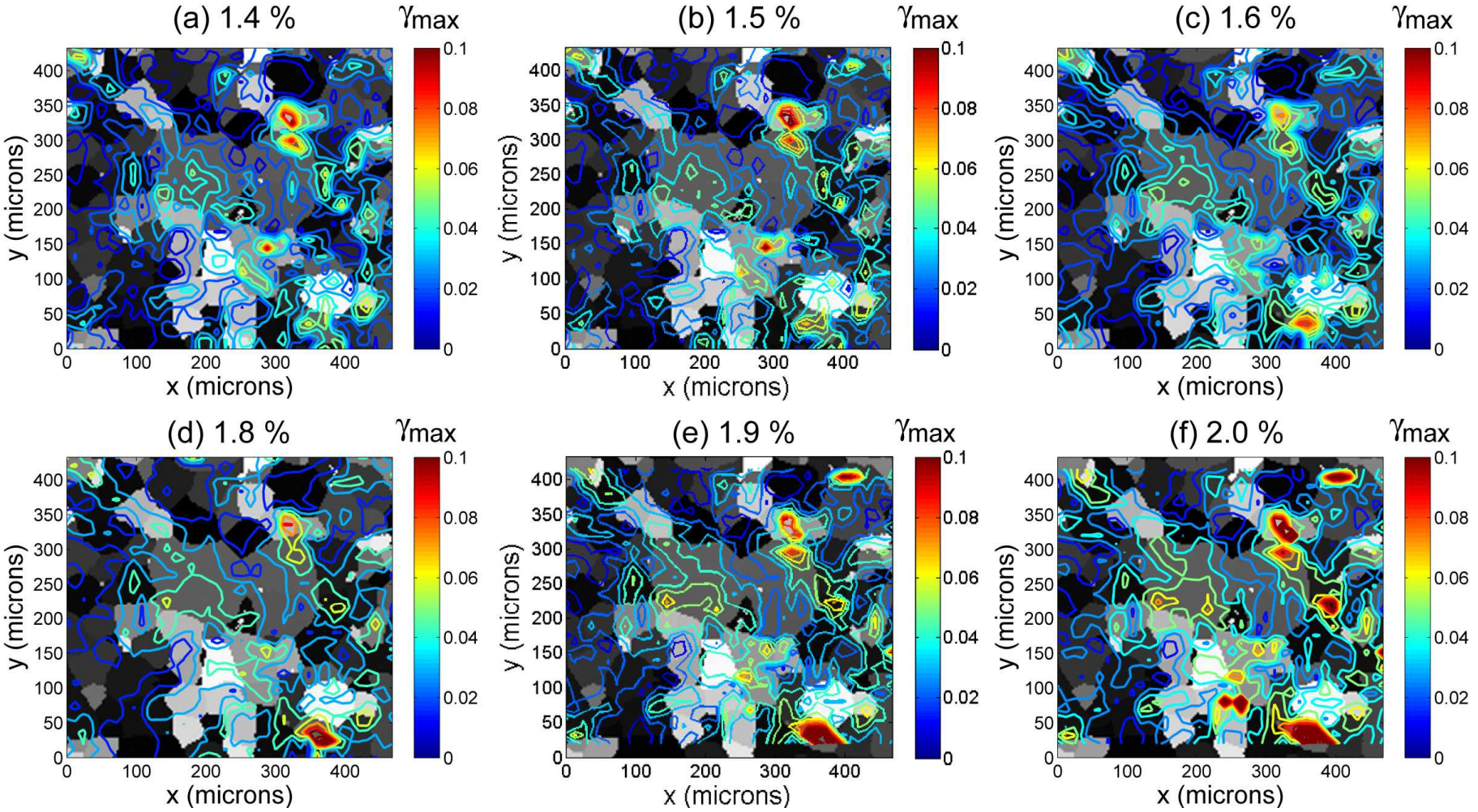




Conclusions

- Data suggest there is some degree of nonuniform deformation in both basal nonbasal oriented specimens
- In basal orientation, there is a significant correlation between prismatic Schmid factor and strain localization
- Bands of deformation exceed the length scale of single grains

Evolution of Strain With Load



Correlation between texture and strain is implied by post-mortem analysis

- Red grains oriented favorably for pyramidal slip (hard)
- Blue and green grains oriented favorably for prismatic slip (easy)