

**Lecture given by  
Prof. Dierk Raabe (d.raabe@mpie.de)  
at RWTH-Taiwan Conference  
at GFI / RWTH Aachen  
16. August 2006 at RWTH Aachen**

*(shortened version for edoc without movies)*





**1917** Foundation of the MPIE (Gesellschaft bürgerlichen Rechts) by:  
*Verein Deutscher Eisenhüttenleute (VDEh) and  
Kaiser-Wilhelm-Gesellschaft*

**1971** MPIE forms a limited liability company (GmbH)  
*(Stahlinstitut-VDEh: 50% Max-Planck-Society: 50%)*

**1934** New institute's buildings in Düsseldorf

**2000-2007** Complete renovation of all institute's buildings

**Directors of the Institute:**

<i>1917 – 1923</i>	<i>Prof. Wüst</i>
<i>1923 – 1944</i>	<i>Prof. Körber</i>
<i>1944 – 1959</i>	<i>Prof. Wever</i>
<i>1959 – 1970</i>	<i>Prof. Oelsen</i>
<i>1971 – 1990</i>	<i>Prof. Engell</i>
<i>1990 - 2002</i>	<i>Prof. Neumann</i>

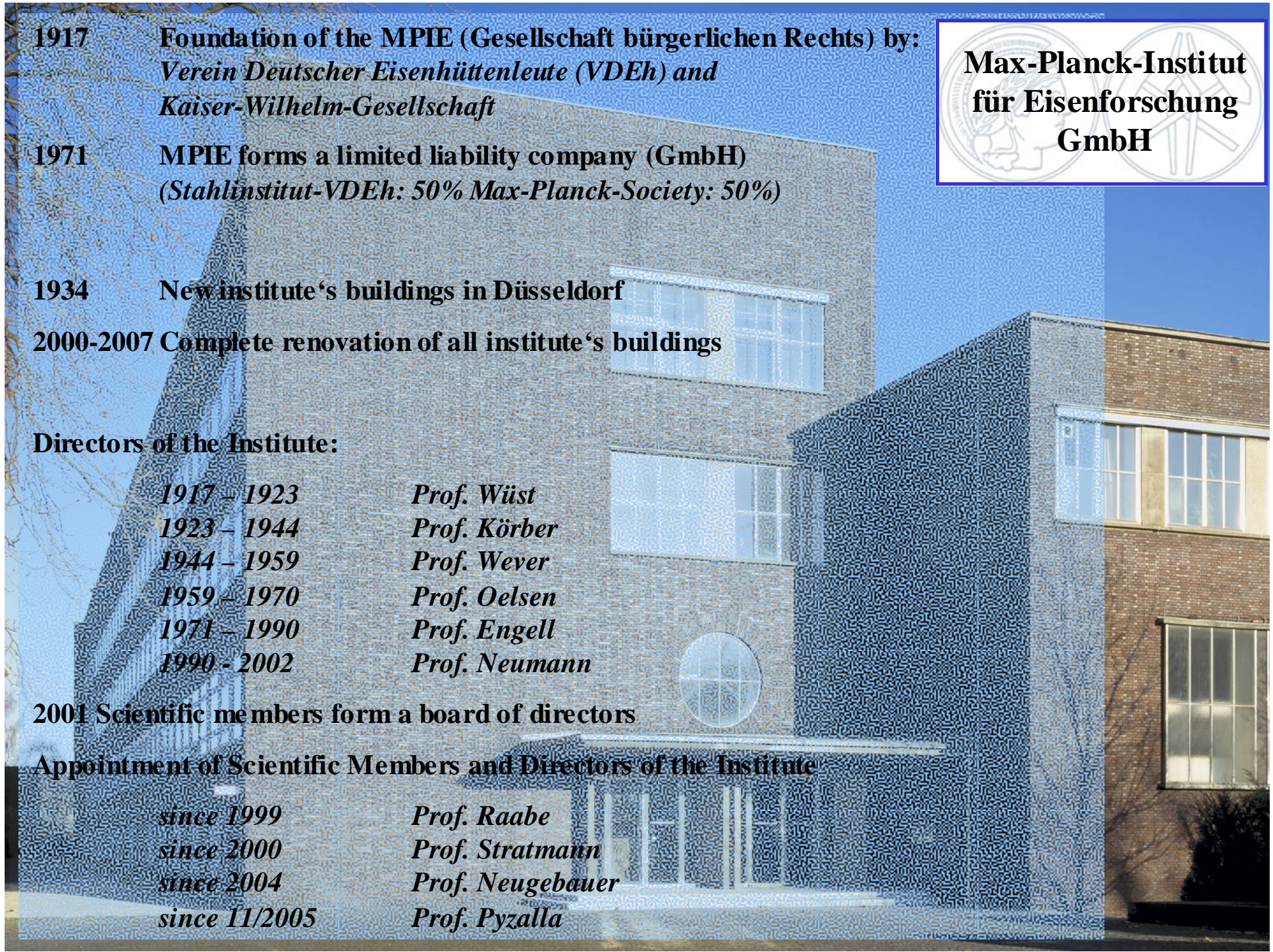
**2001** Scientific members form a board of directors

**Appointment of Scientific Members and Directors of the Institute**

<i>since 1999</i>	<i>Prof. Raabe</i>
<i>since 2000</i>	<i>Prof. Stratmann</i>
<i>since 2004</i>	<i>Prof. Neugebauer</i>
<i>since 11/2005</i>	<i>Prof. Pyzalla</i>



**Max-Planck-Institut  
für Eisenforschung  
GmbH**





**Departments:** 5

**Lab and office space:** 8.300 m<sup>2</sup>

**Personnel:** in total: 225

for steel industry:  
27 t€full costs /  
employee

102 financed by institutional funds

*Executives* 5

*Administration* 13

*Techn. Services* 8

*Scientific services* 26

*Scientists* 29

*Engineers* 32

*Others* 6

remaining personell  
(mostly scientitst) on 3rd party funds

**Budget:** 13,5 Mio €(40% MPG, 40% VDEh, 20%

13 ct / t steel  
(0.02 %)

**Expenses:** 58% Personnel  
28% Consumables  
8% Investments  
6% Rental



*Gesellschafter :*  
*Max-Planck-Society, Steel Institute VDEh*

**Review Board**

**Trustees Board**

***MPIE***

**Executive Board**

**Jörg  
Neugebauer**

**Dierk  
Raabe**

**Anke  
Pyzalla**

**Martin  
Stratmann**

**Herbert  
Wilk**

**Georg  
Frommeyer**

*Computational  
Materials  
Design*

*Microstructure  
Physics  
and Metal  
Forming*

*Diagnostics  
and  
Technology  
of Steels*

*Interface  
Chemistry  
and  
Surface  
Technology*

*Administration*

*Materials  
Technology*



# Department for Microstructure Physics and Metal Forming

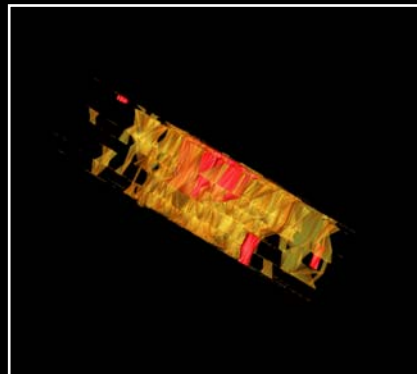
D. Raabe, F. Roters, S. Zaefferer, D. Ponge

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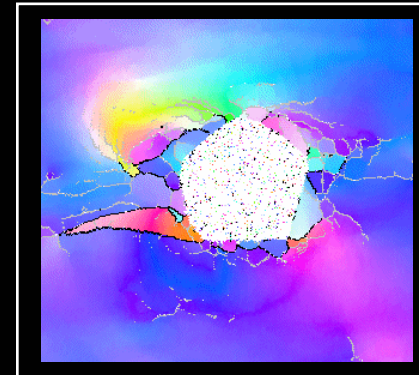
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new steels



3D electron  
microscopy



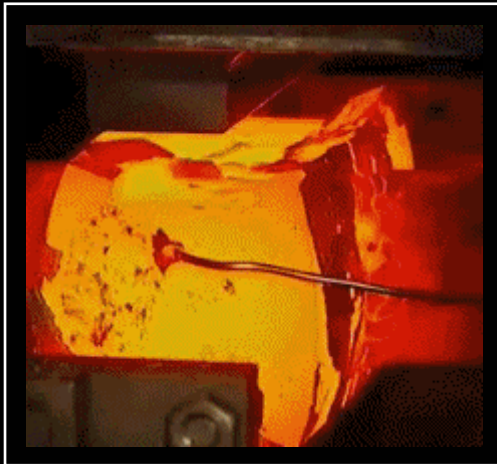
complex  
microstructures



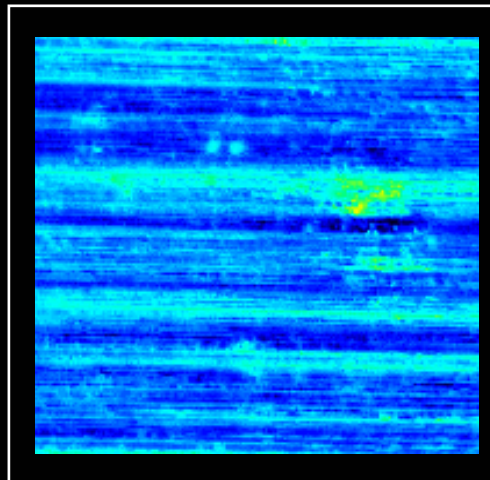
biomaterials  
biological materials



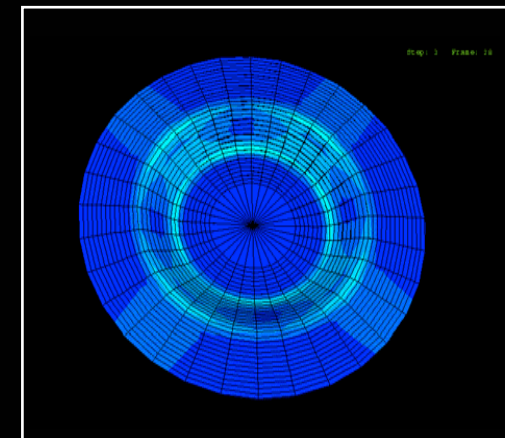
thermomechanical  
treatment



surface micro-mechanics



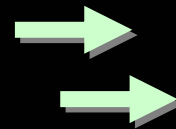
physics-based  
mechanics simulation







new steels



Textures of TWIP steels  
Simulation of recrystallization

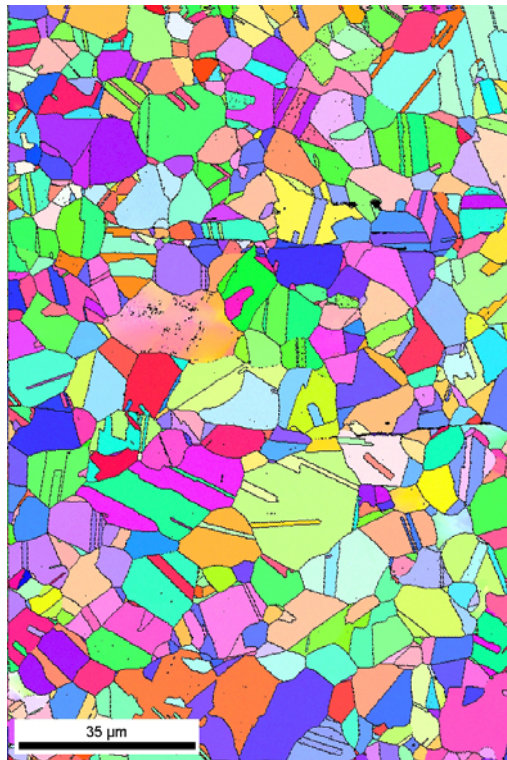


# TWIP center ( $s = 0$ )

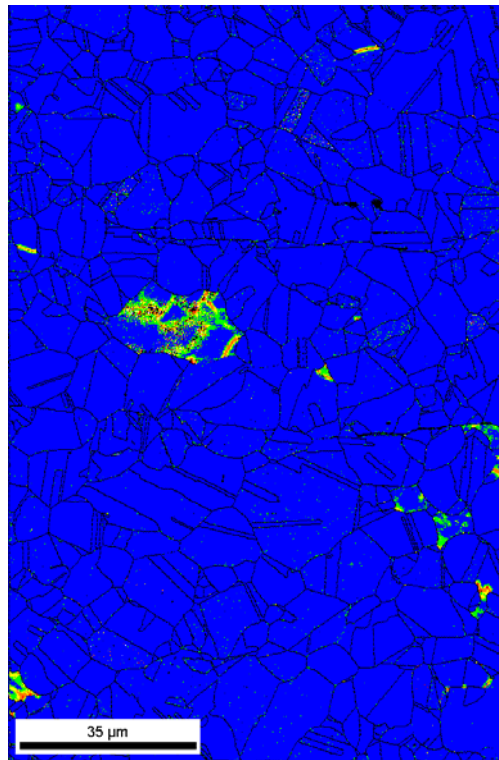


high hot band temperature

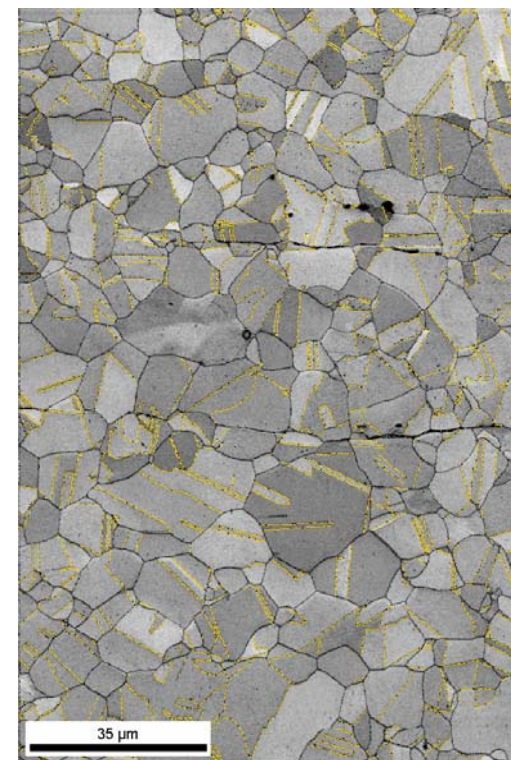
ND



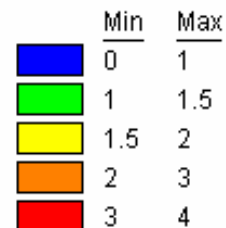
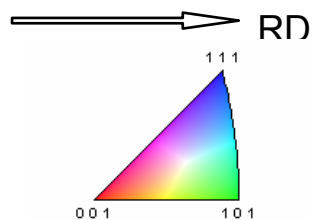
Kernel  
AverageMisorientation



IQ + Sigma 3



ND  
↑



Boundaries: CSL  
Sigma  
 3

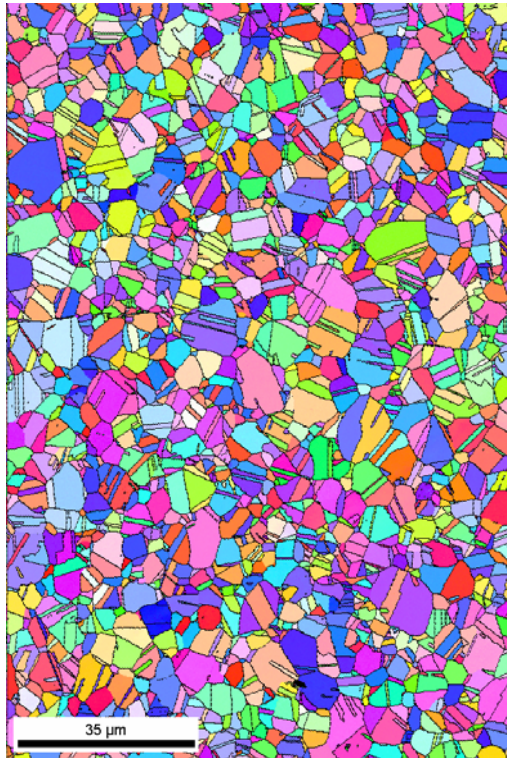


# TWIP subsurface ( $S = 0,8$ )

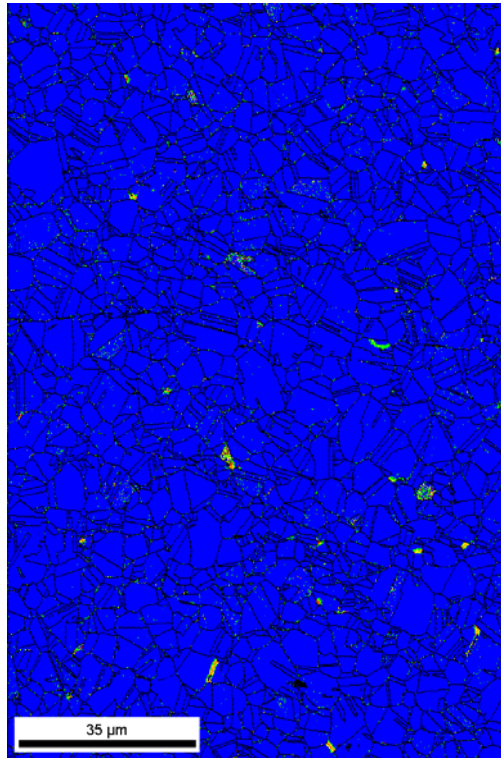


high hot band temperature

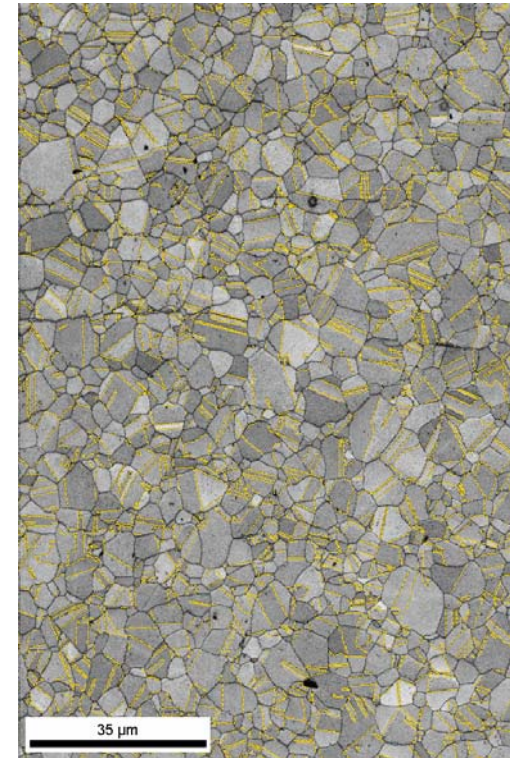
ND



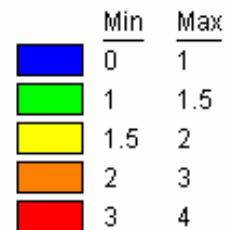
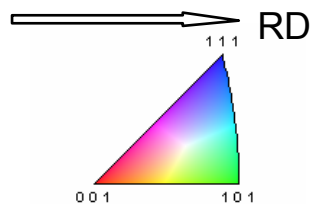
Kernel  
AverageMisorientation



IQ + Sigma 3



ND  
↑



Boundaries: CSL  
Sigma  
3

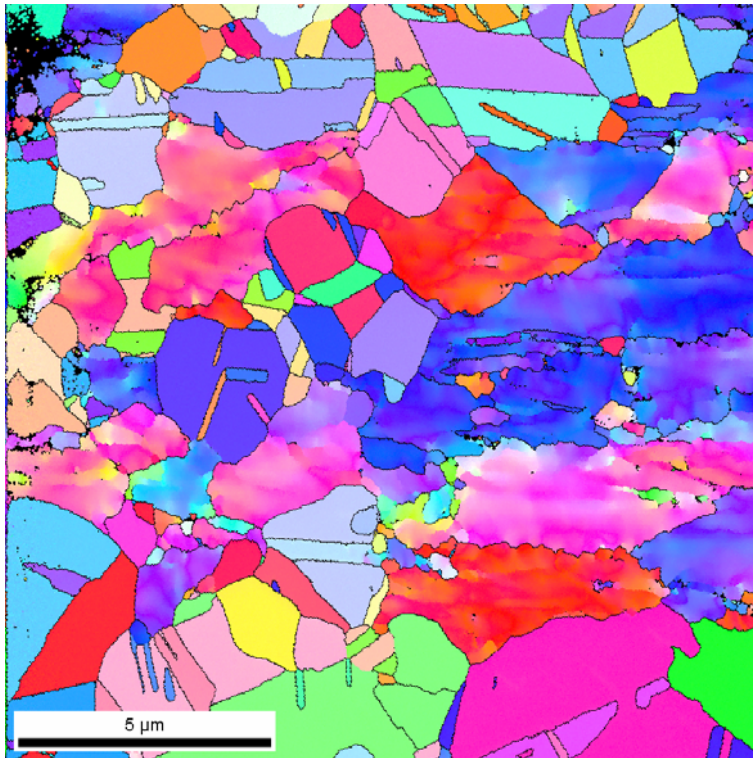


# TWIP subsurface ( $S = 0,8$ )

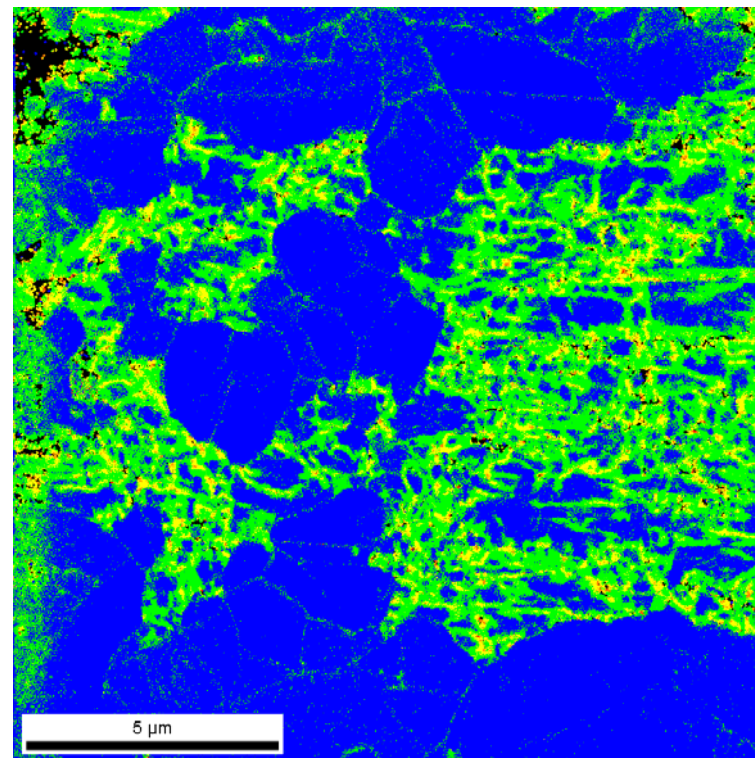


low hot band temperature

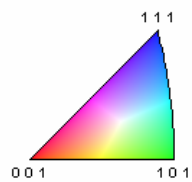
ND



Kernel  
AverageMisorientation



RD



	Min	Max
Blue	0	1
Green	1	1.5
Yellow	1.5	2
Orange	2	3
Red	3	4

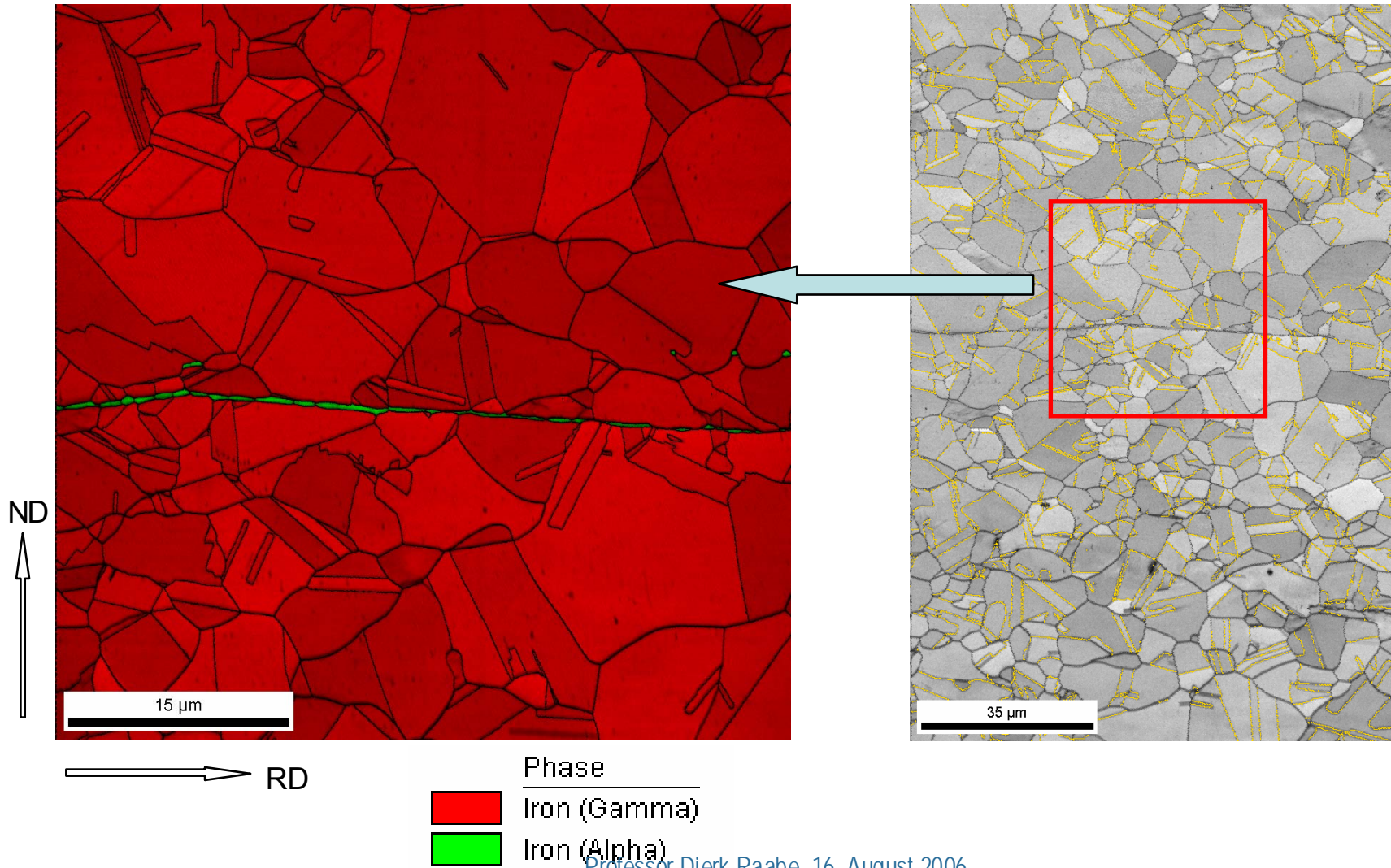


# TWIP subsurface (S = 0,8)



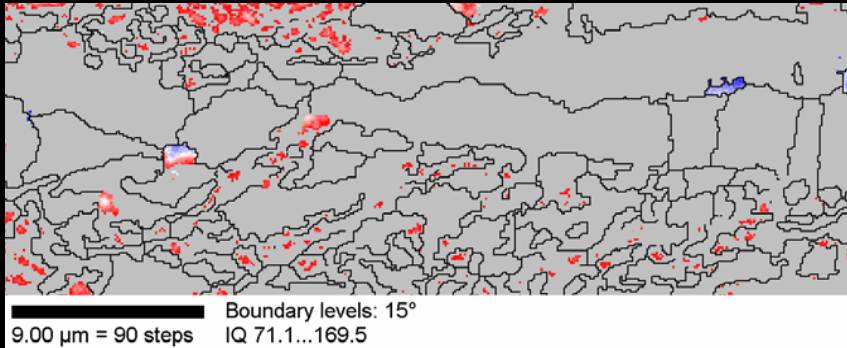
low hot band temperature

Finescan  
(50nm)

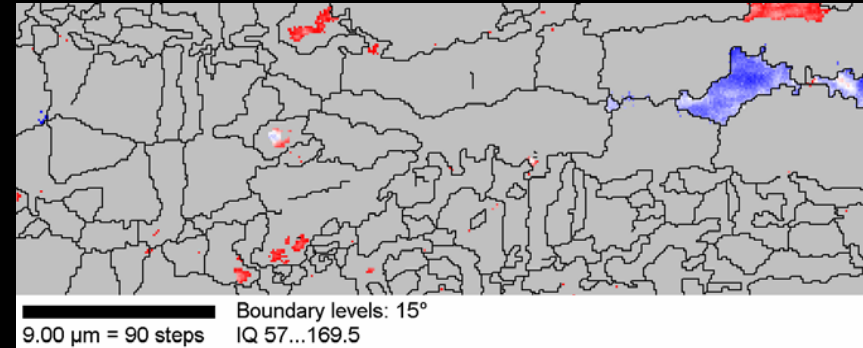




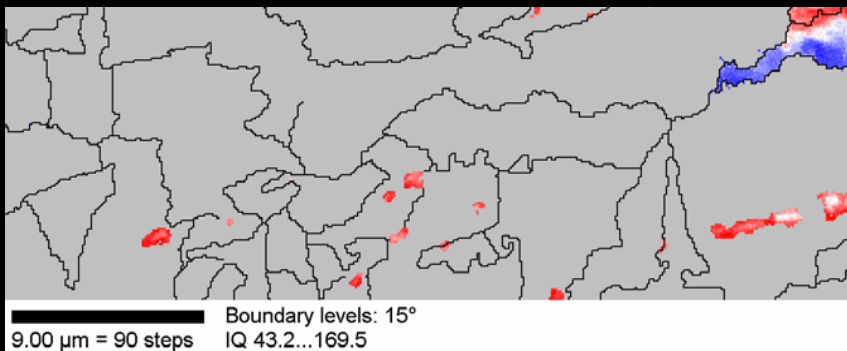
# Recrystallization (IF Steel)



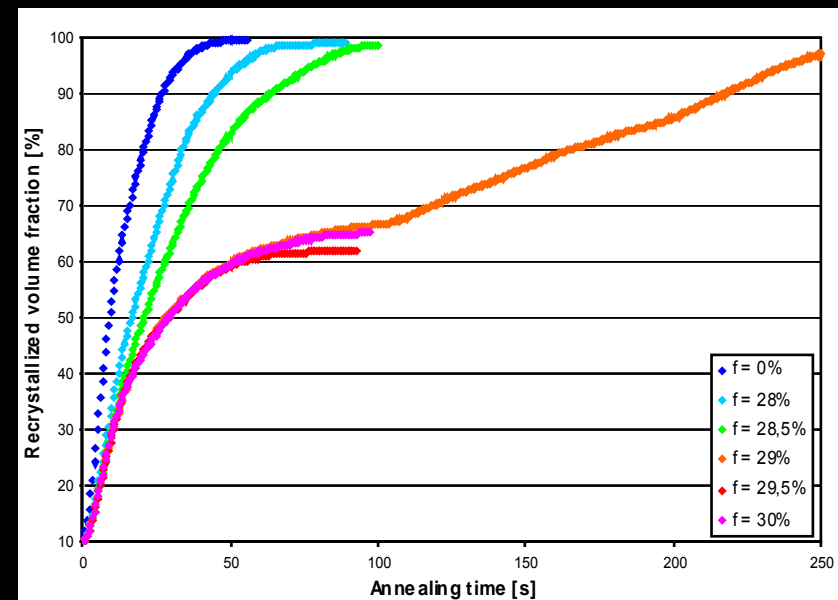
70% of  $\rho_{\text{max}}$



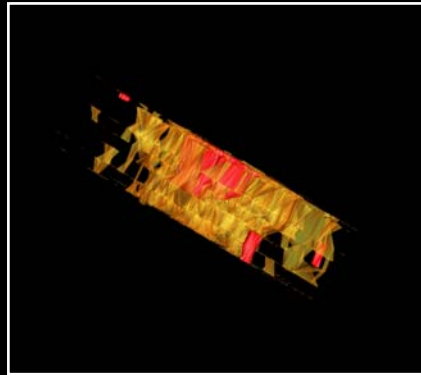
80% of  $\rho_{\text{max}}$



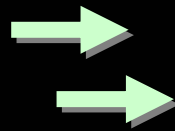
90% of  $\rho_{\text{max}}$







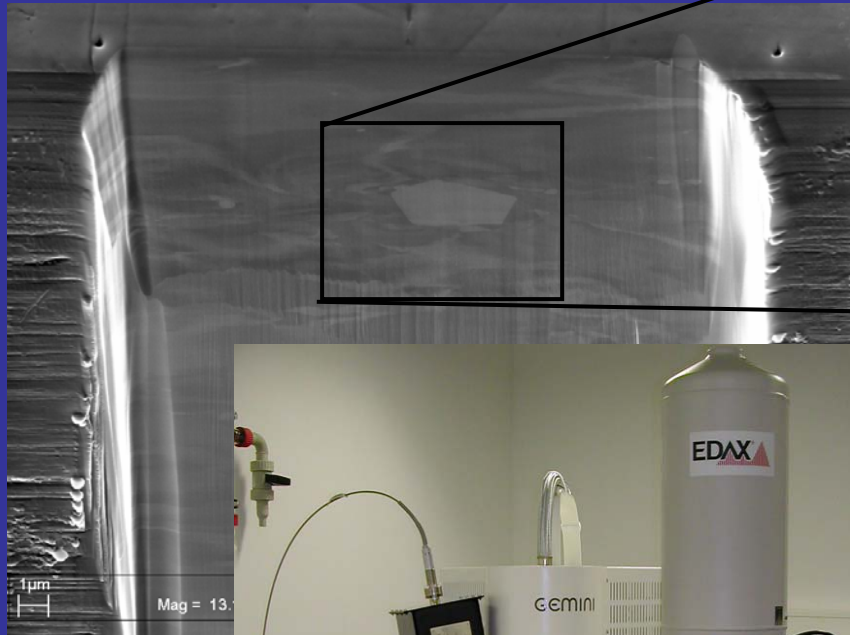
3D electron  
microscopy



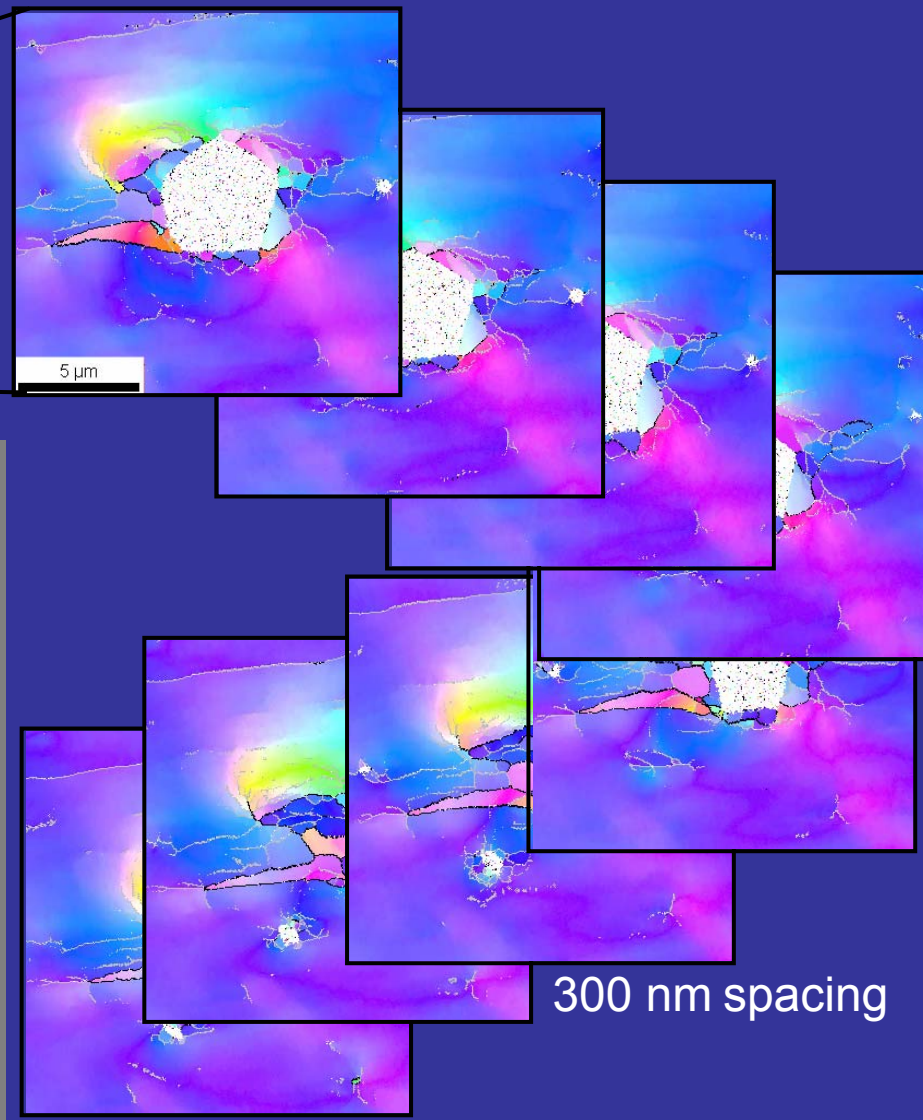
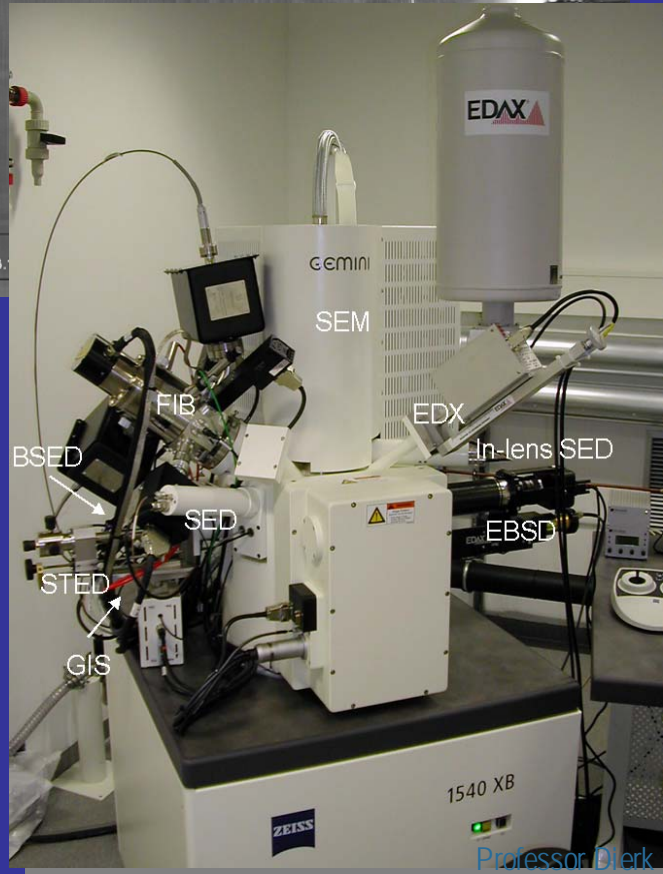
Intermetallics and Steels  
Nanocrystalline metals



# Example: 3D electron orientation microscopy



SE-image

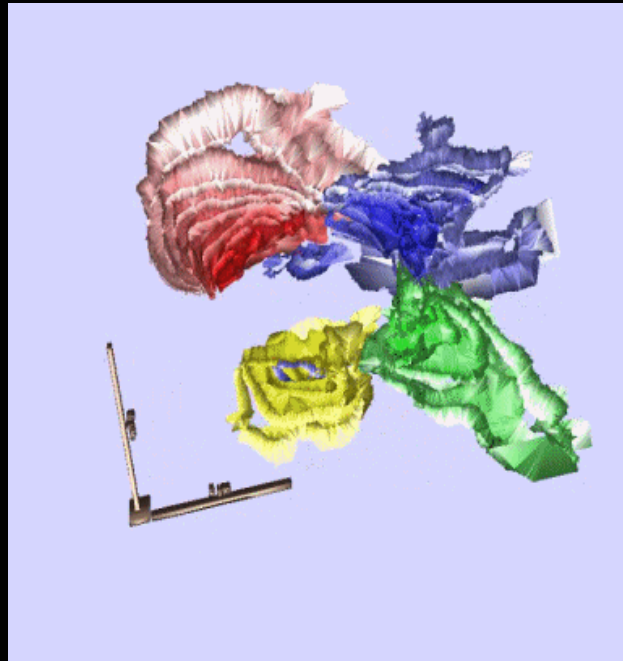




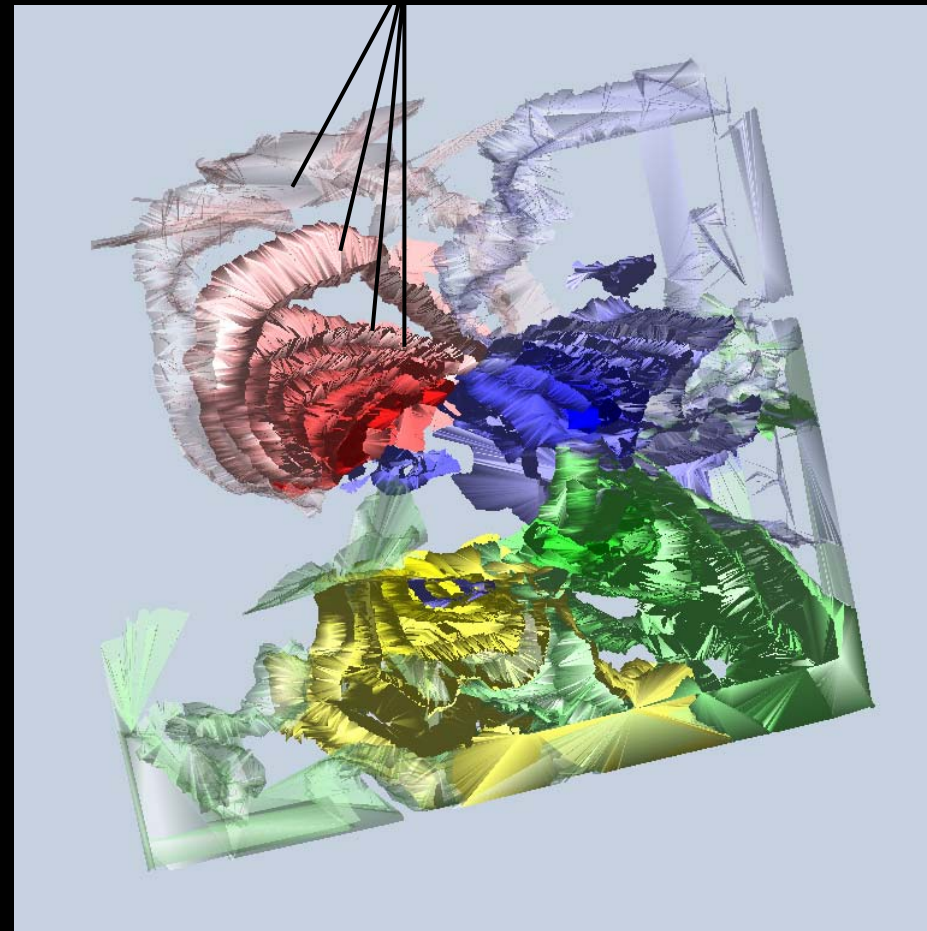
# Example: 3D electron orientation microscopy



5° misorientation steps from shell to shell



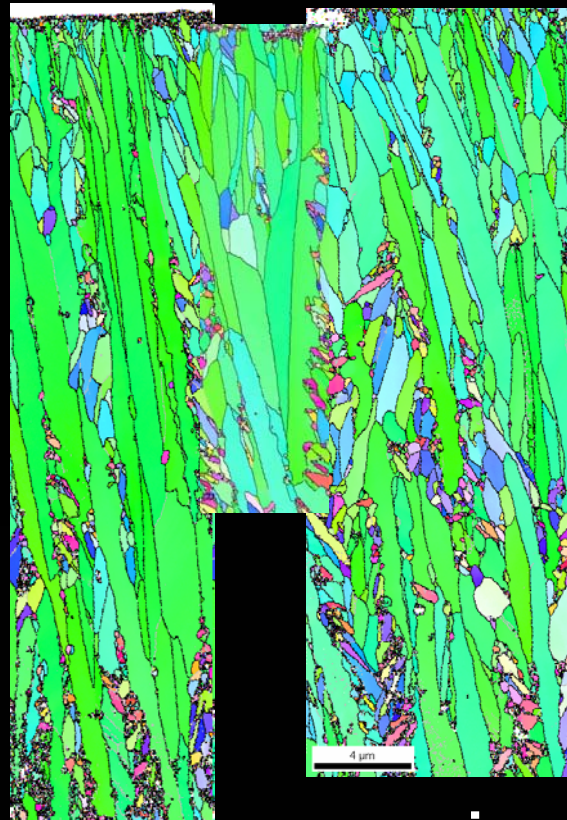
lattice rotations around Laves phase  
in  $\text{Fe}_3\text{Al}$



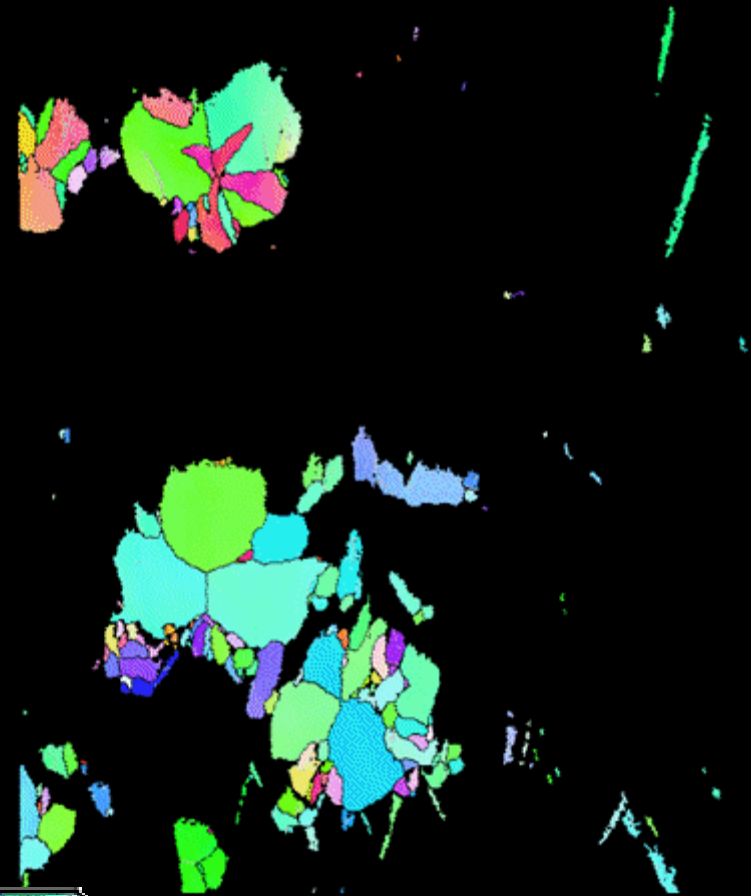
# 3D electron orientation microscopy



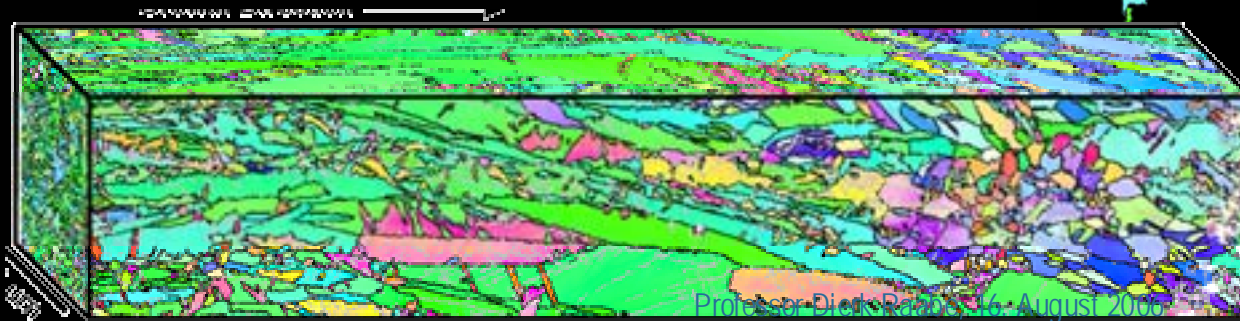
isolated pyramid



cross view



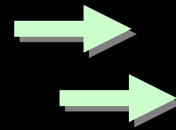
top view







biomaterials  
biological materials



Natural mineralized chitin composites  
Beta-Ti

# Methods and systematics



1) structure, texture

TEM, SEM, EBSD, EDX, FIB, X-ray (lab-scale), Synchrotron

2) properties

indentation, compression tests, tensile tests, photogrammetry

3) specimens

mineralized chitin-protein tissue

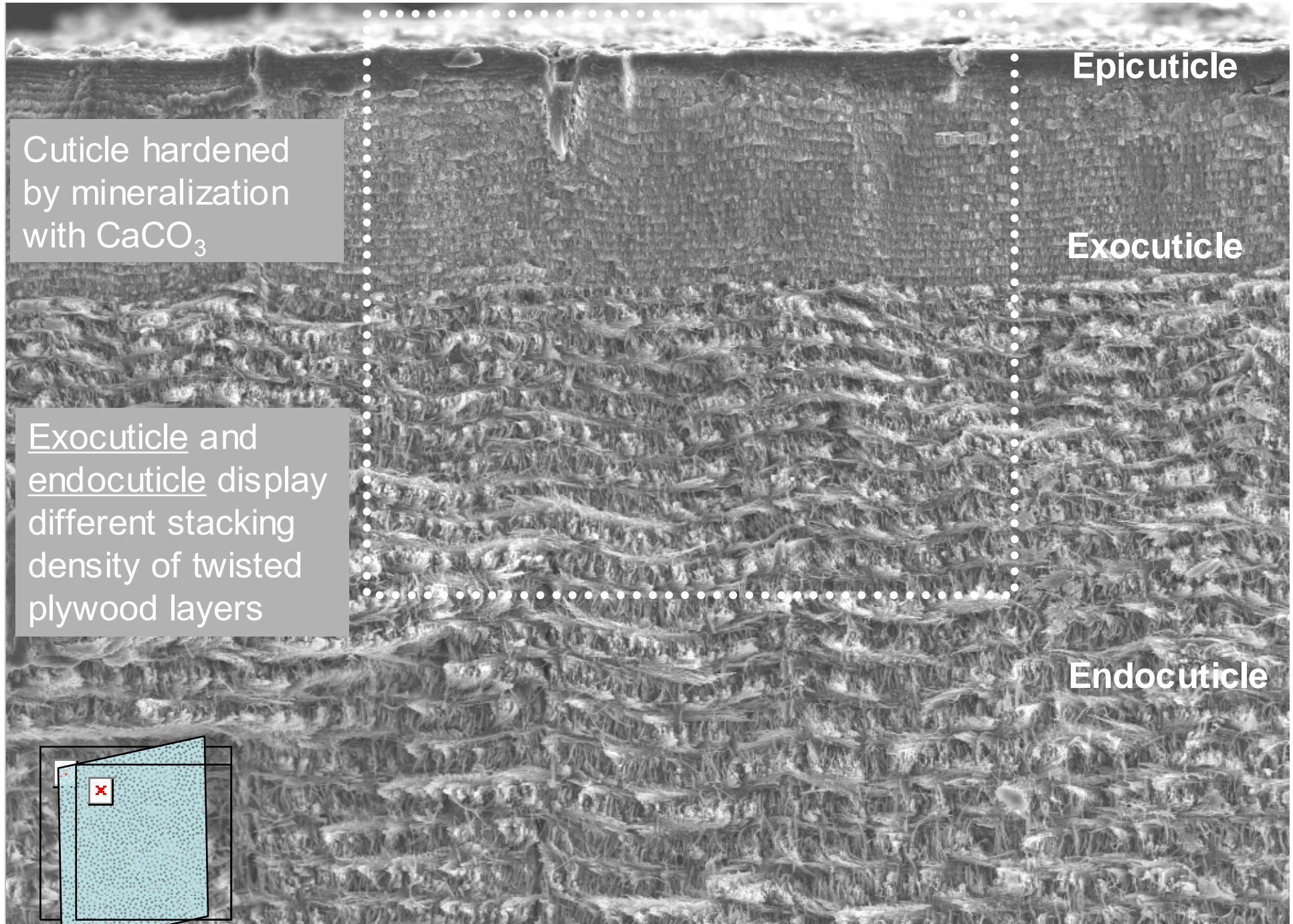


mineral content

Professor Dierk Raabe 16. August 2016







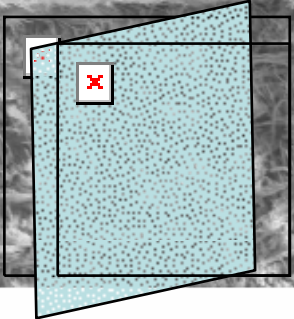
Cuticle hardened by mineralization with  $\text{CaCO}_3$

Exocuticle and endocuticle display different stacking density of twisted plywood layers

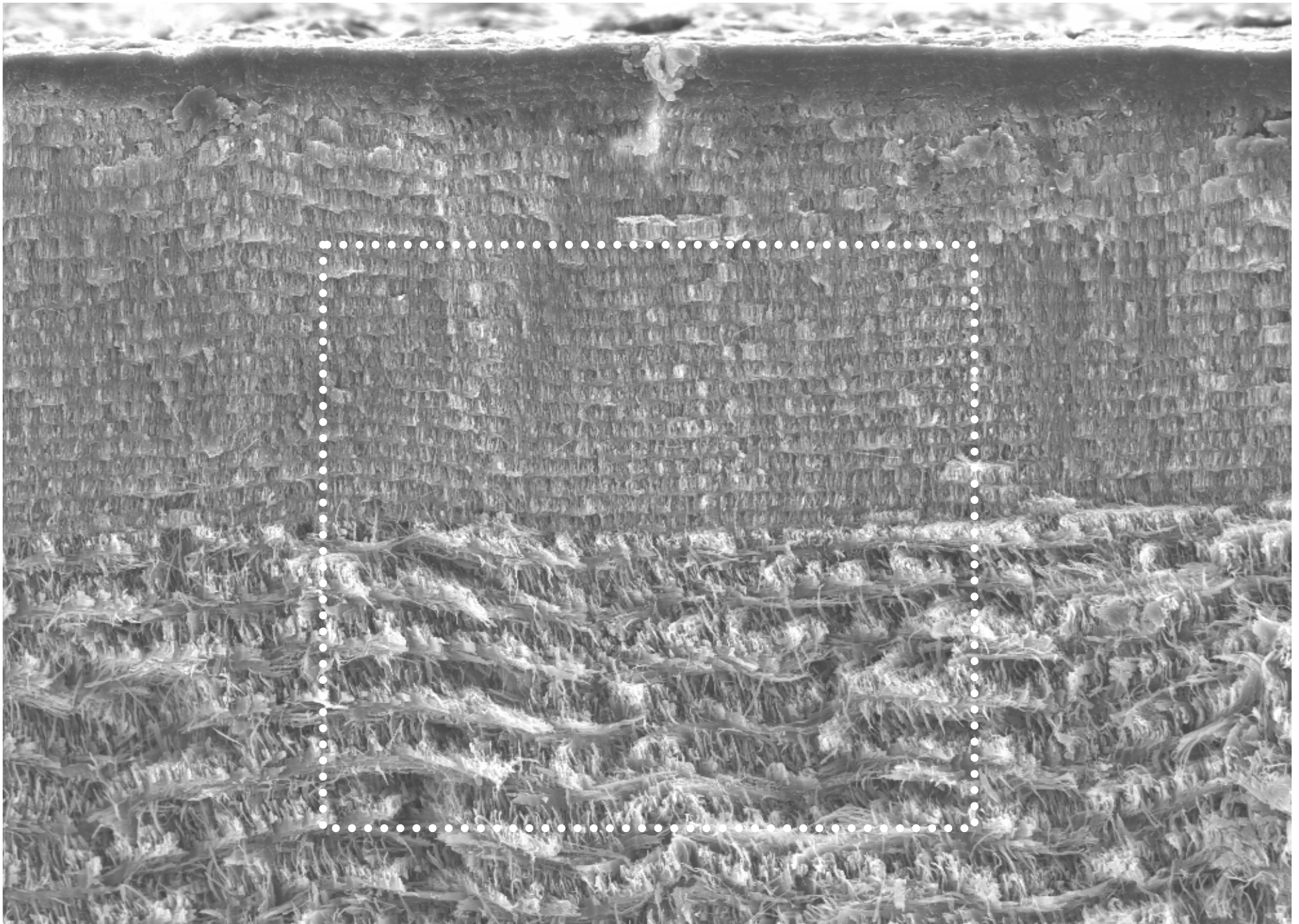
Epicuticle

Exocuticle

Endocuticle



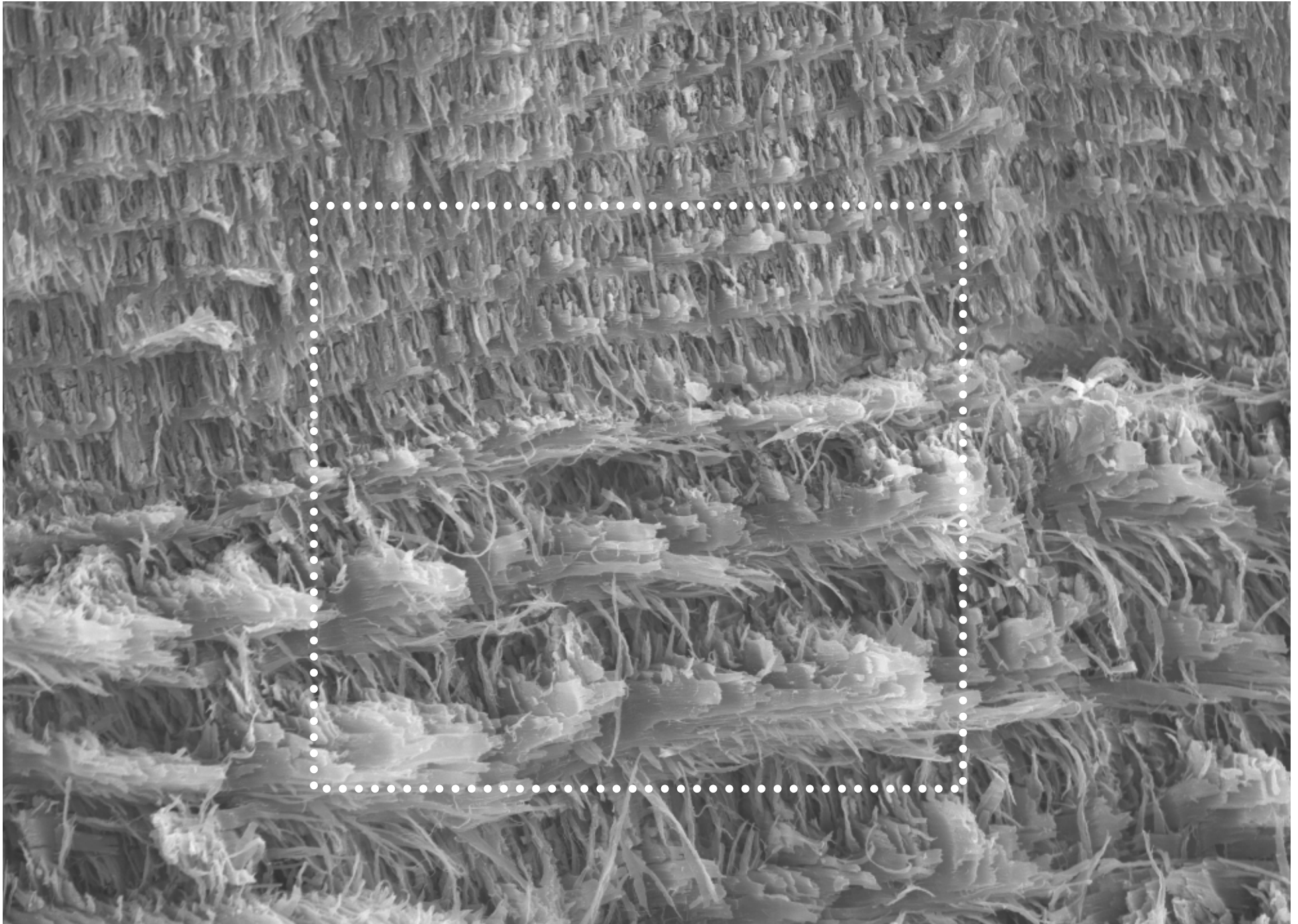




Professor Dierk Raabe, 16. August 2006

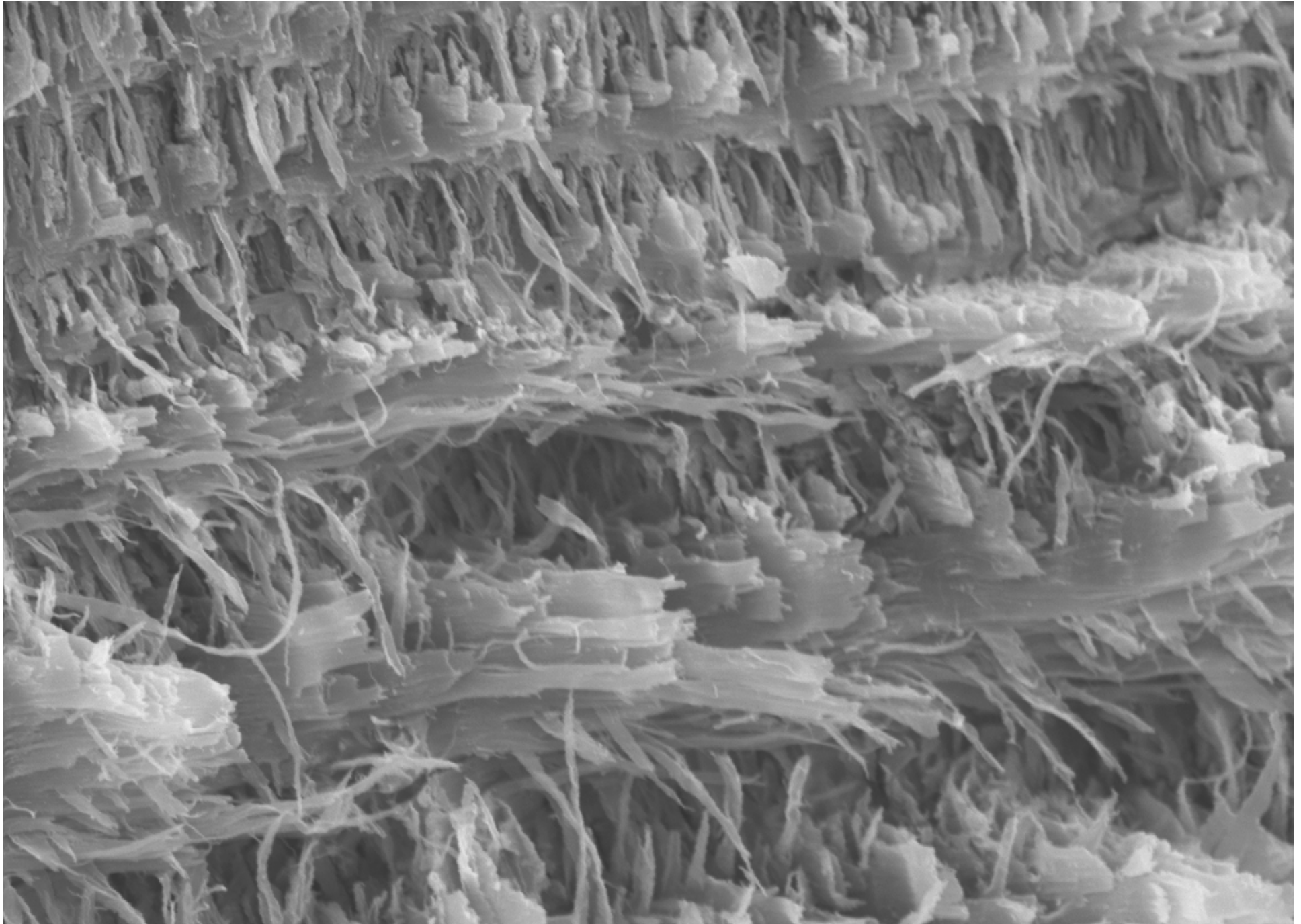
— 100  $\mu\text{m}$  —





Professor Dierk Raabe, 16. August 2006

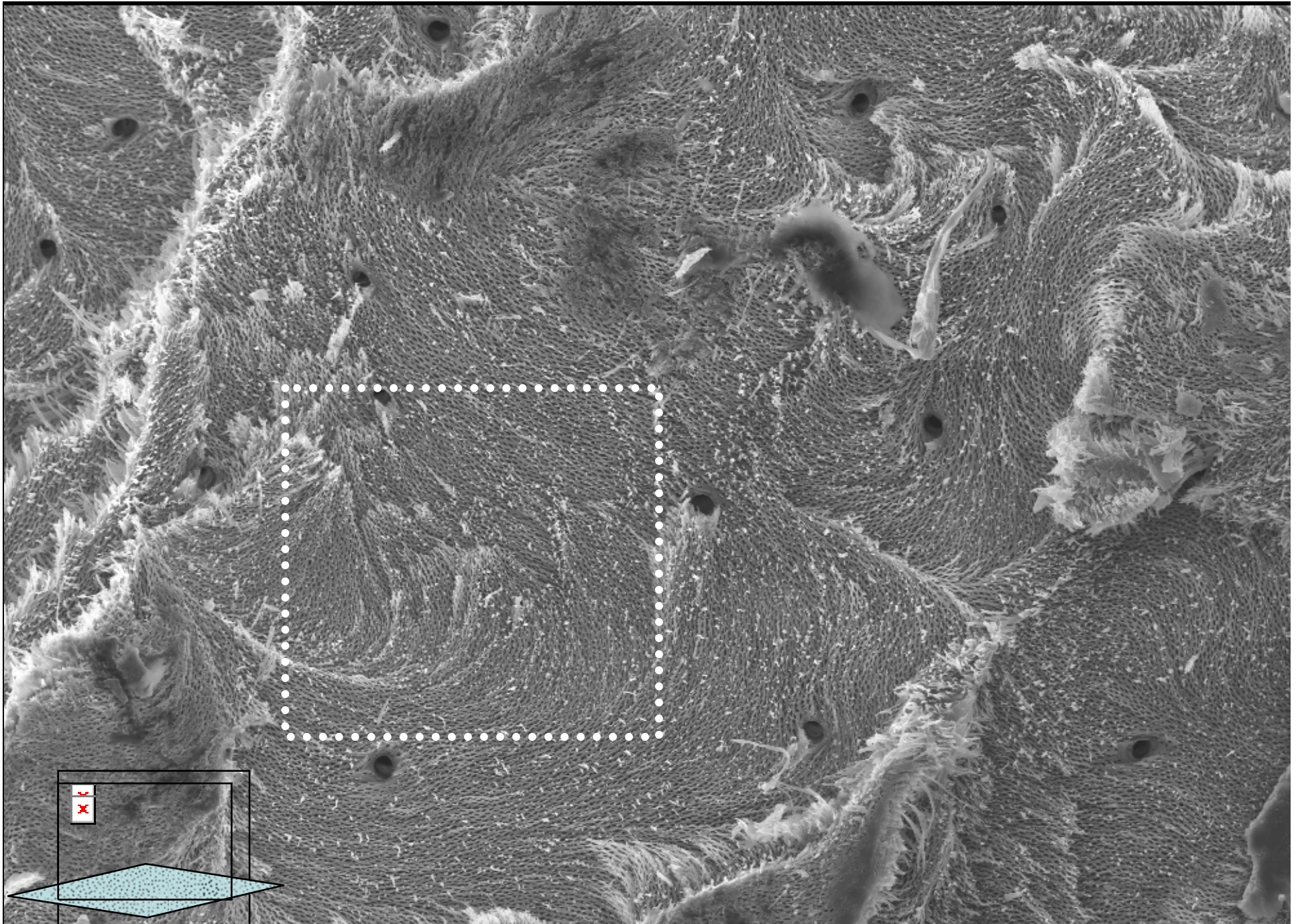
— 30  $\mu\text{m}$  —



Professor Dierk Raabe, 16. August 2006

┌ 10  $\mu$ m ─┘

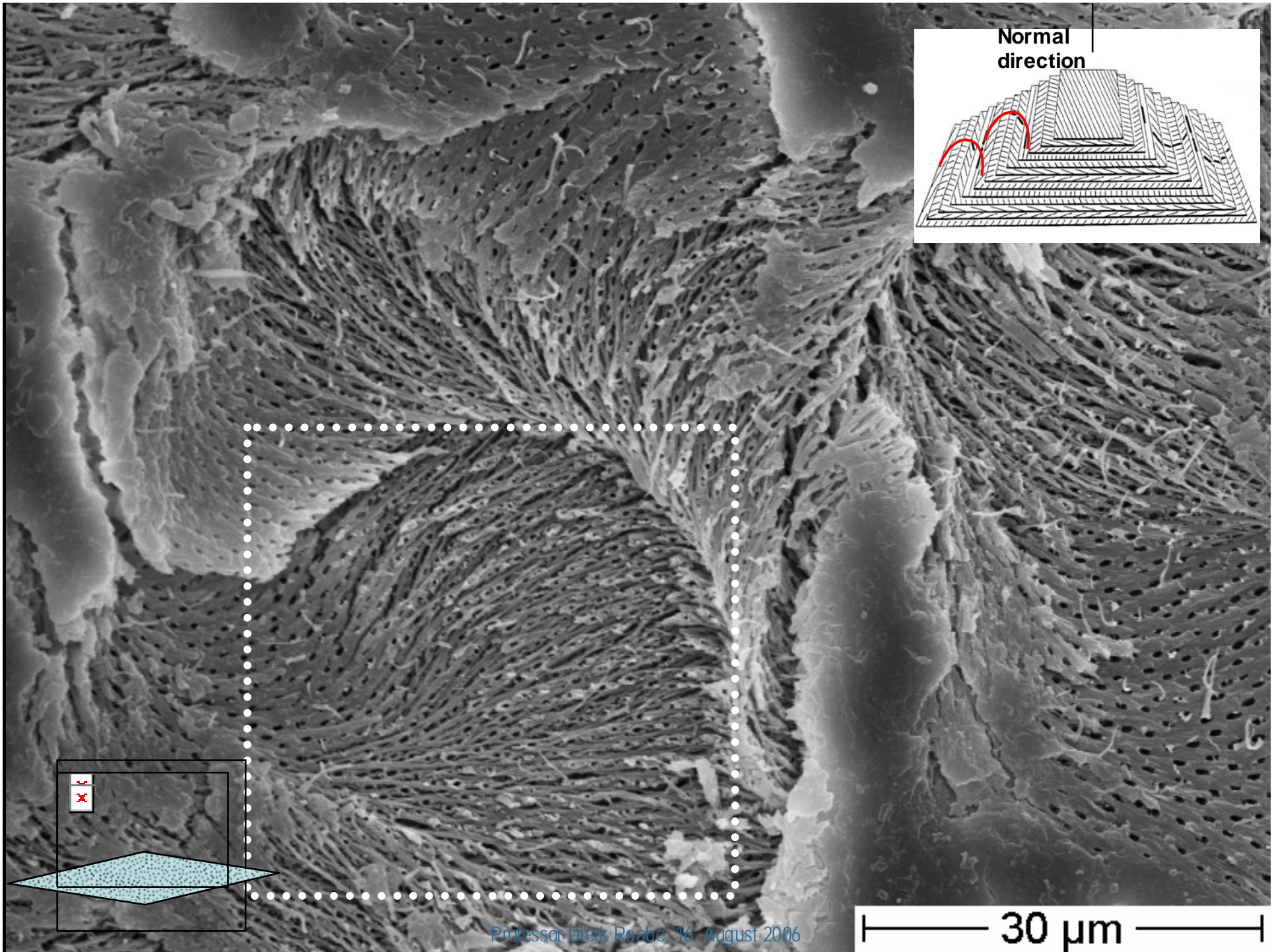




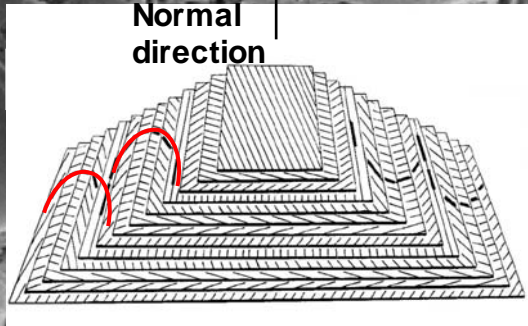
Professor Dierk Raabe, 16. August 2006

— 100  $\mu\text{m}$  —

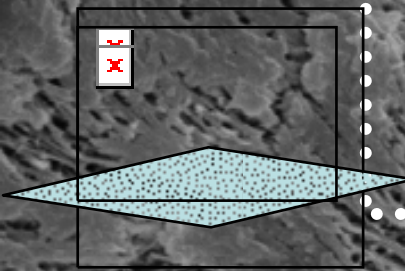




Normal  
direction

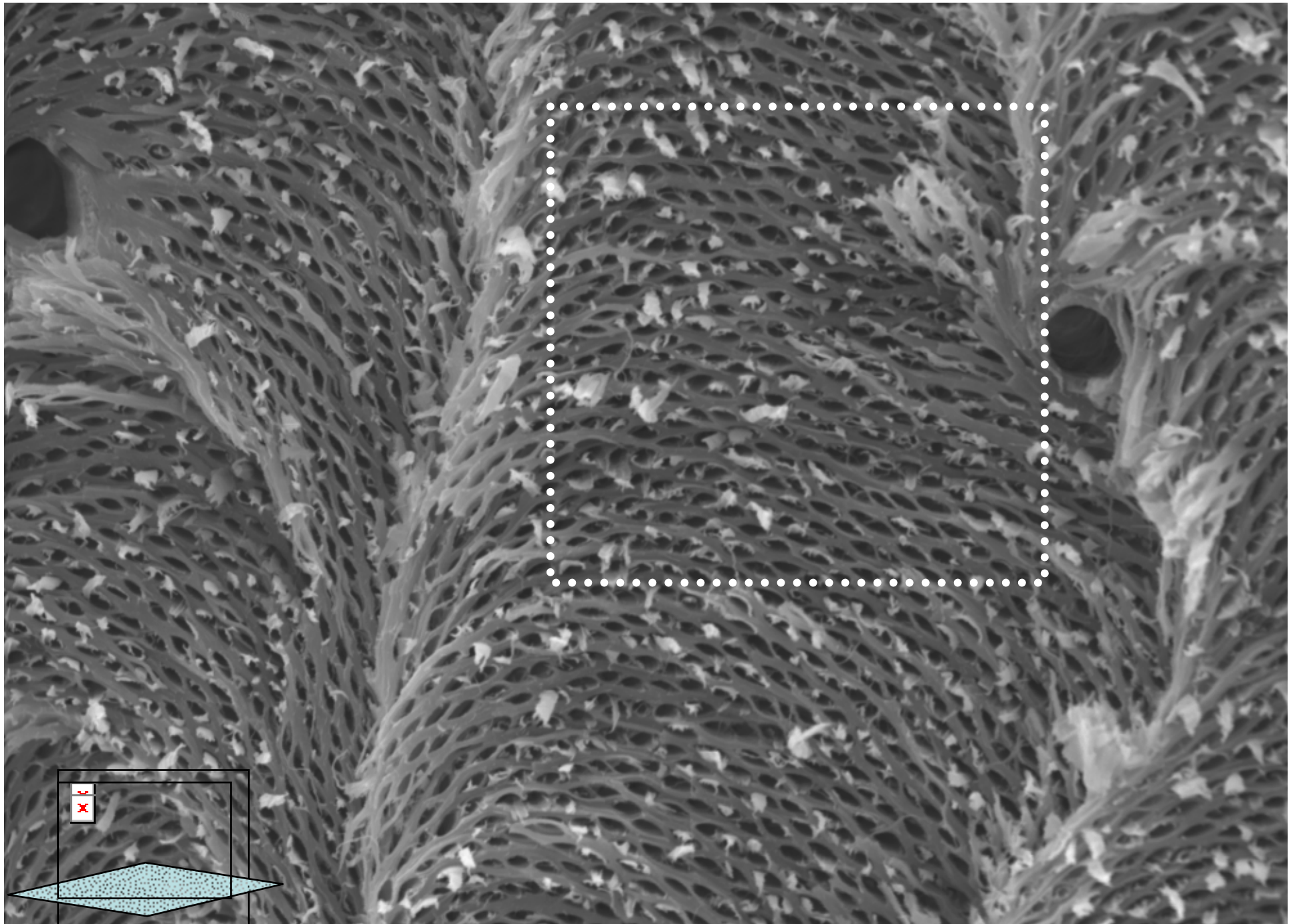


X



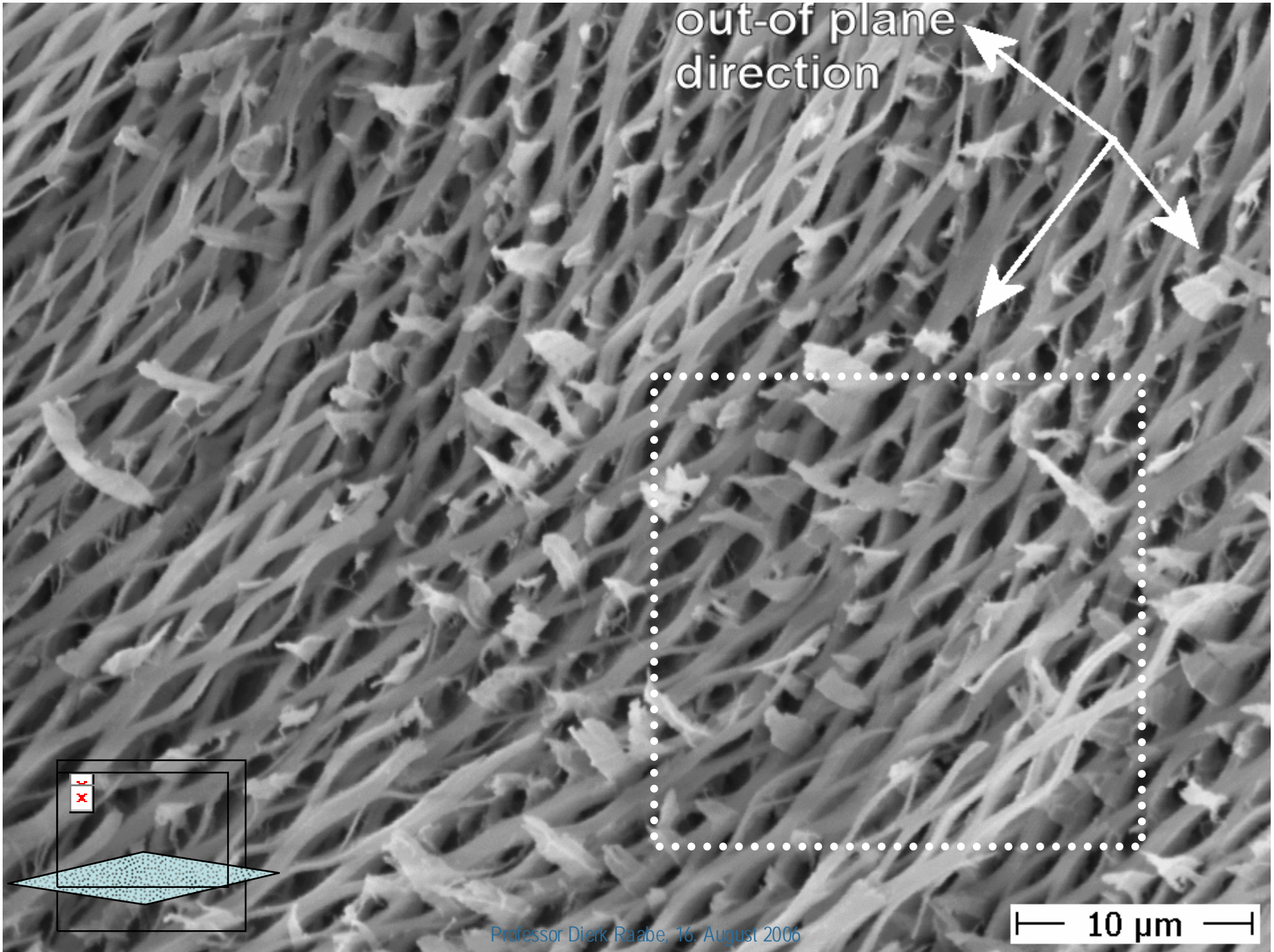
30  $\mu\text{m}$



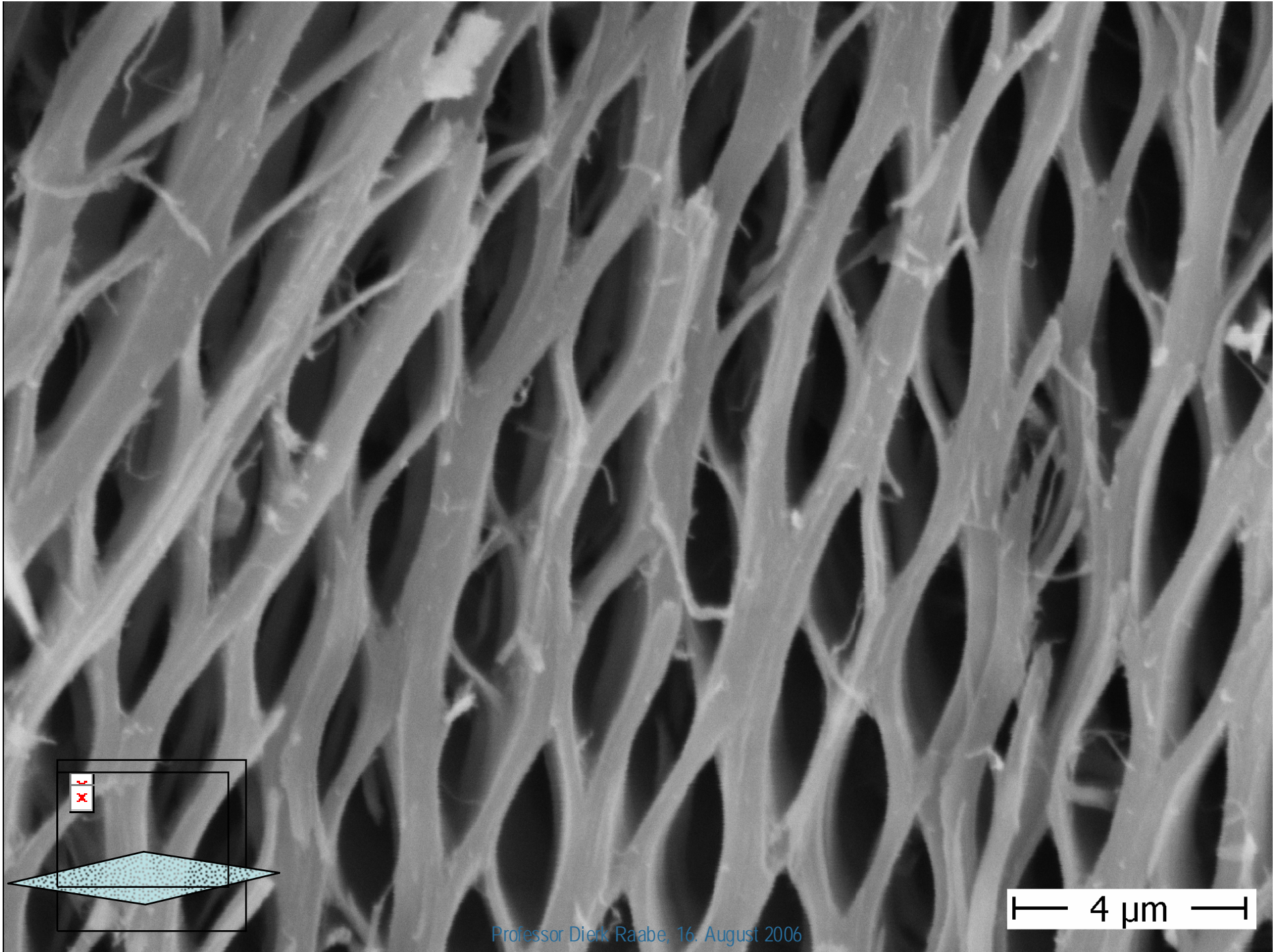


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— 20  $\mu\text{m}$  —

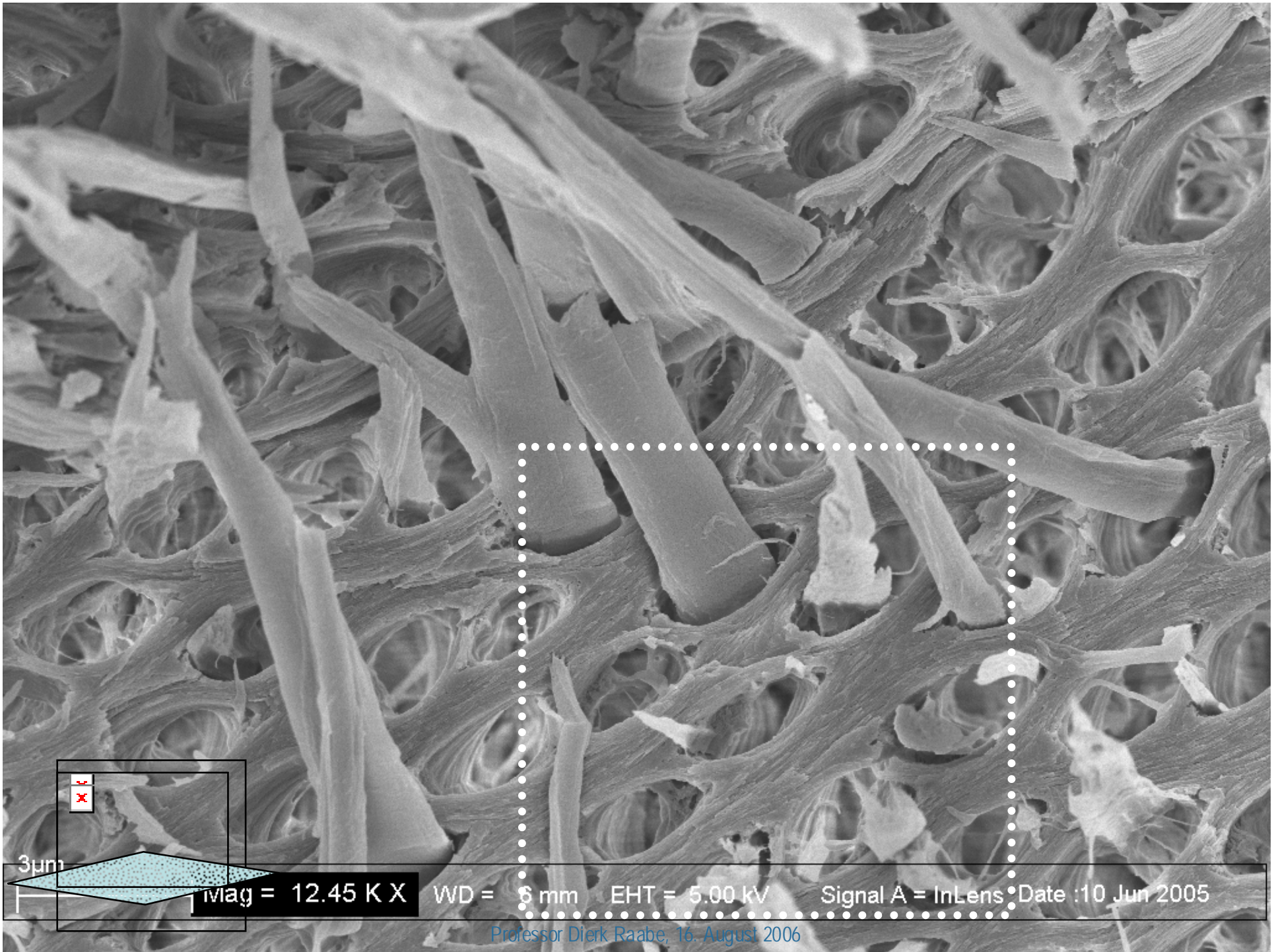






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3  
X

3µm

Mag = 12.45 K X

WD = 6 mm

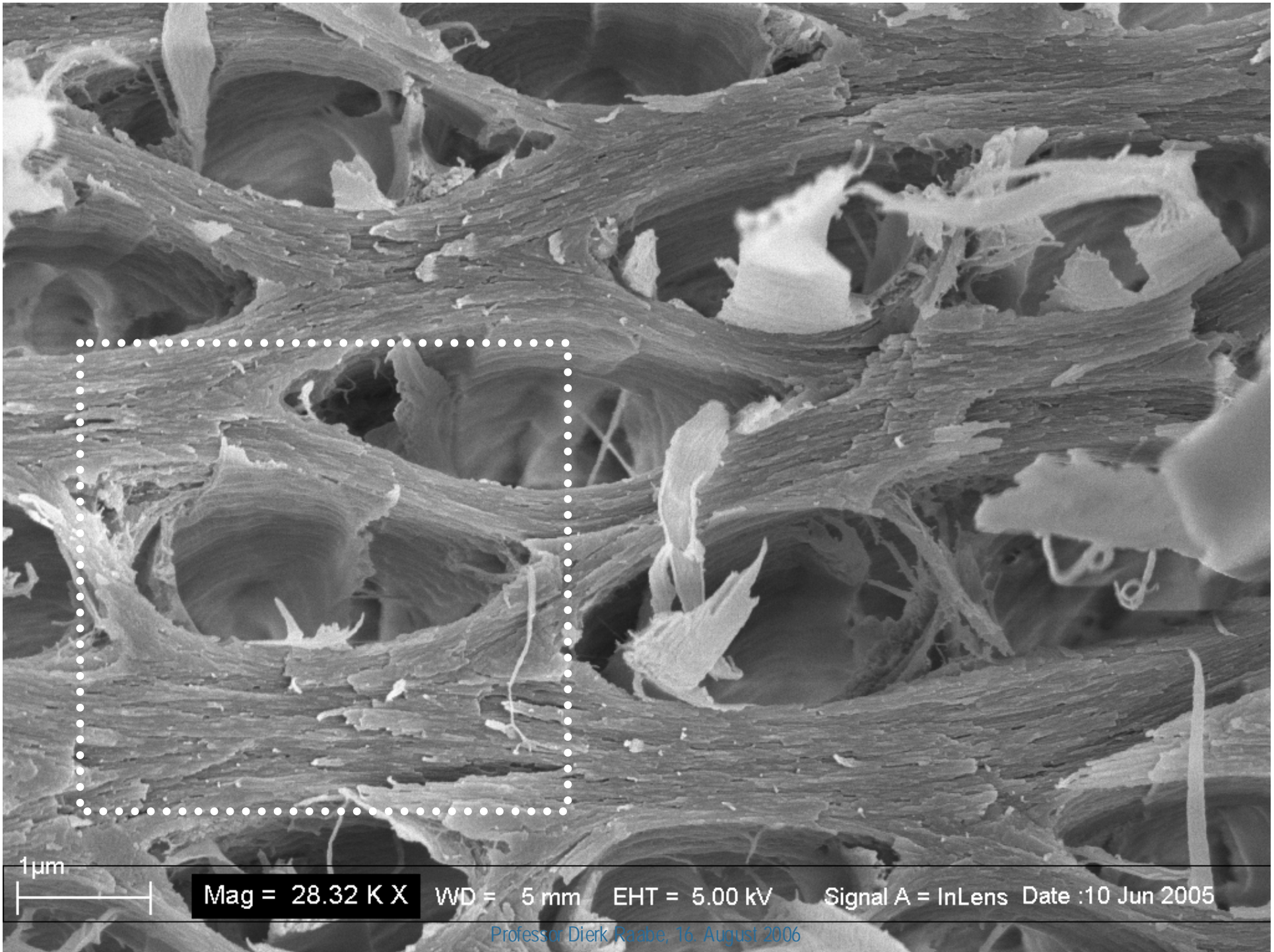
EHT = 5.00 kV

Signal A = InLens

Date : 10 Jun 2005

Professor Dierk Raabe, 16. August 2006





1µm

Mag = 28.32 K X

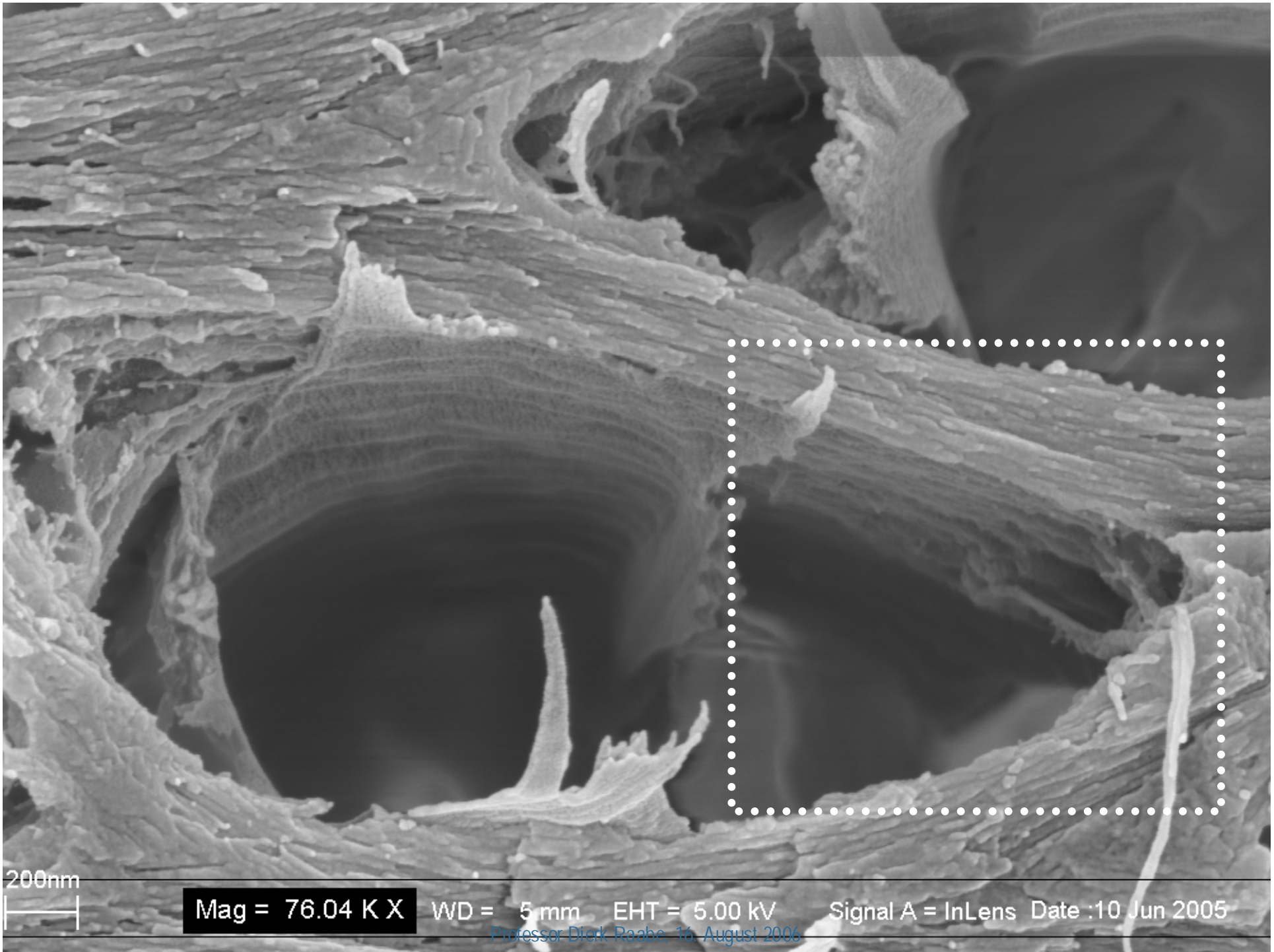
WD = 5 mm

EHT = 5.00 kV

Signal A = InLens

Date :10 Jun 2005

Professor Dierk Raabe, 16. August 2006



200nm  
|  
|

Mag = 76.04 K X    WD = 5 mm    EHT = 5.00 kV    Signal A = InLens    Date :10 Jun 2005

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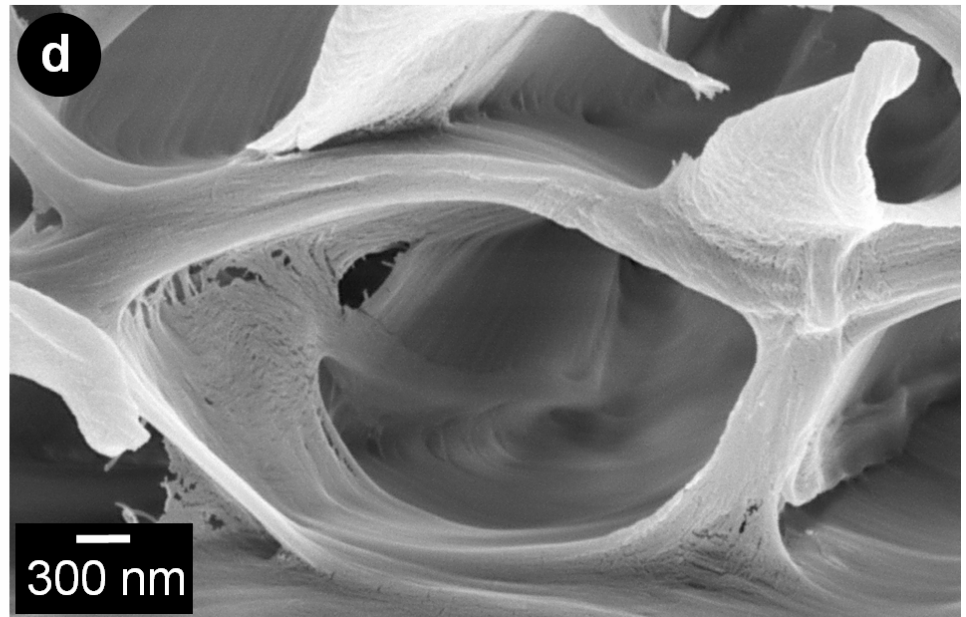
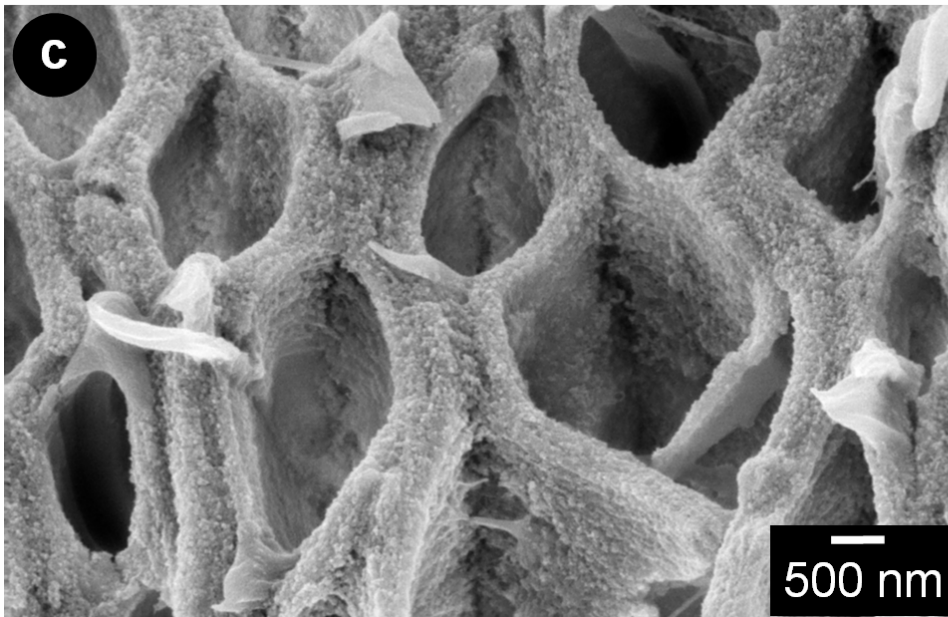
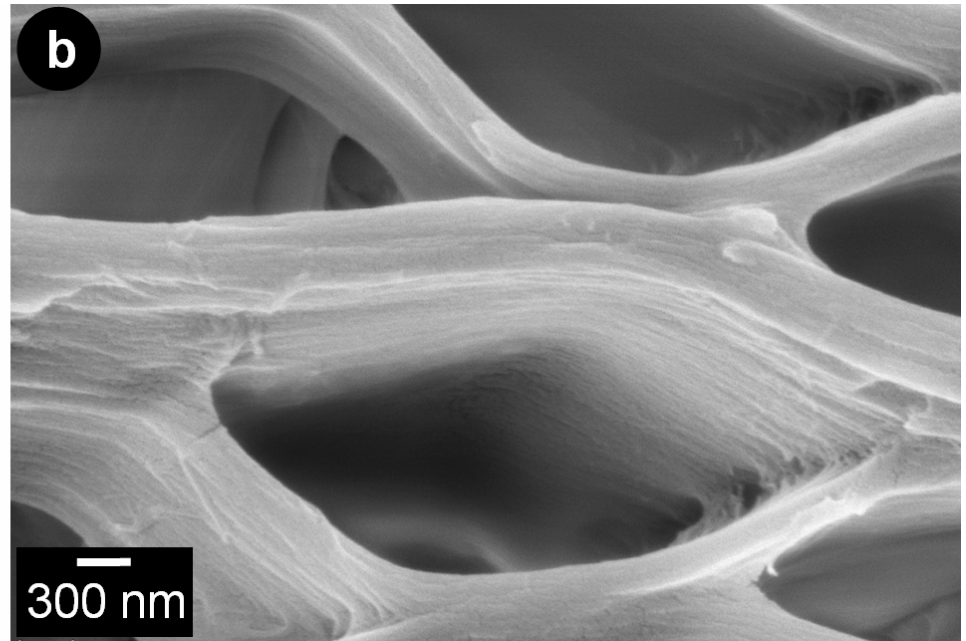
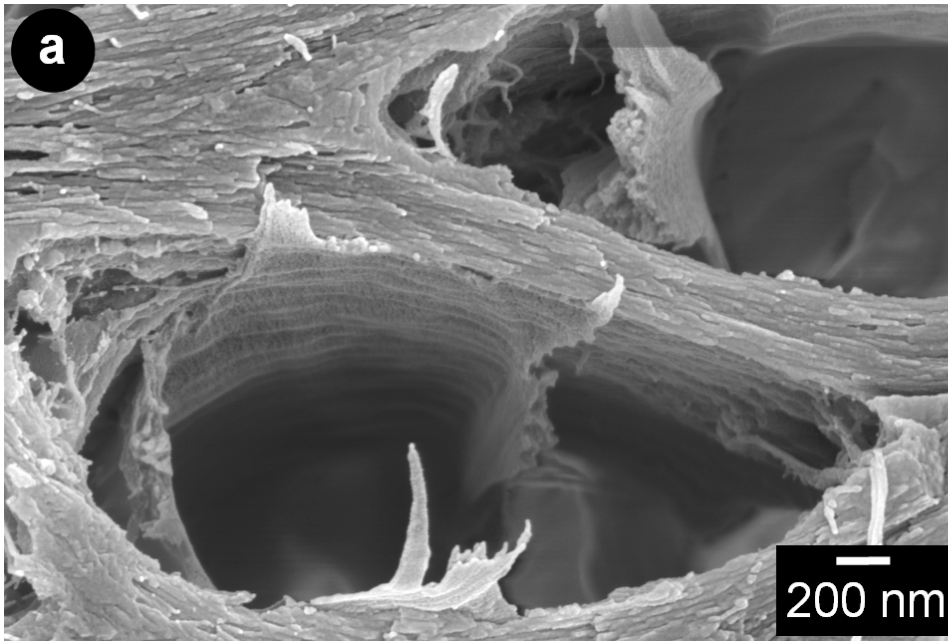




100nm

Mag = 133.31 K X WD = 5 mm EHT = 5.00 kV Signal A = InLens Date :9 Jun 2005

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(a) Untreated cuticle, (b) decalcified cuticle (EDTA, 0.15M), (c) deproteinized cuticle (NaOH, 1M) and (d) decalcified and deproteinized cuticle (EDTA, 0.15M + NaOH, 1M).



# X-ray wide angle diffraction, lobster



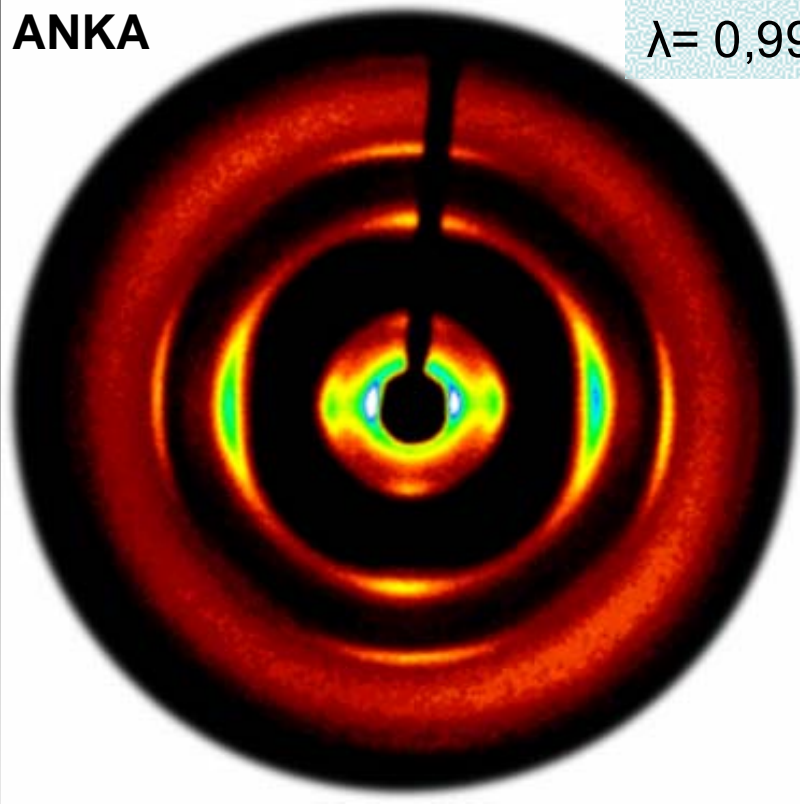
ANKA

$\lambda = 0,99955 \text{ \AA}$

very strong chitin textures

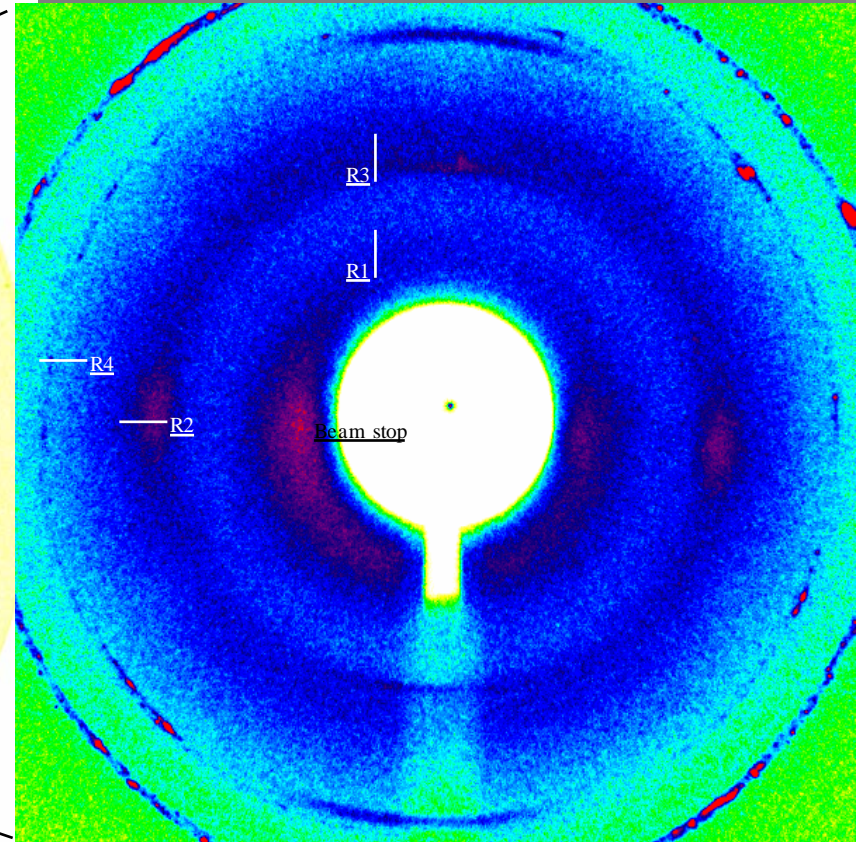
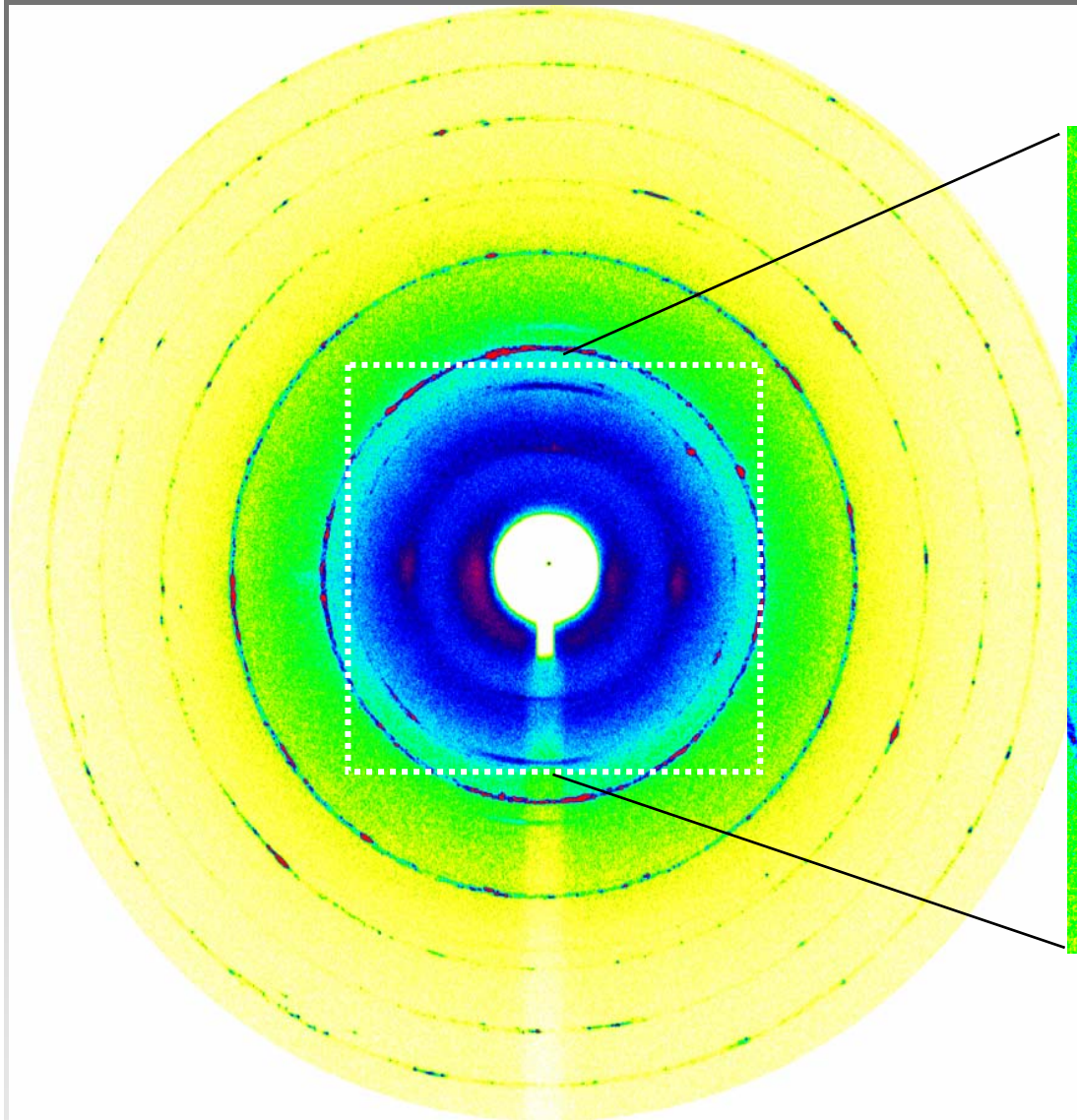
Co-target

$\lambda = 1,7889 \text{ \AA}$





# Synchrotron x-ray, wide angle, lobster



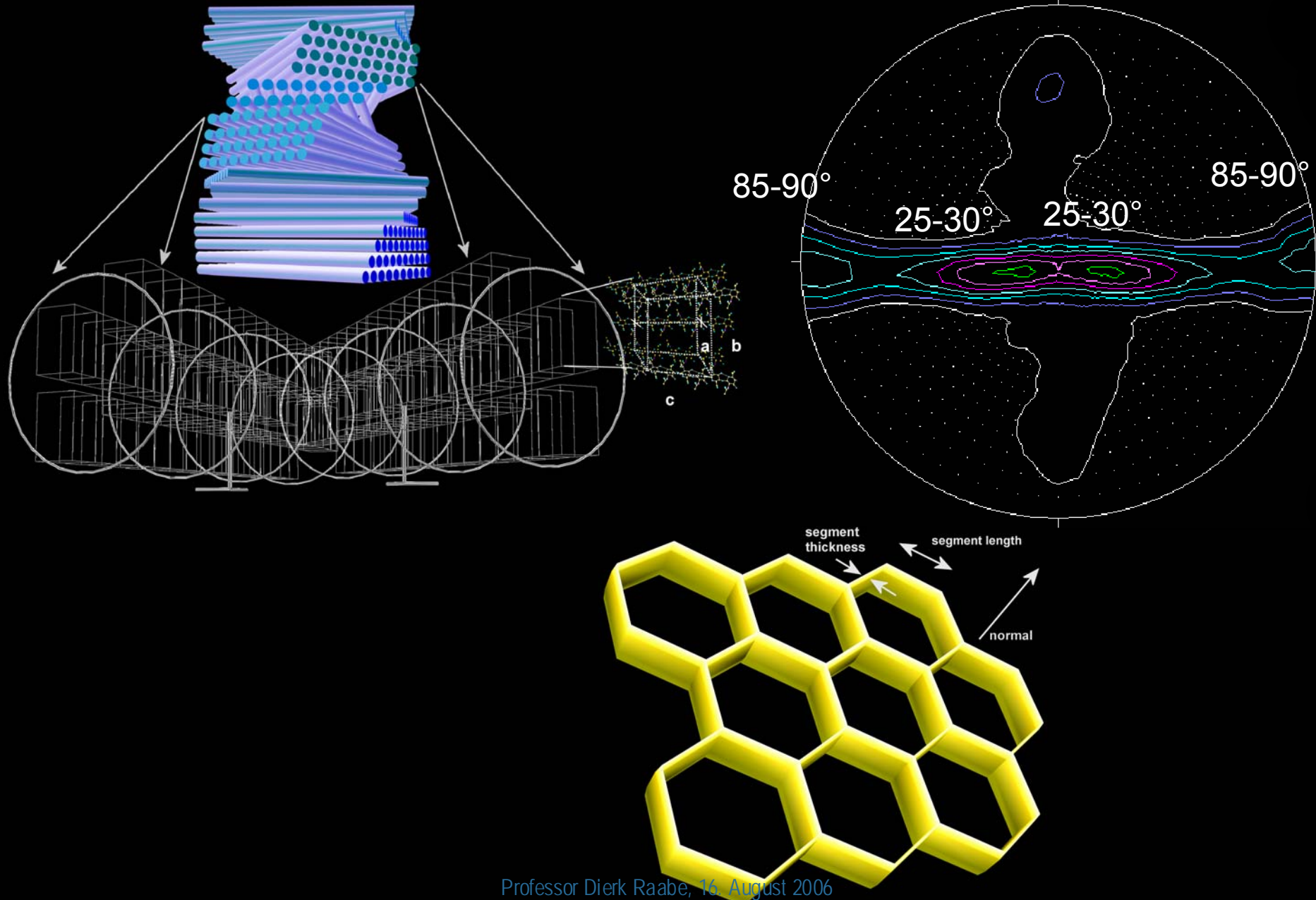
very strong chitin textures  
clusters of calcite ?

DESY (BW5),  $\lambda=0.196 \text{ \AA}$ .

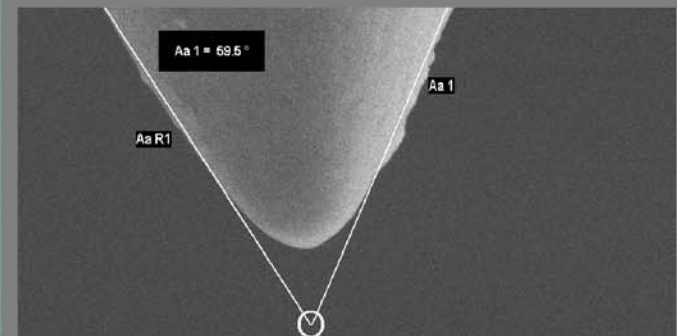
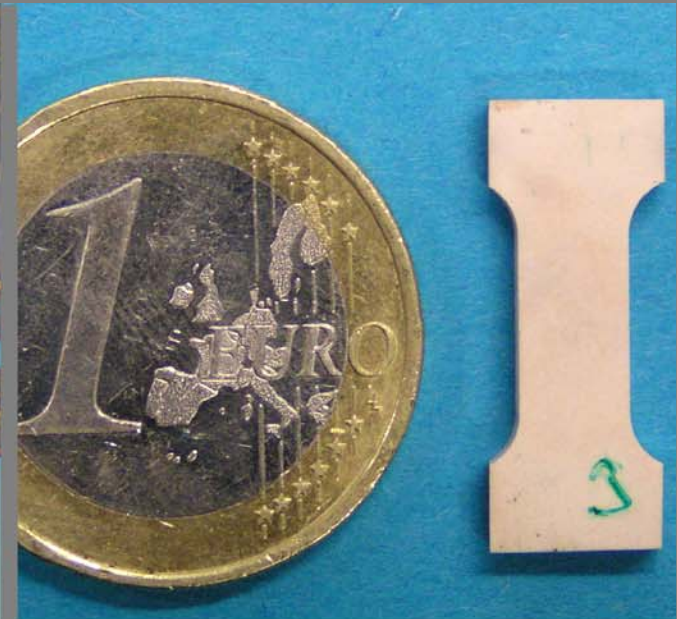
Professor Dierk Raabe, 16. August 2006



# Structure and texture of chitin



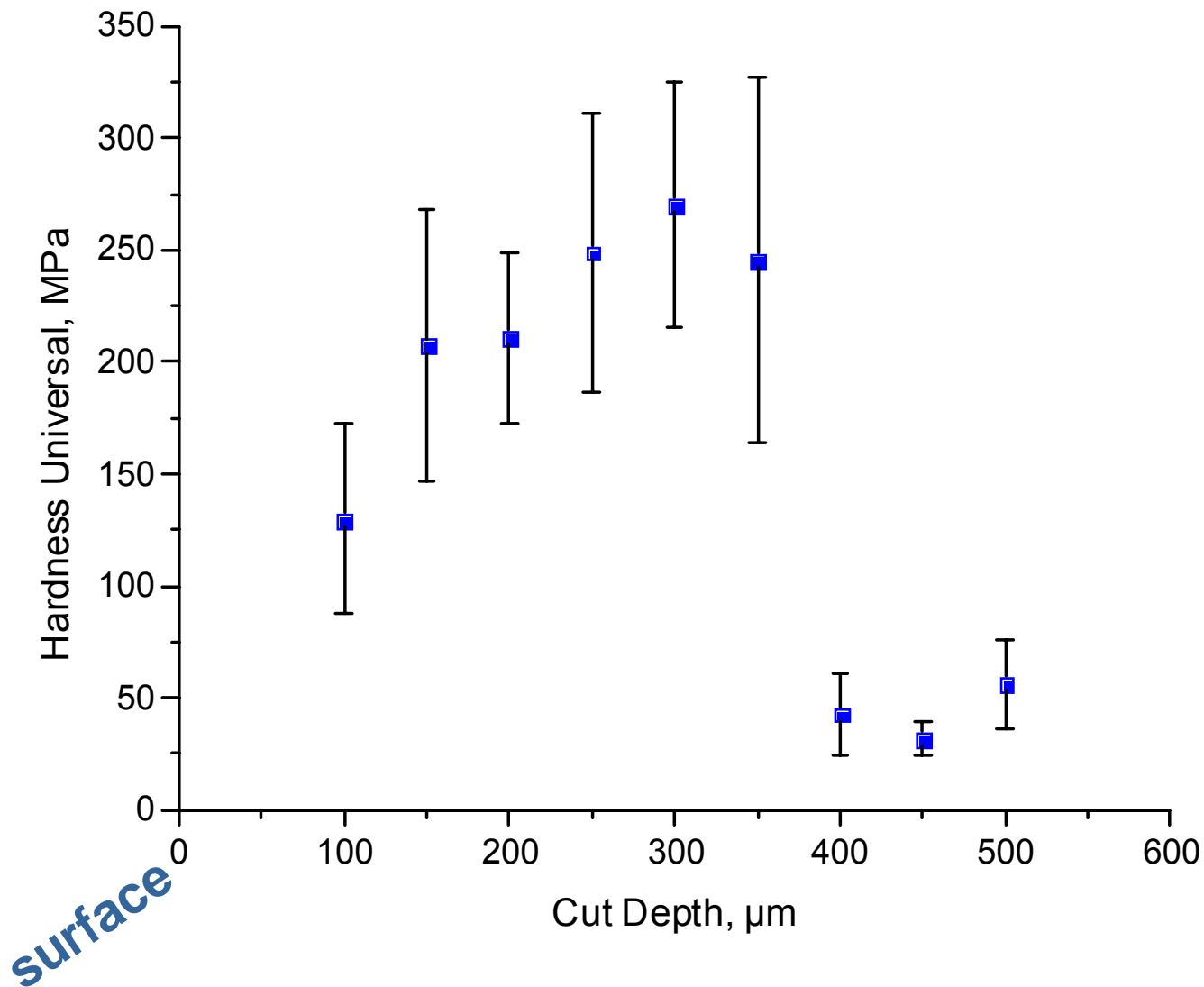
# Tensile testing, Indentation



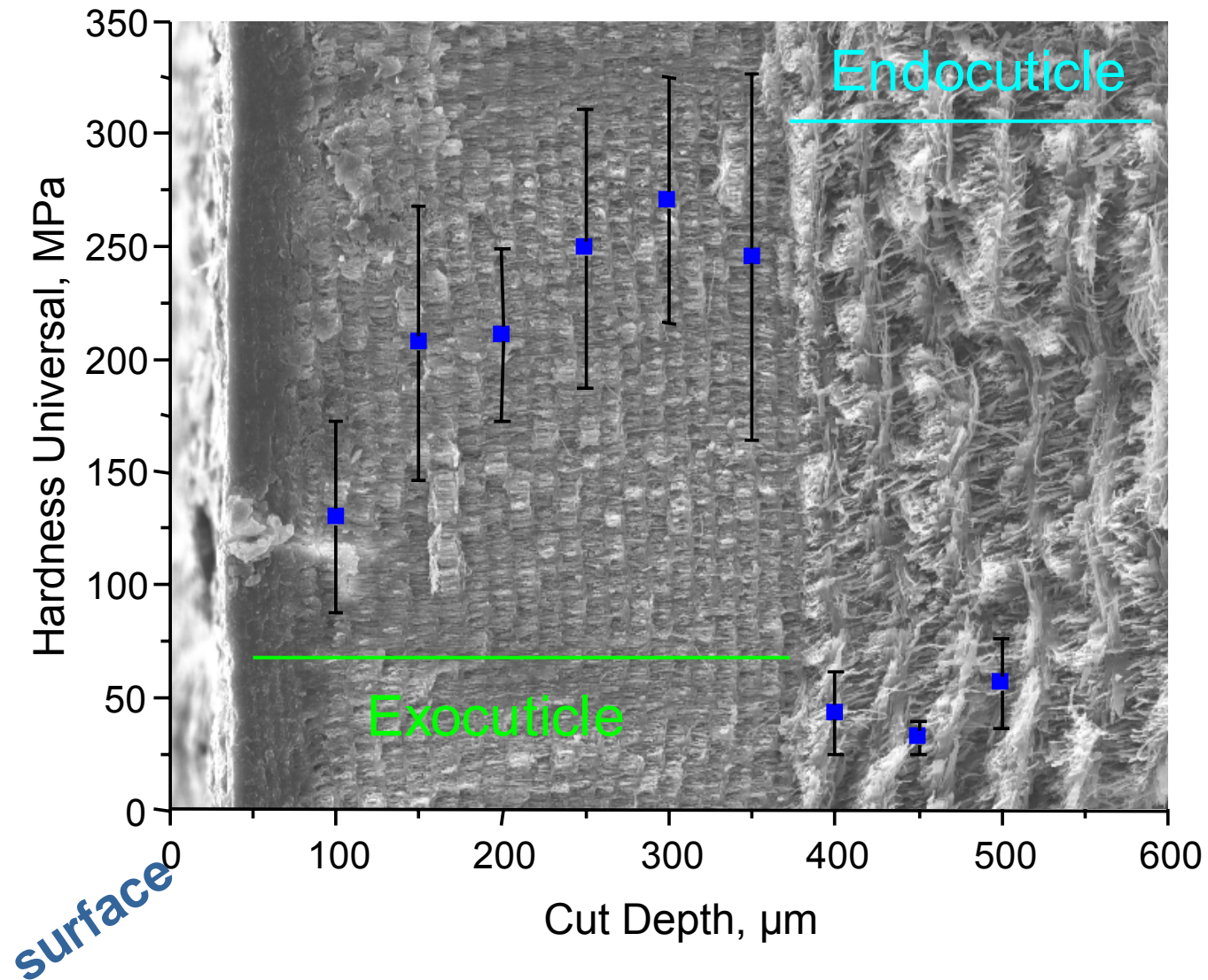




## Hardness profile parallel to surface



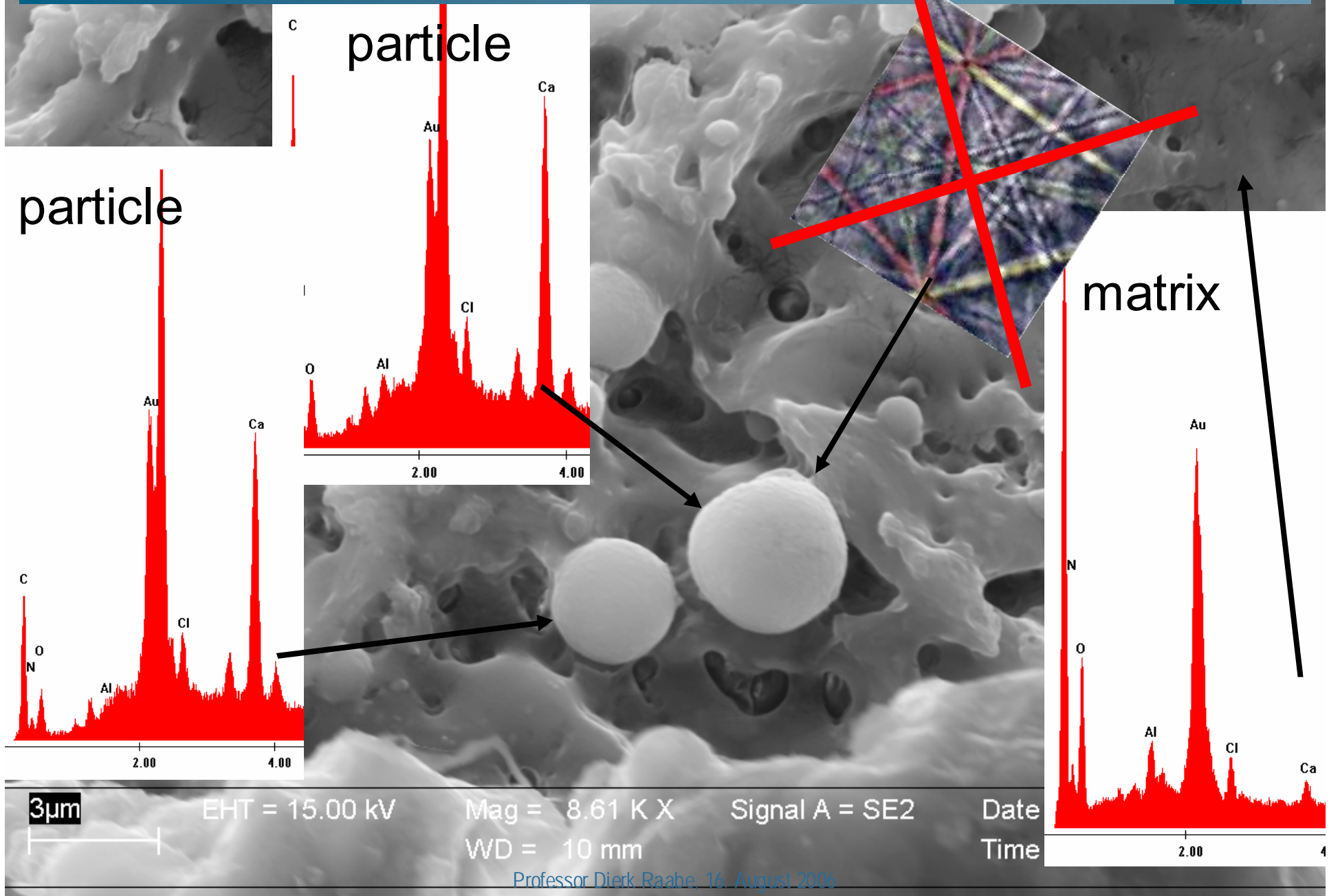
# Hardness



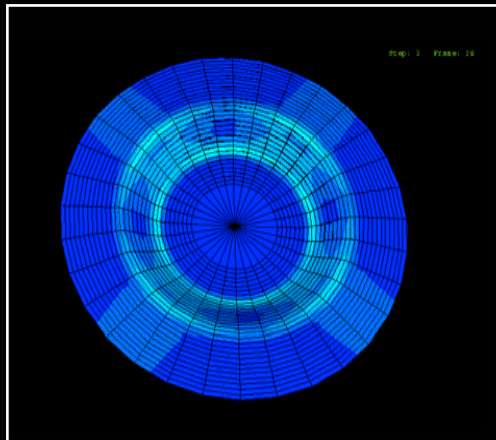




# Horseshoe crab, FIB+EBSD, Ca, no Kikuchi



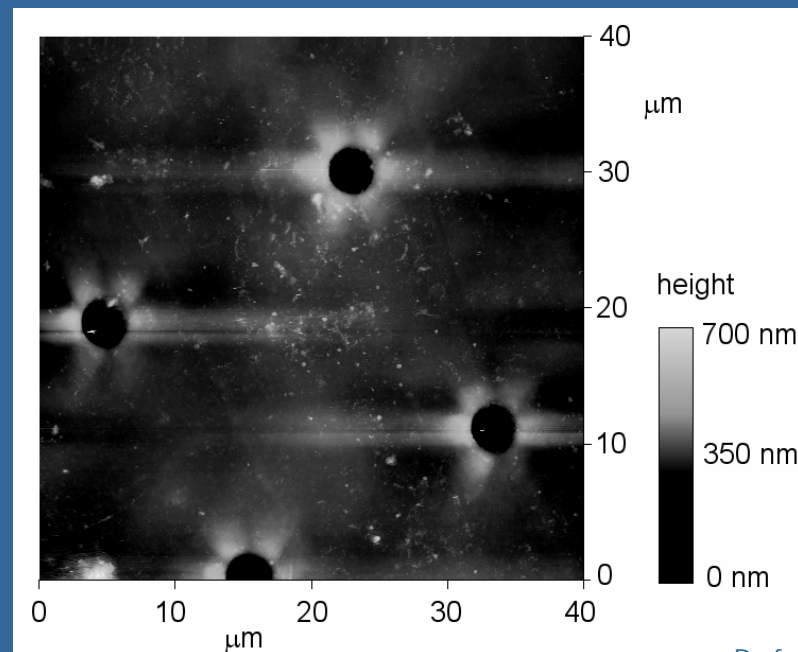
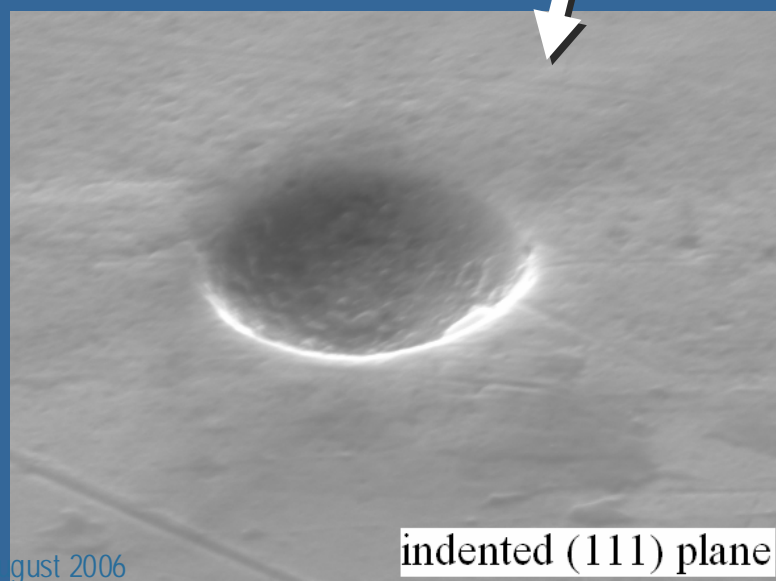
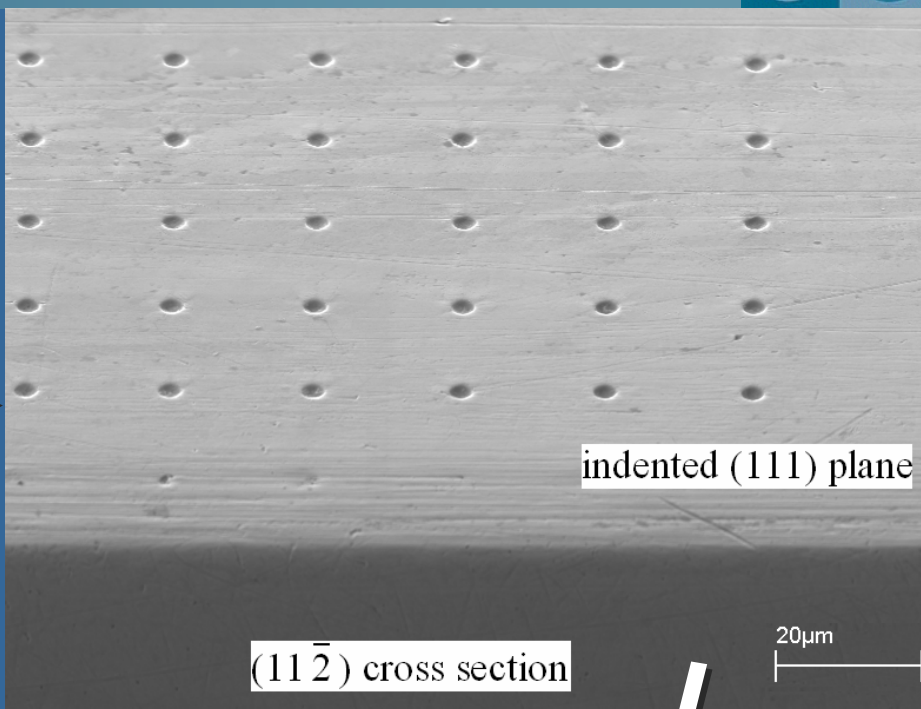
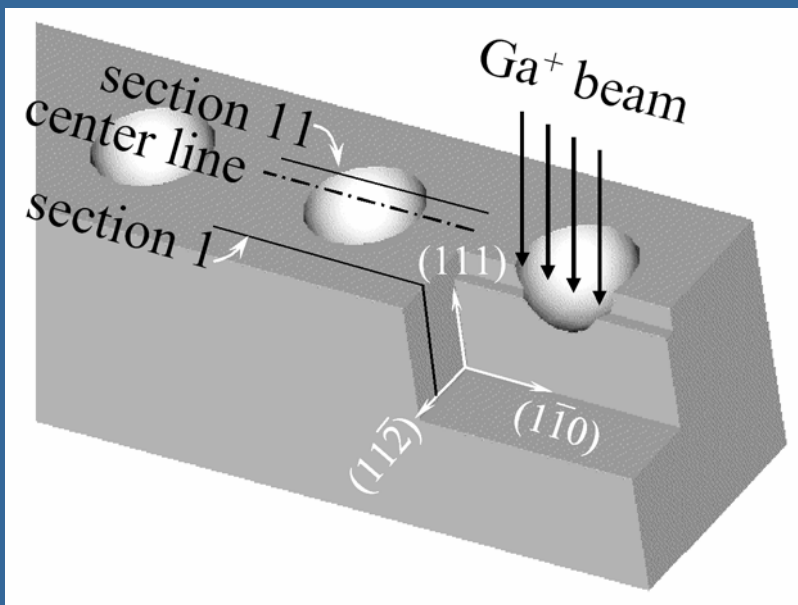
physics-based  
micro-mechanics simulations



Constitutive crystal mechanics  
modeling



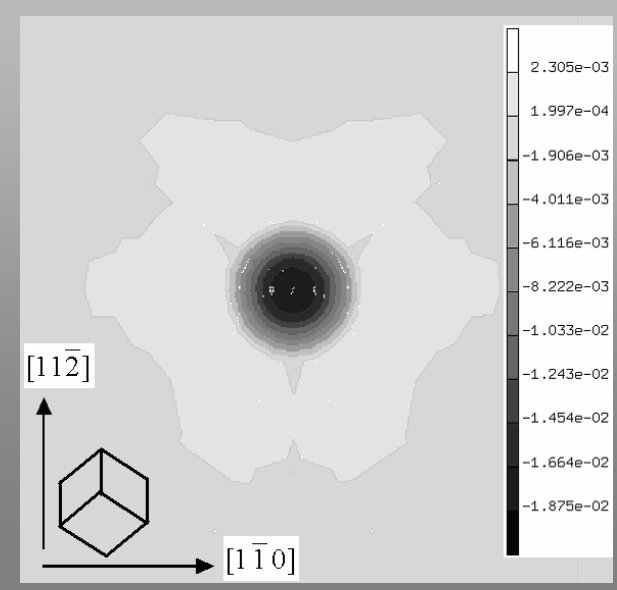
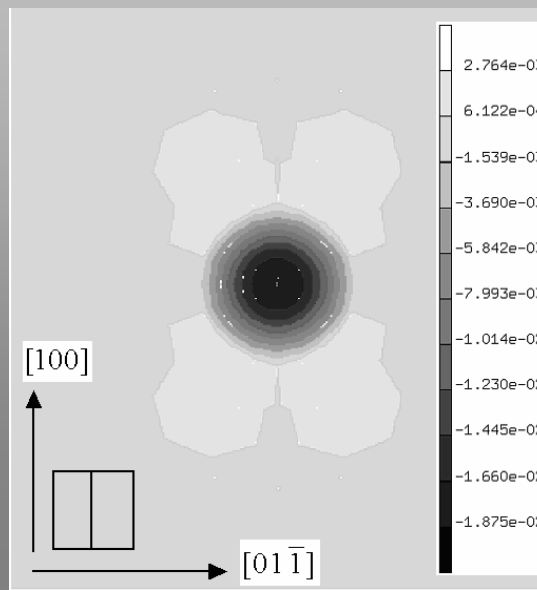
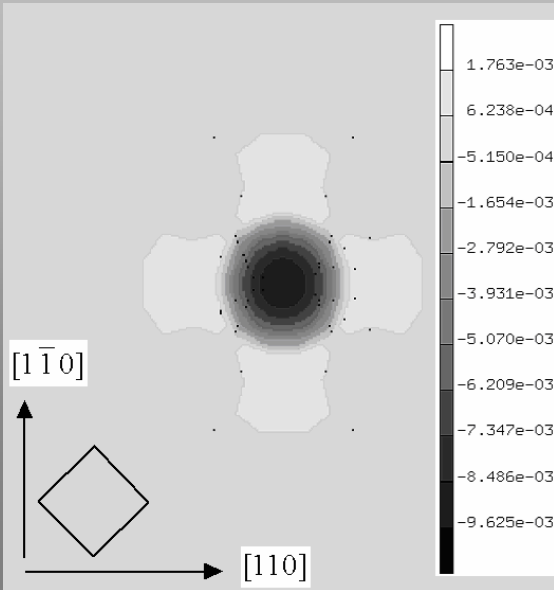
# Nanoindentation - 3D



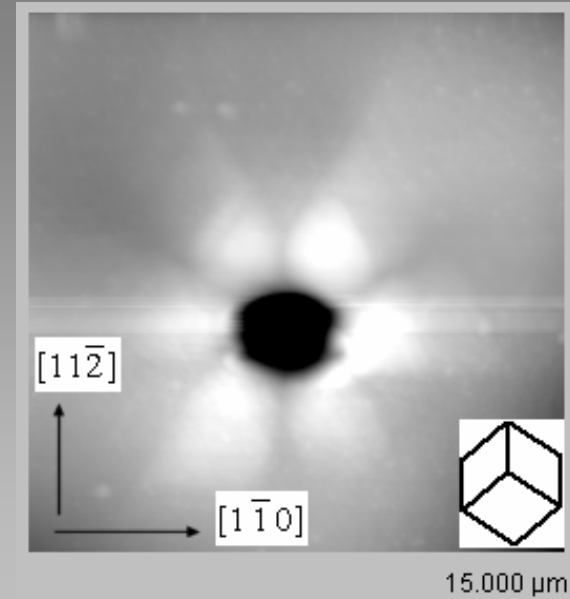
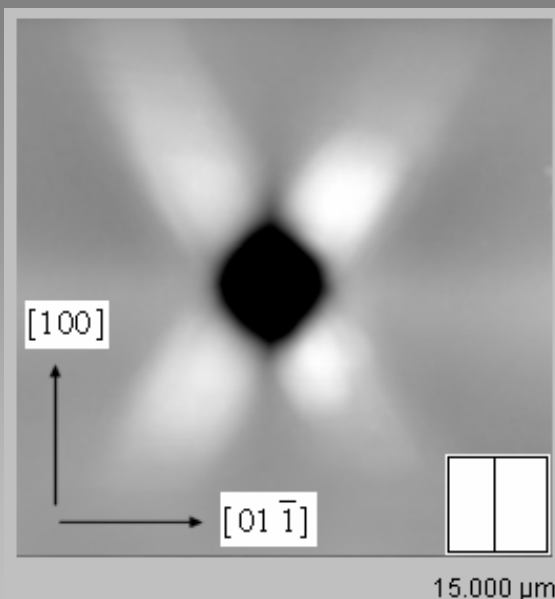
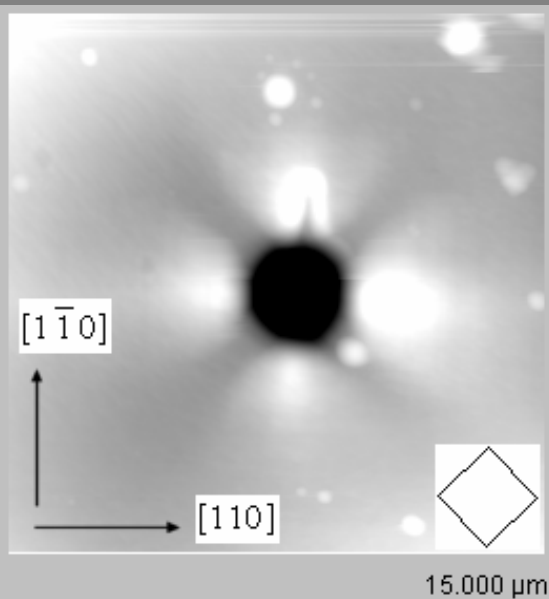
# Nanoindentation - 2D



simulation

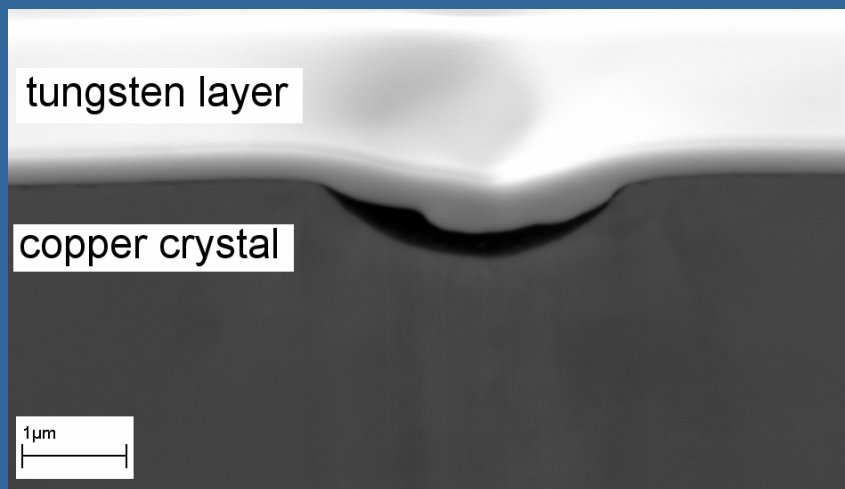
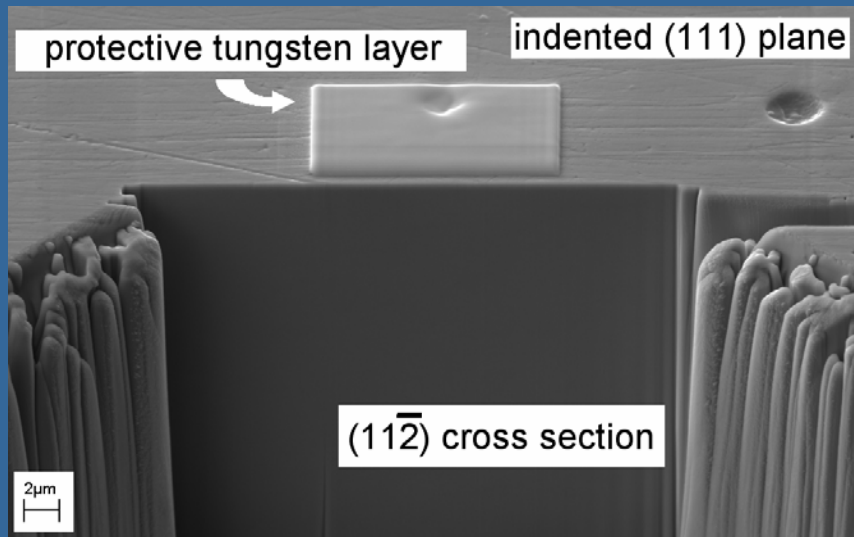


experiment

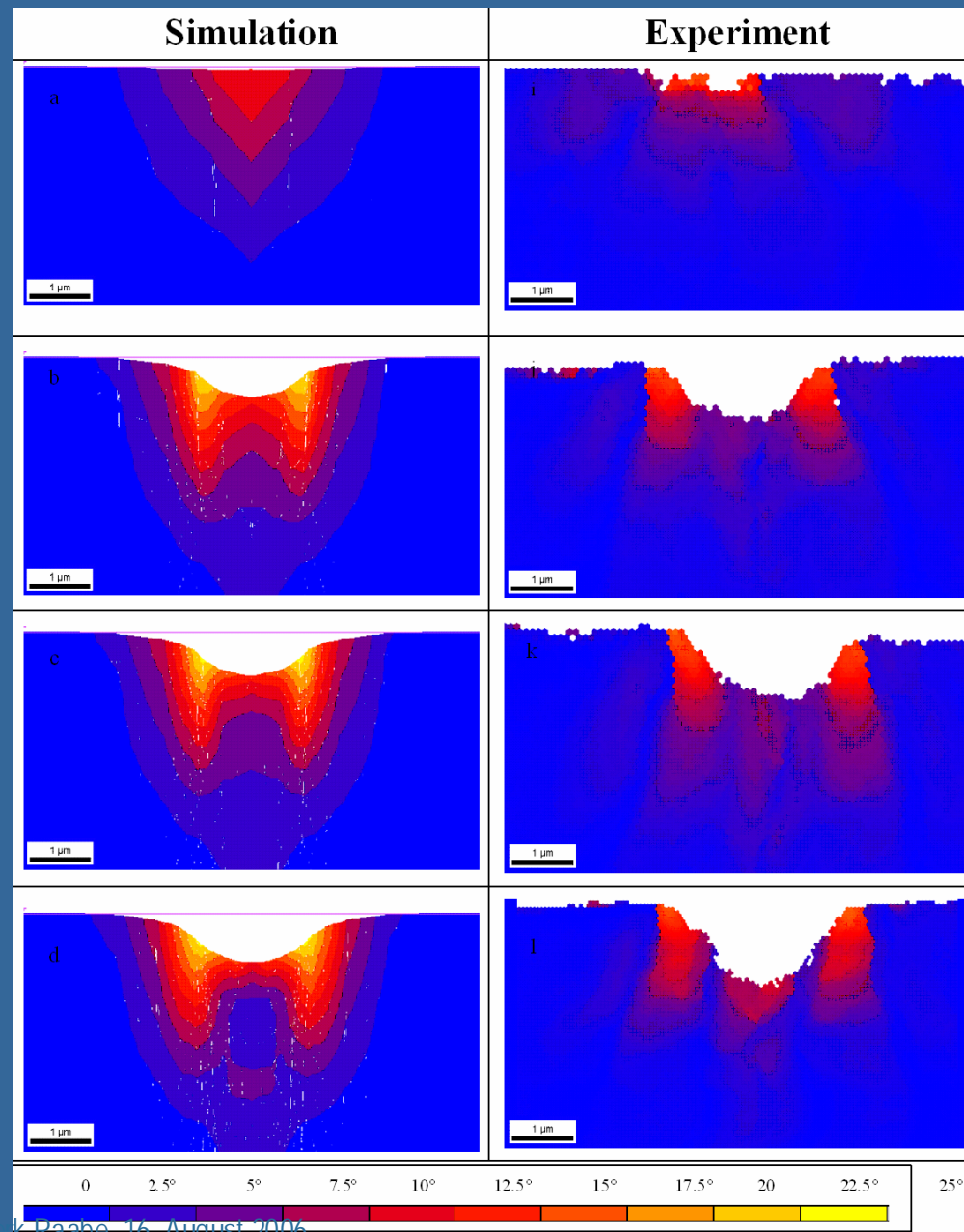




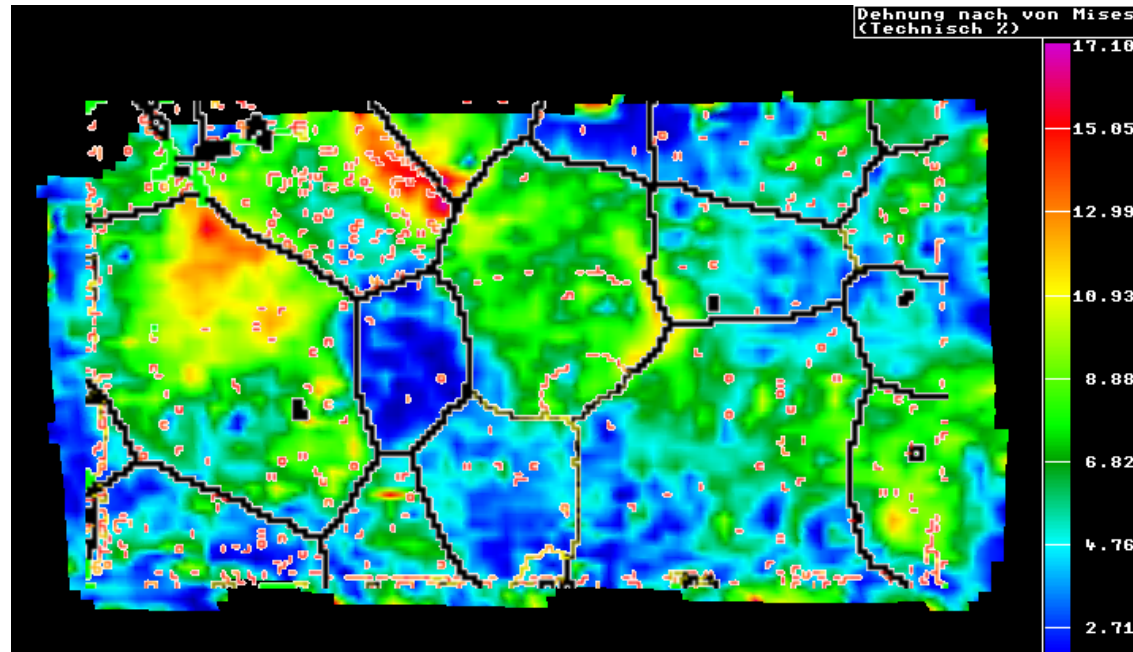
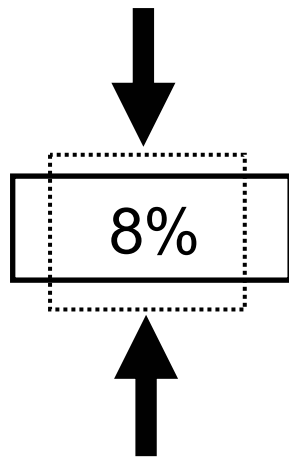
# Nanoindentation - 3D



absolute values of orientation change

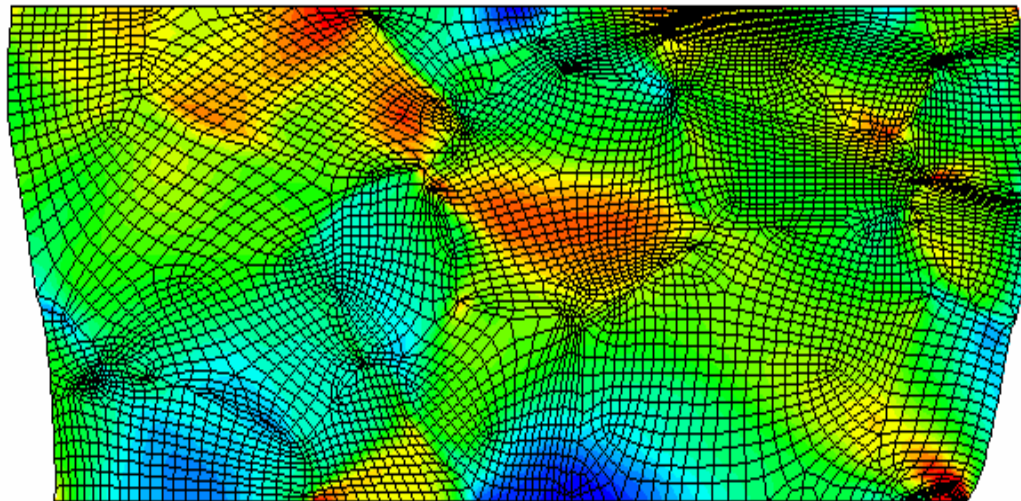


# 2D Oligocrystals (few grains), Al, plane strain



Experiment  
(DIC, EBSD)  
v Mises strain

von-Mises strain



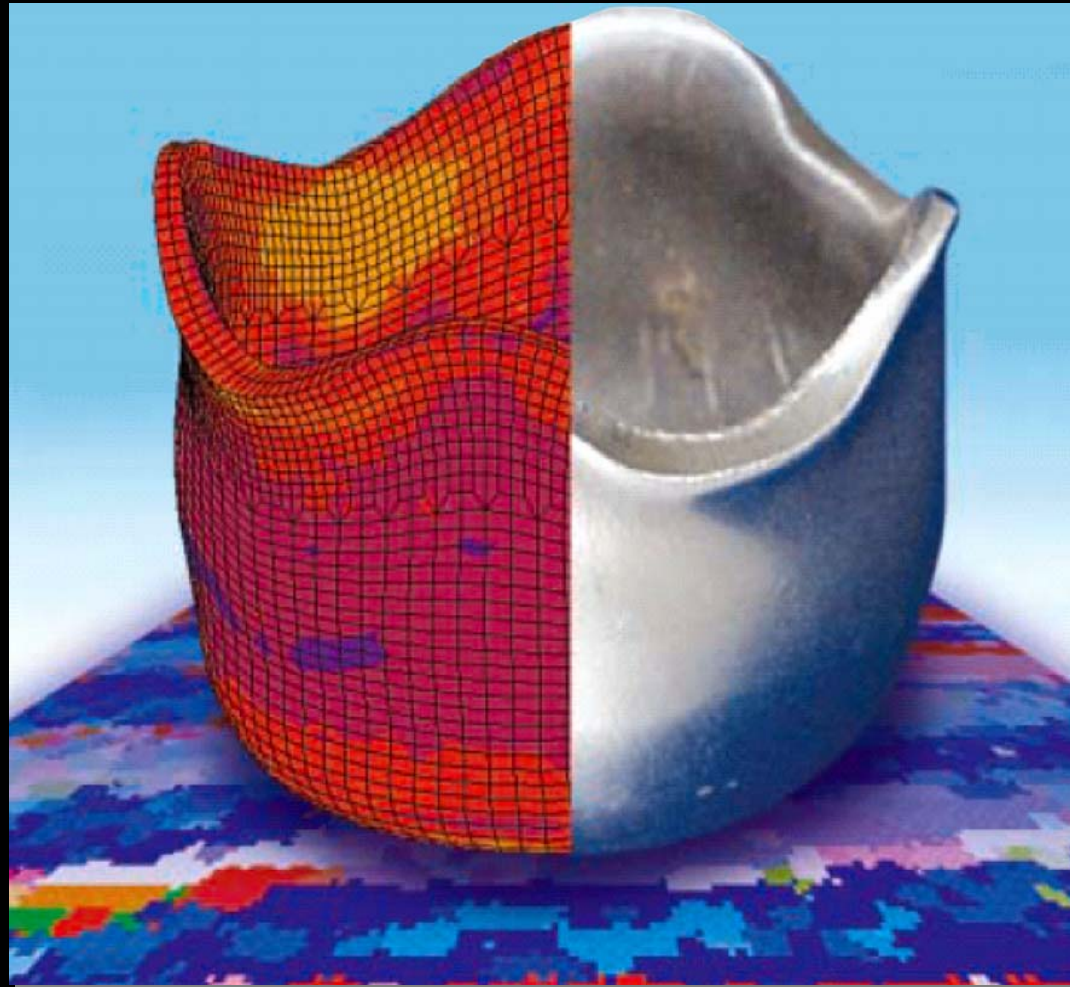
Simulation  
(CP-FEM)  
v Mises strain



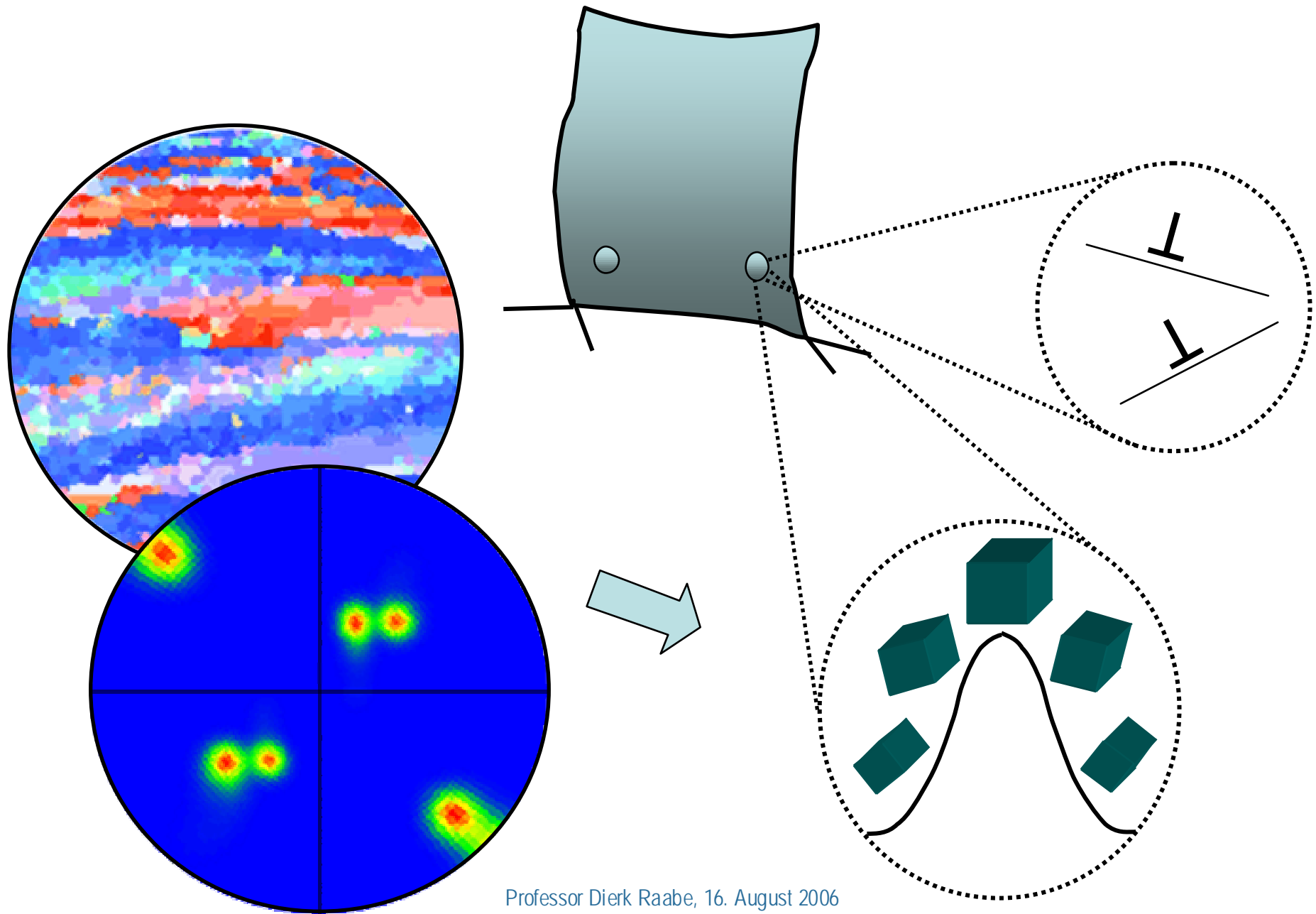
# Crystal Mechanics FEM (large scale)



many crystals ( $10^{10}$ )

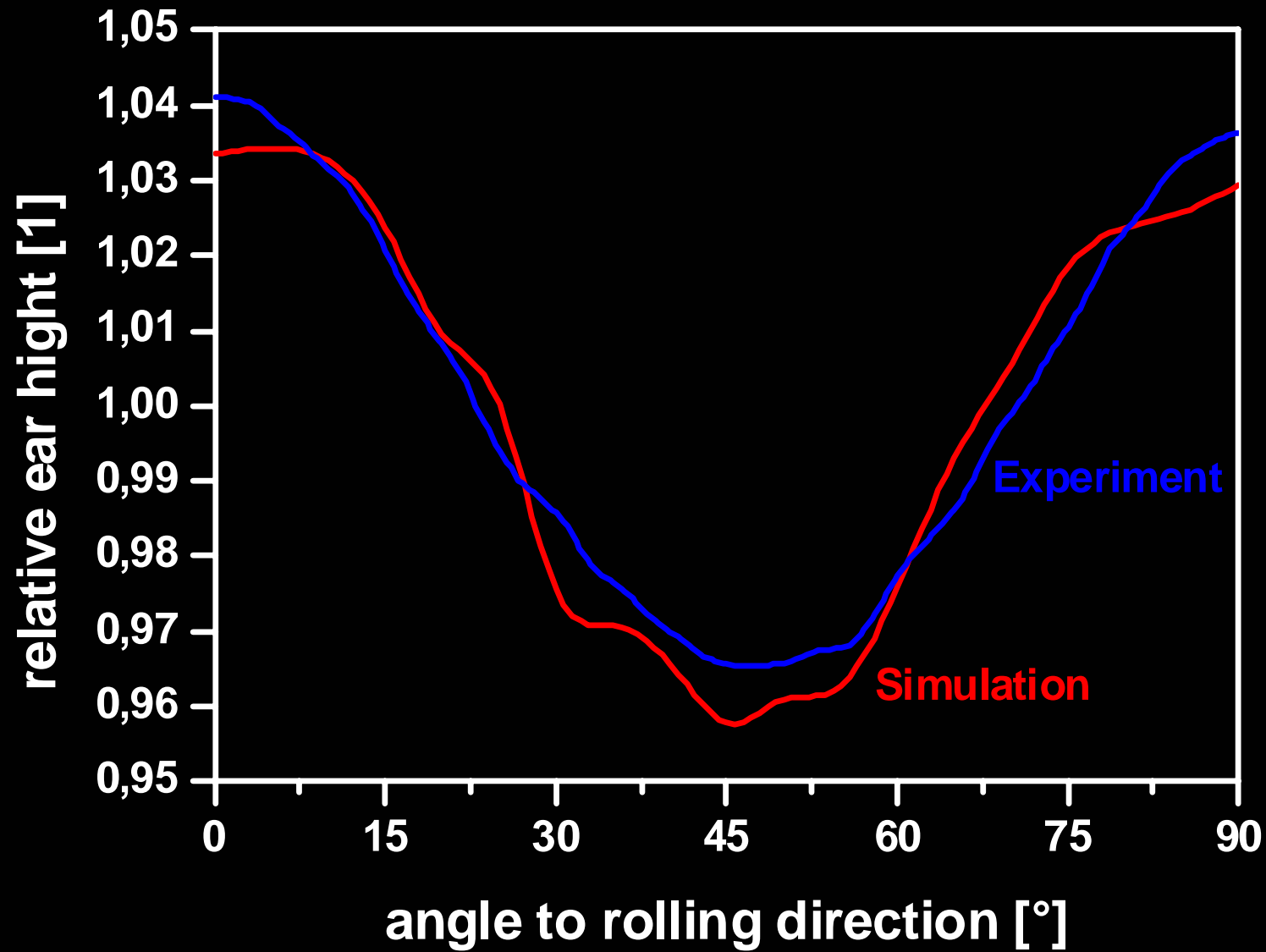


# Theory of Anisotropy





# Crystal Plasticity FEM



!! Thanks !! to the team



Roters, Ma: crystal mechanics  
Sachs, Romano, Al-Sawalmih, Fabritius: chitin-composites  
Zaefferer, Bastos: 3D Microscopy

Deutsche  
Forschungsgemeinschaft



Professor Dierk Raabe, 16. August 2006