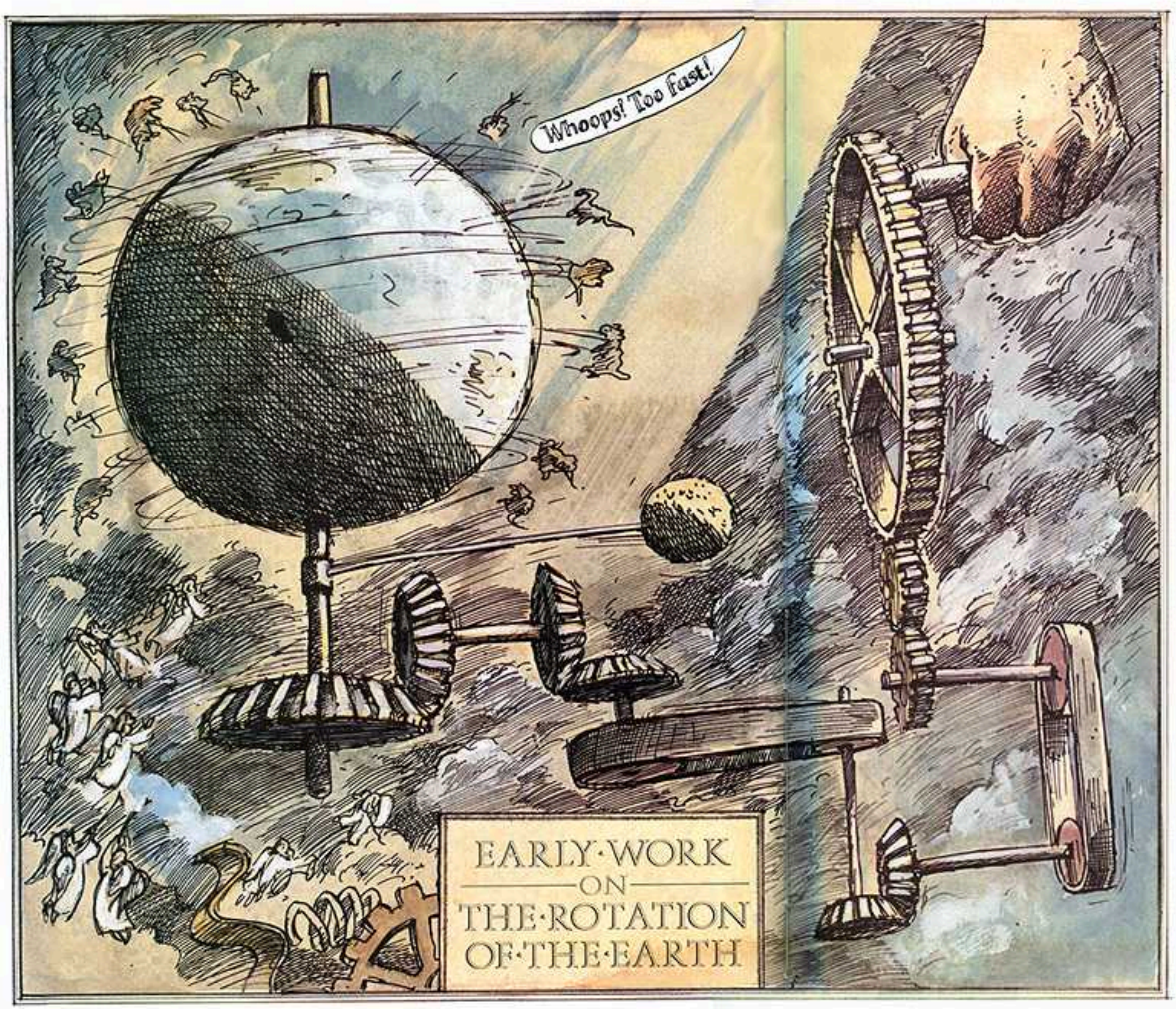
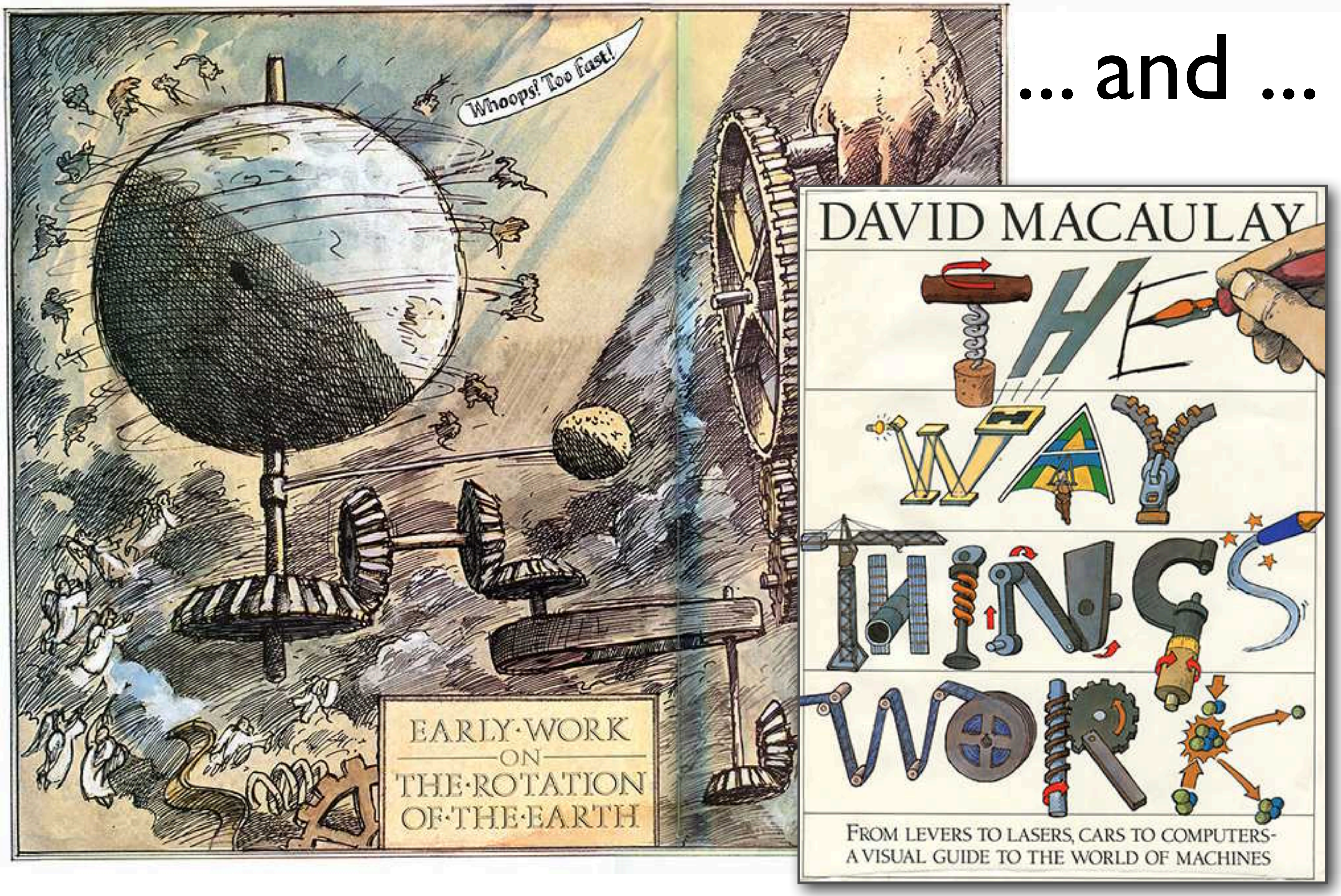
deep earth



... oder wie Langsamkeit funktioniert

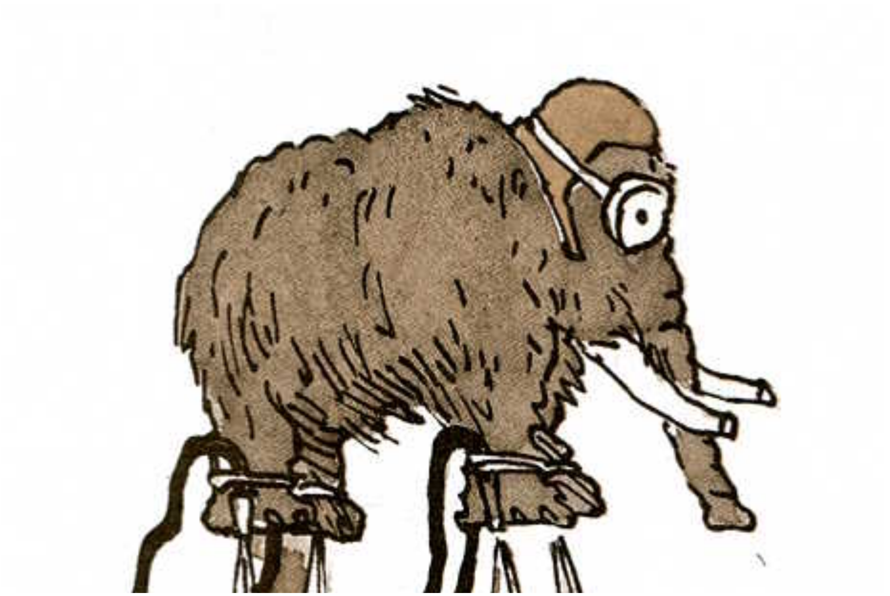
... and ...



... down there

brought to you

by:



Renée Heilbronner	Holger Stünitz, Tromsø
	Jan Tullis, Brown Univ.
Rüdiger Kilian	Brian Evans, MIT
Anja Thust	Andreas Kronenberg, TAMU
Matěj Peč	Barbara John, Univ. Wyoming

SNF

Einleitung

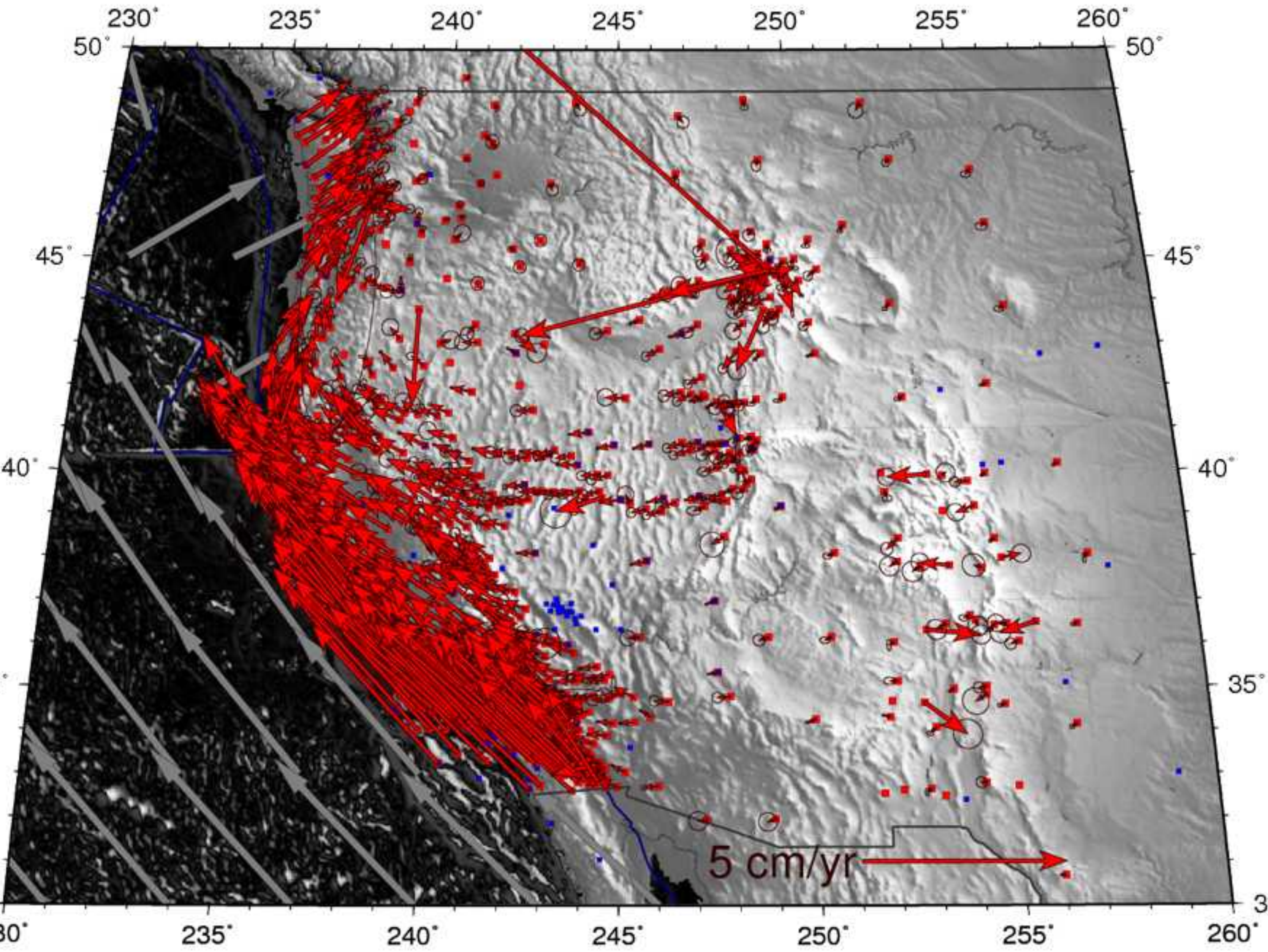
Hauptteil

Schluss

PBO MIT GPS velocities

GMT 2008 Oct 4 09:03:49 Red: PBO (90% uncertainty, only data with $\sigma_v < 0.5$ cm/yr errors). Blue: UNAVCO GPSVEL1.0 sites. Grey: NUVEL-1A NAM fixed. Contact: twb@usc.edu

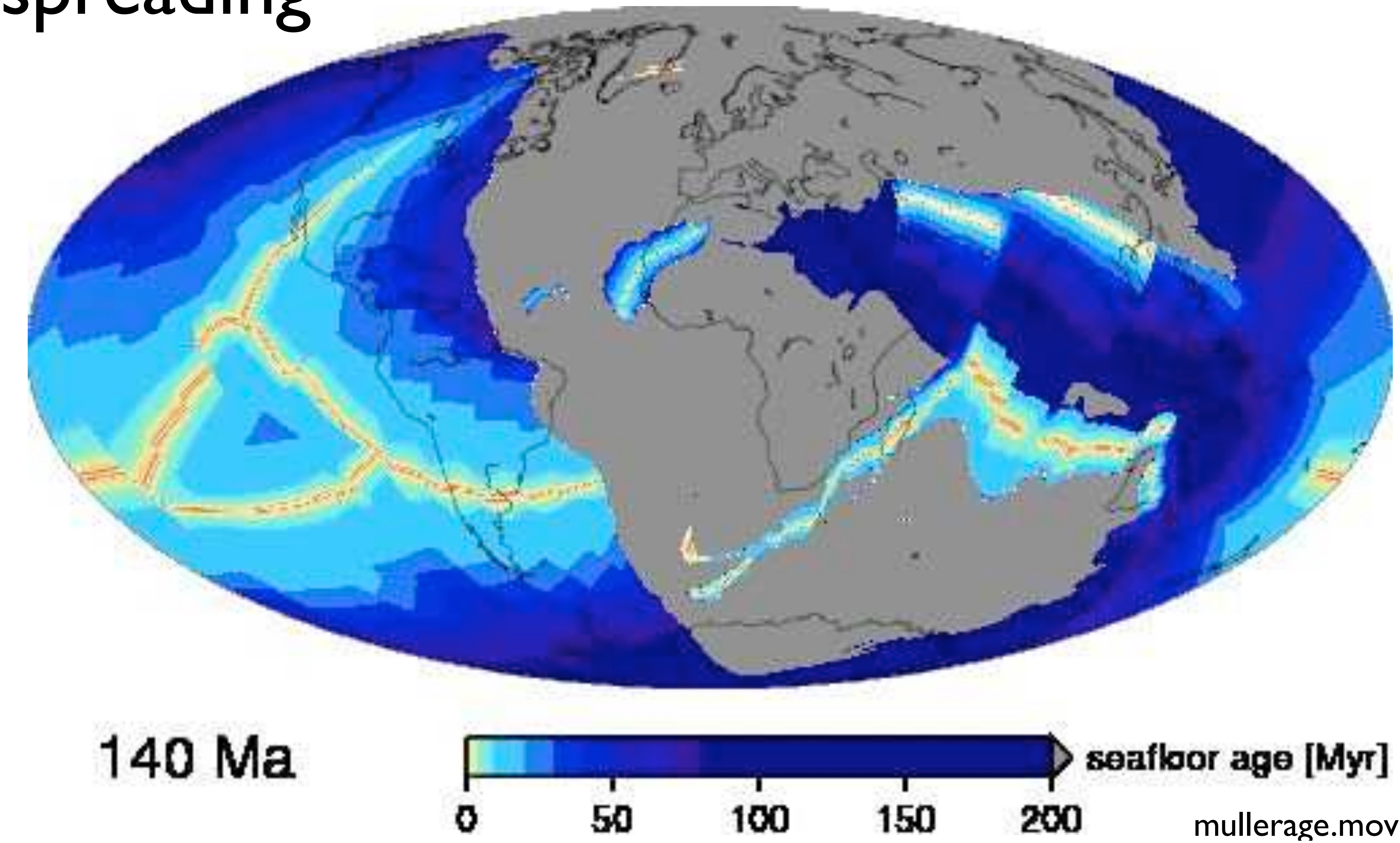
Release date: 2008-09-30 (20080930124552)



gemessene Langsamkeit
plate motion

velocity = displacement / time
(in ms^{-1})

geological reconstruction from sea floor spreading

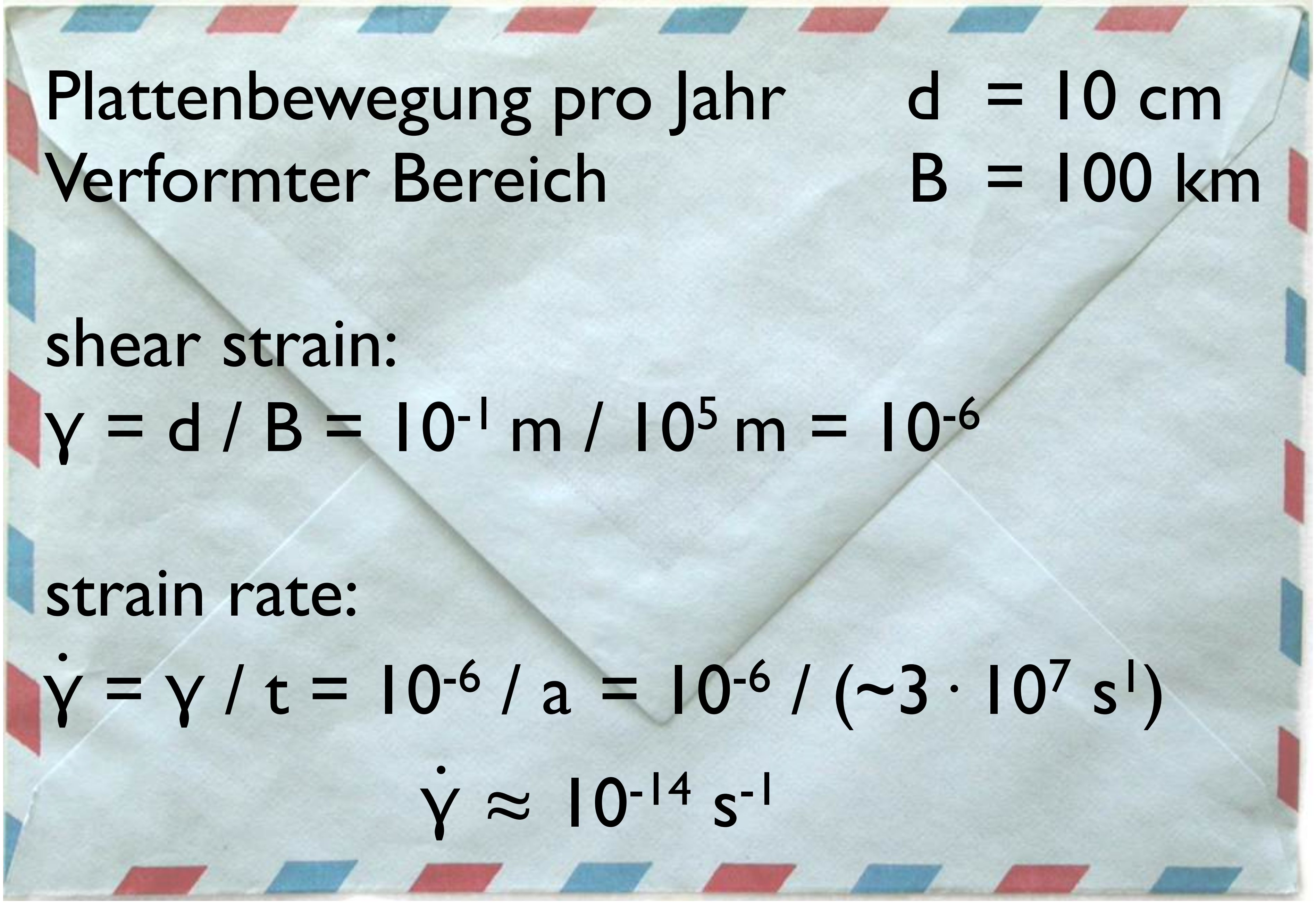


mullerage.mov2

berechnete Langsamkeit
geological deformation

strain = displacement / length
strain rate = strain / time
(in s^{-1})

Beispiel: San Andreas Fault



Plattenbewegung pro Jahr $d = 10$ cm
Verformter Bereich $B = 100$ km

shear strain:

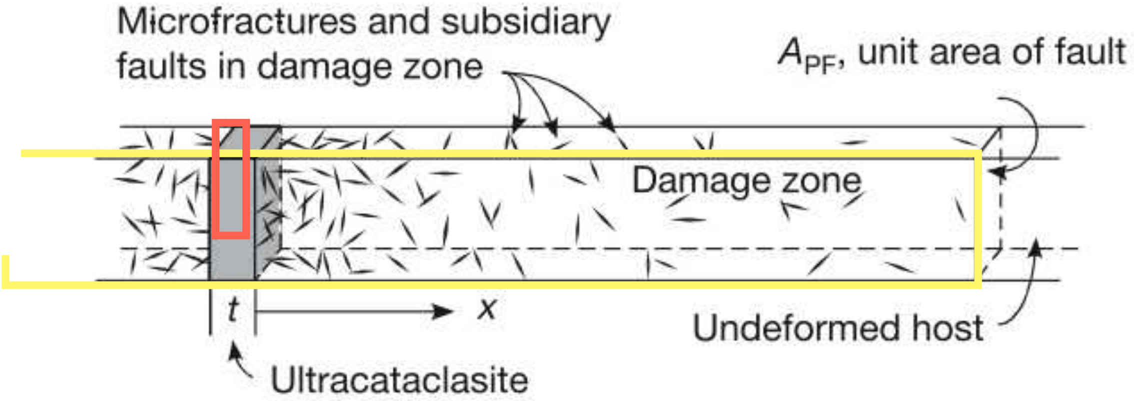
$\gamma = d / B = 10^{-1}\,\mathrm{m} / 10^{5}\,\mathrm{m} = 10^{-6}$

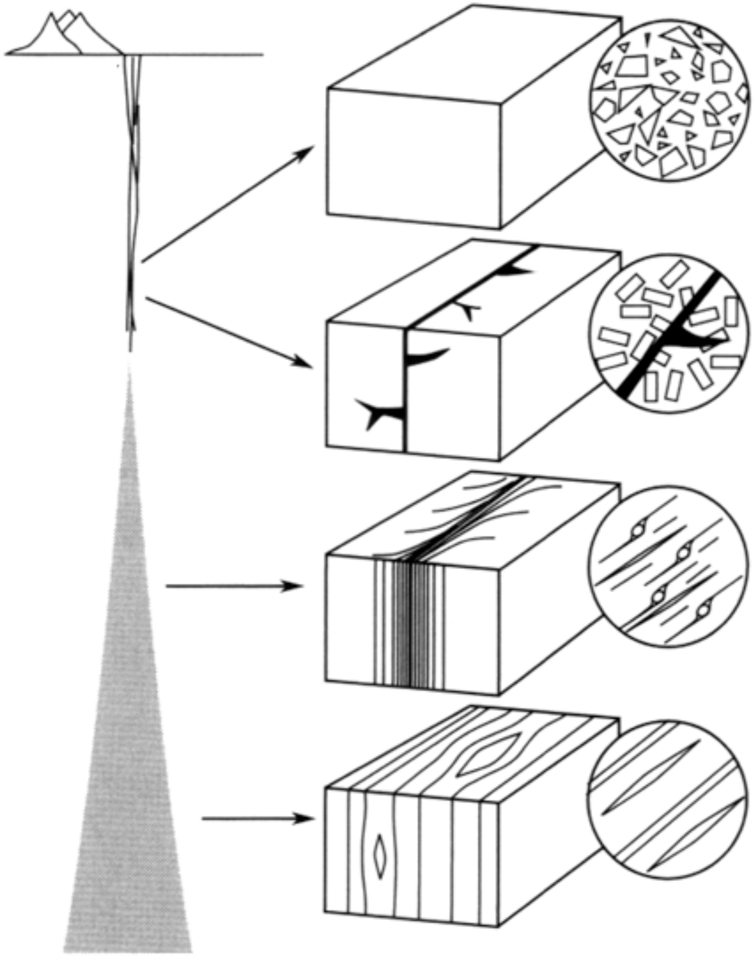
strain rate:

$\dot{\gamma} = \gamma / t = 10^{-6} / a = 10^{-6} / (\sim 3 \cdot 10^{7}\,\mathrm{s}^{1})$

$$\dot{\gamma} \approx 10^{-14}\,\mathrm{s}^{-1}$$

Lokalisierung





$$100\text{km} \Rightarrow 100\text{m} = 10^3$$

$$\dot{\gamma} = 10^{-11}\ s^{-1}$$

$$100\text{km} \Rightarrow 1\text{mm} = 10^8$$

$$\dot{\gamma} = 10^{-6}\ s^{-1}$$

Lokalisierung

100km ⇒ 100m = 10^3

$\dot{\Upsilon} = 10^{-11}\ \mathrm{s}^{-1}$

1% der Zeit :

$\dot{\Upsilon} = 10^{-9}\ \mathrm{s}^{-1}$

fast !

100km ⇒ 1mm = 10^8

$\dot{\Upsilon} = 10^{-6}\ \mathrm{s}^{-1}$

1 Sekunde / Jahr:

$\dot{\Upsilon} \approx 30\ \mathrm{s}^{-1}$

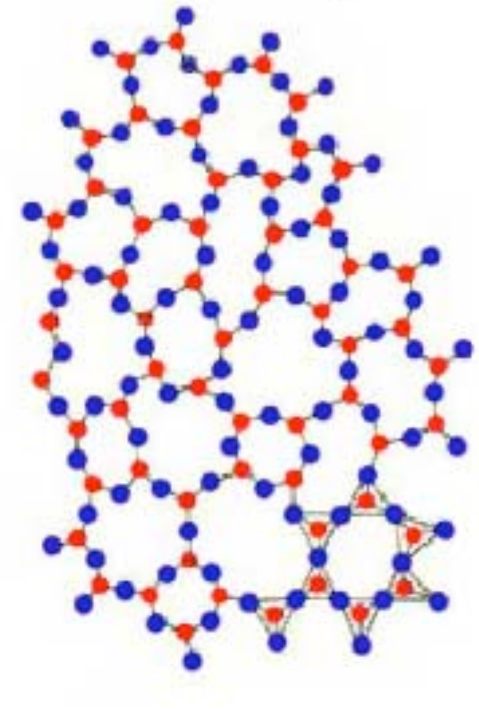
seismic !

$1\ \mathrm{a} \approx 3 \cdot 10^7\ \mathrm{s}$

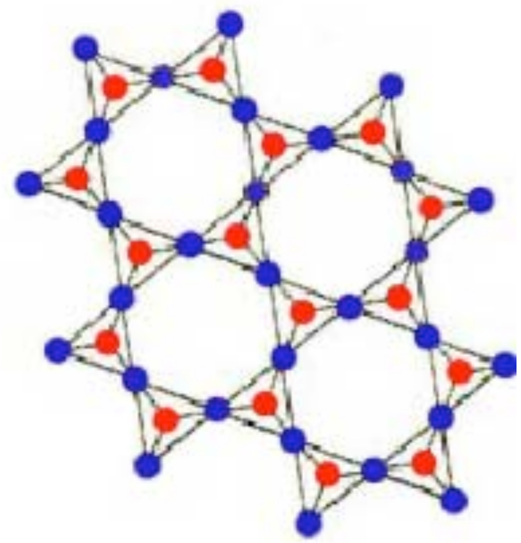
kontinuum-diskontinuum
kristalline Festkörper

isotrop

amorphes SiO_2
(Glas)



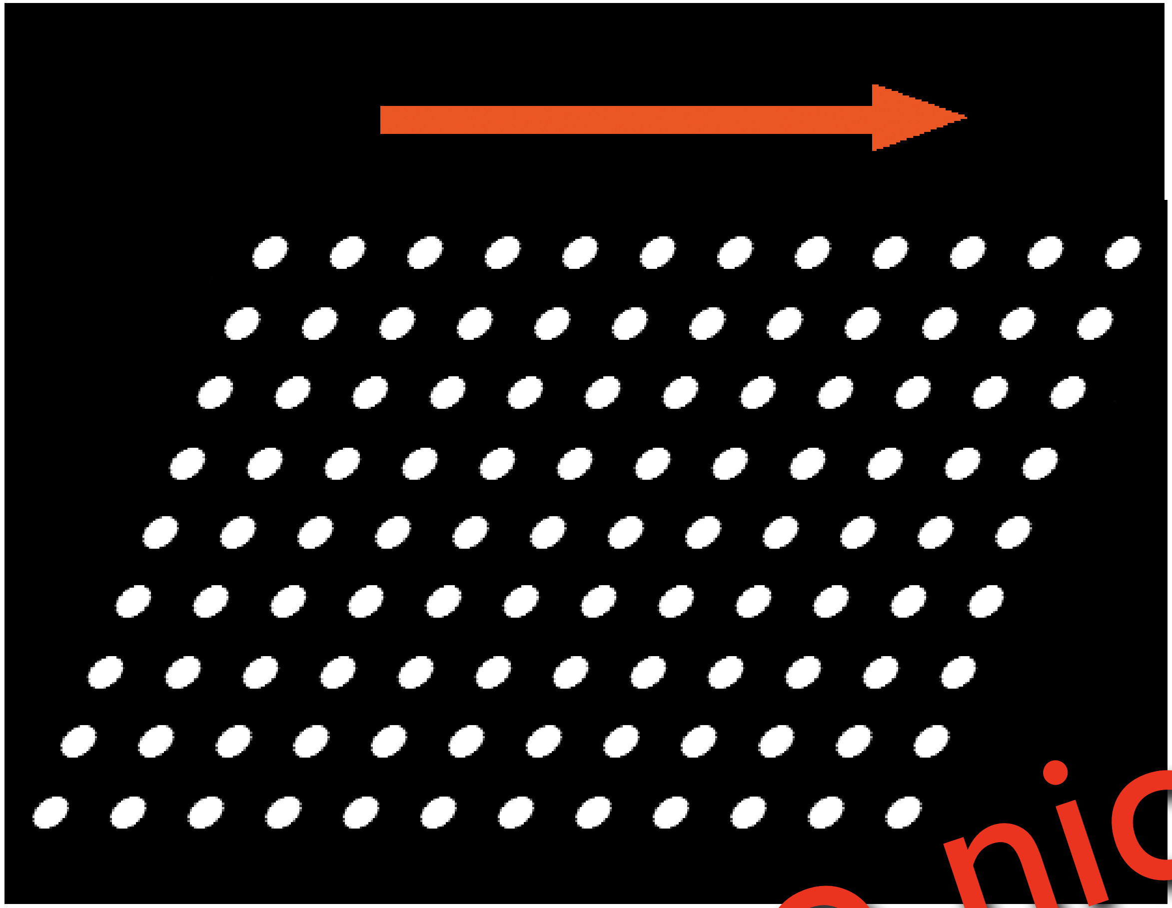
kristallines SiO_2
(Quarz)



anisotrop

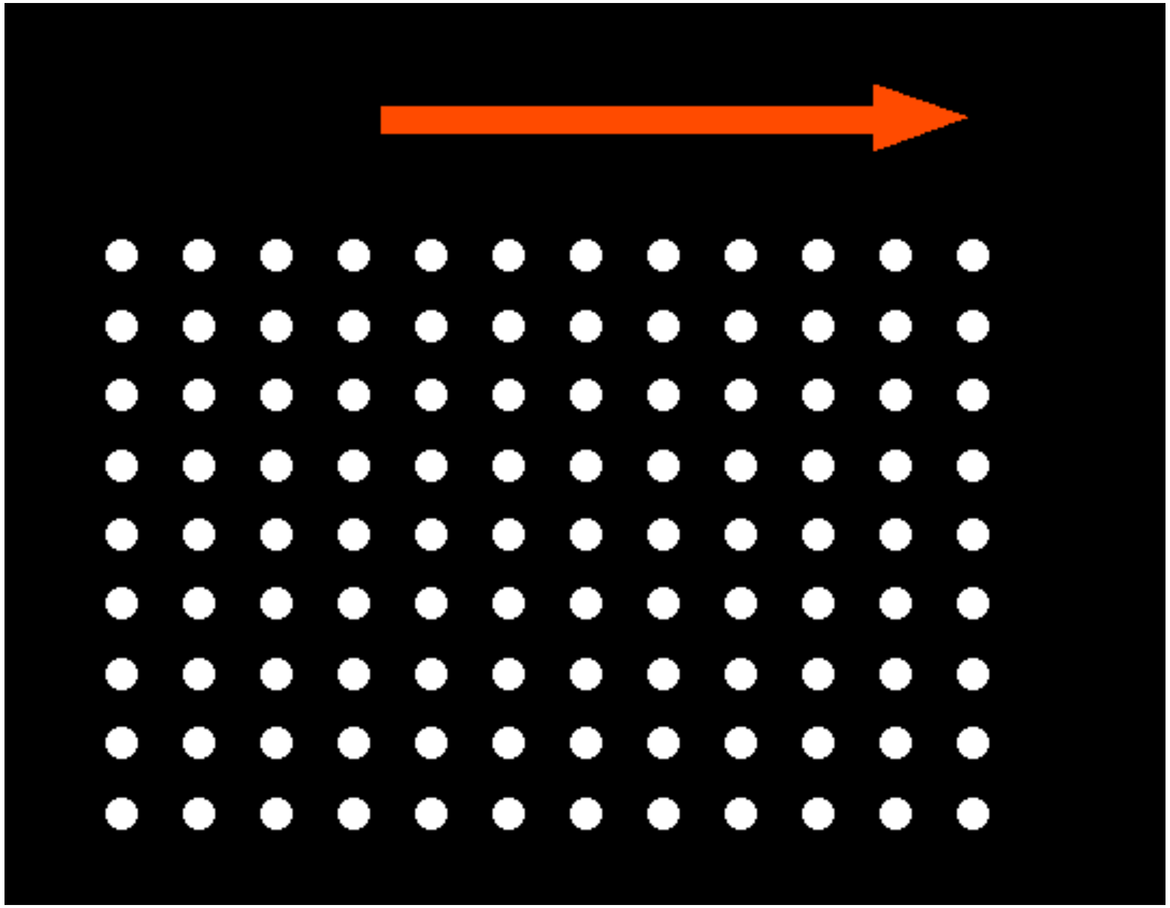
O ● Si ●

Deformation von Kristallen



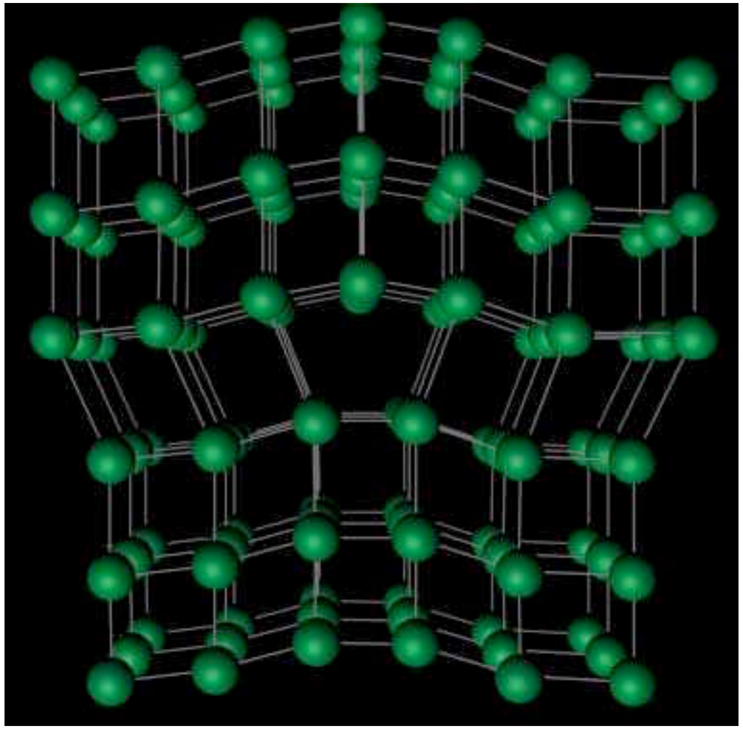
so nicht !

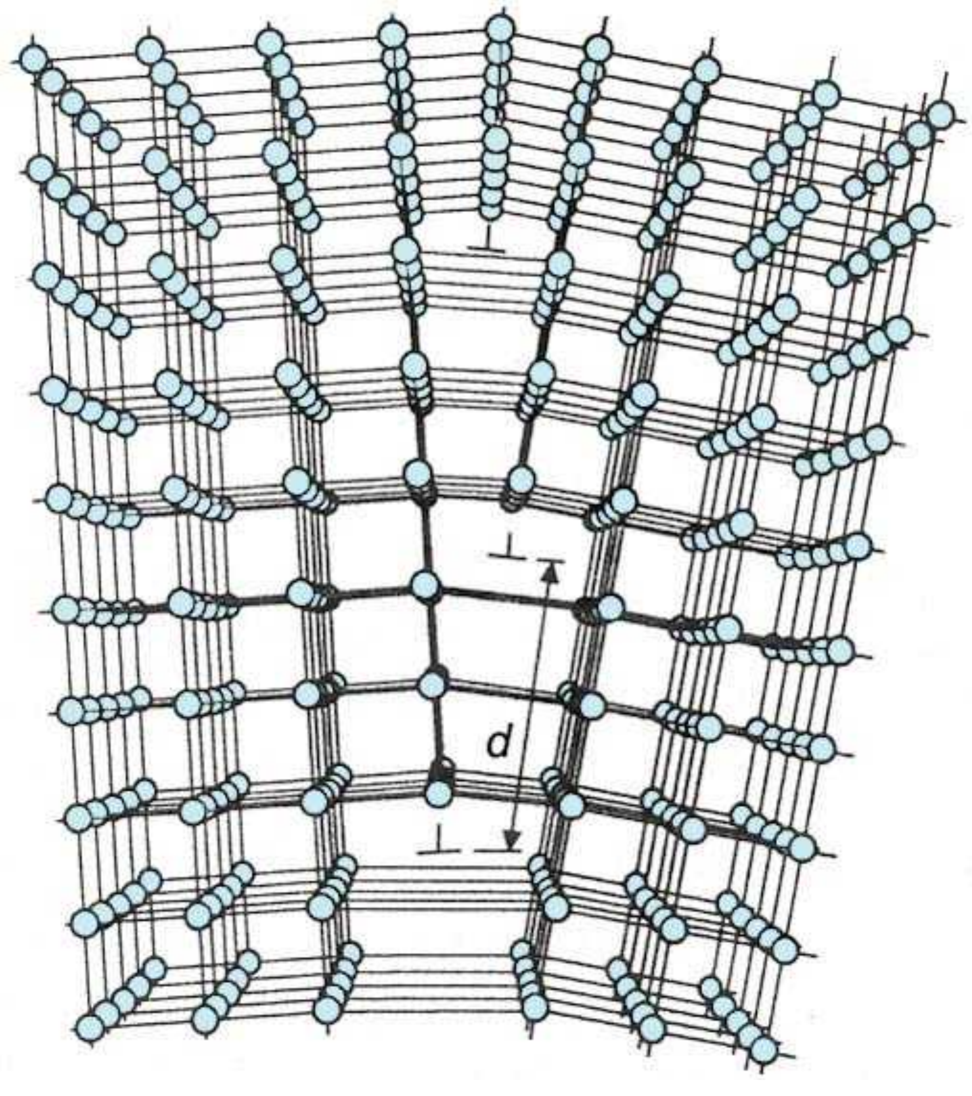
Versetzungen



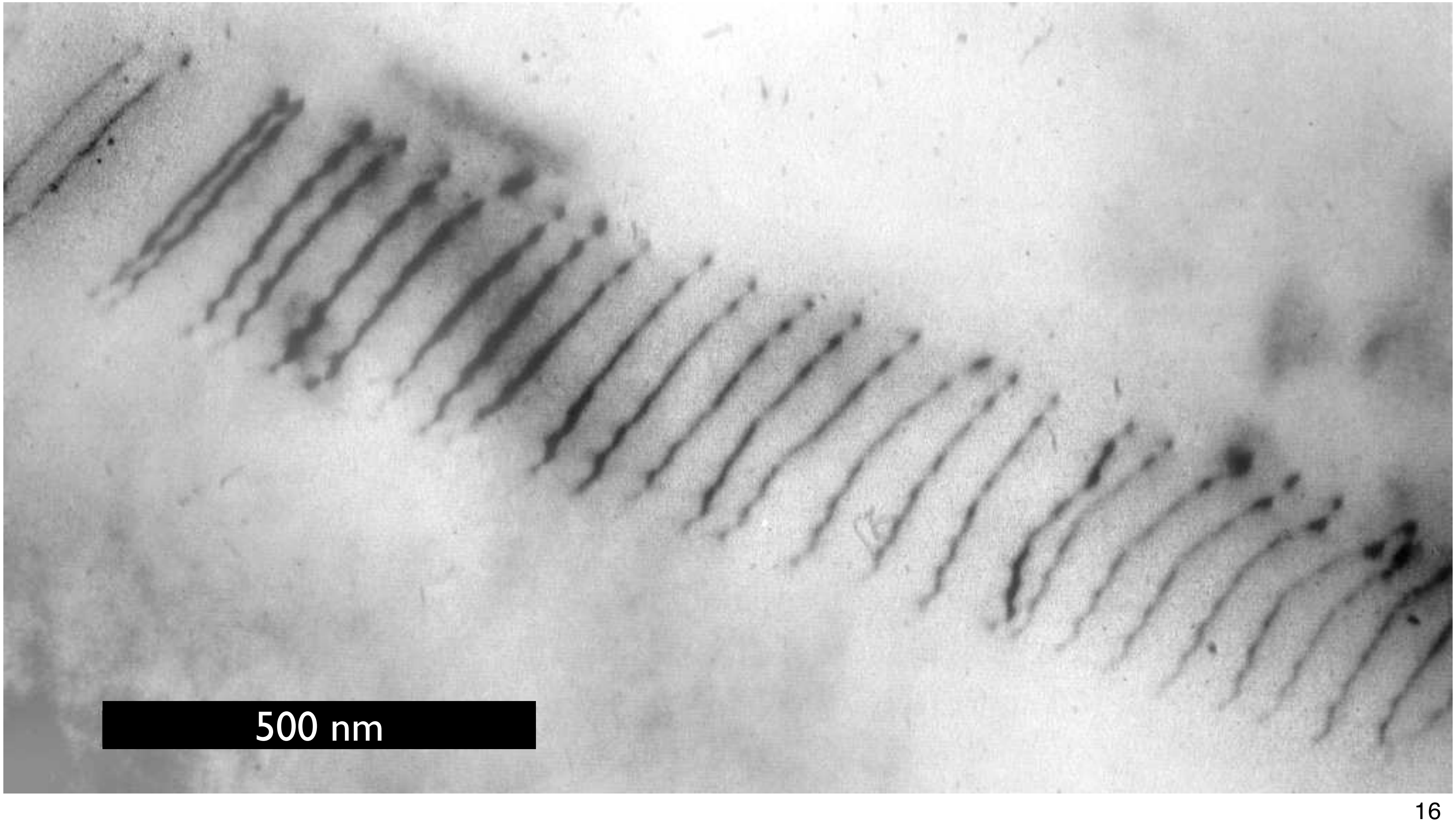
sondern so !

edge dislocation

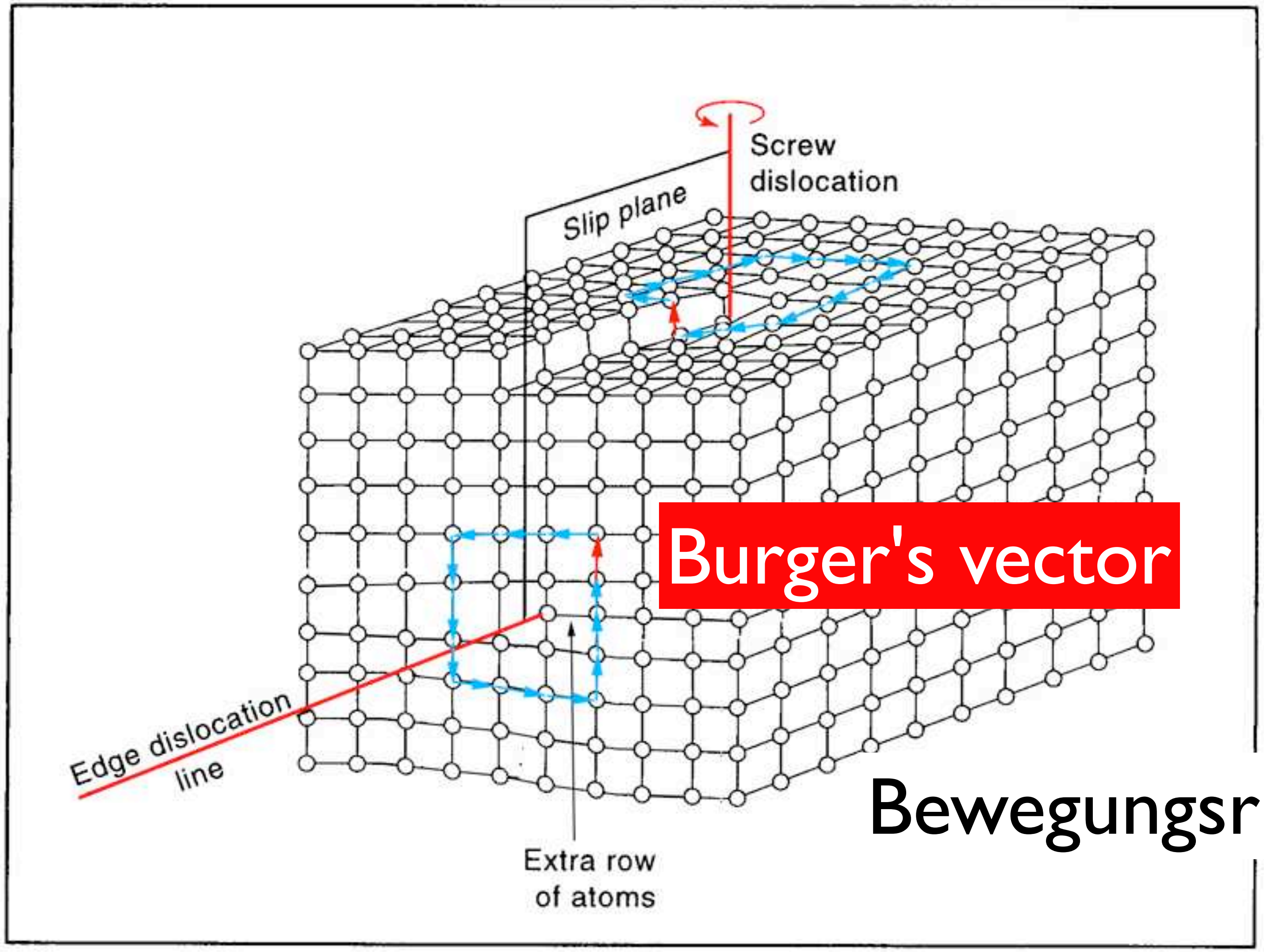




edge dislocation



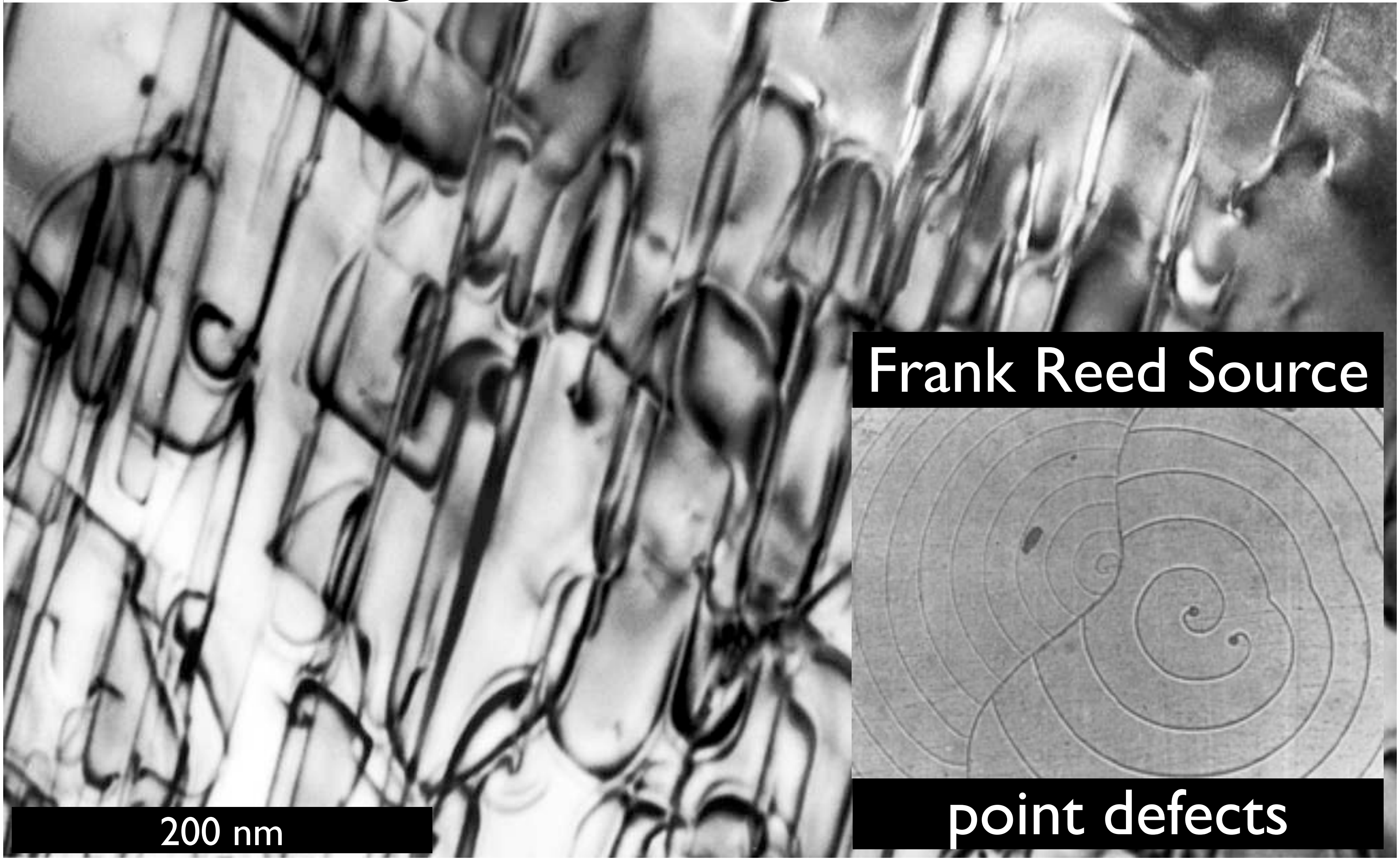
screw & edge dislocation



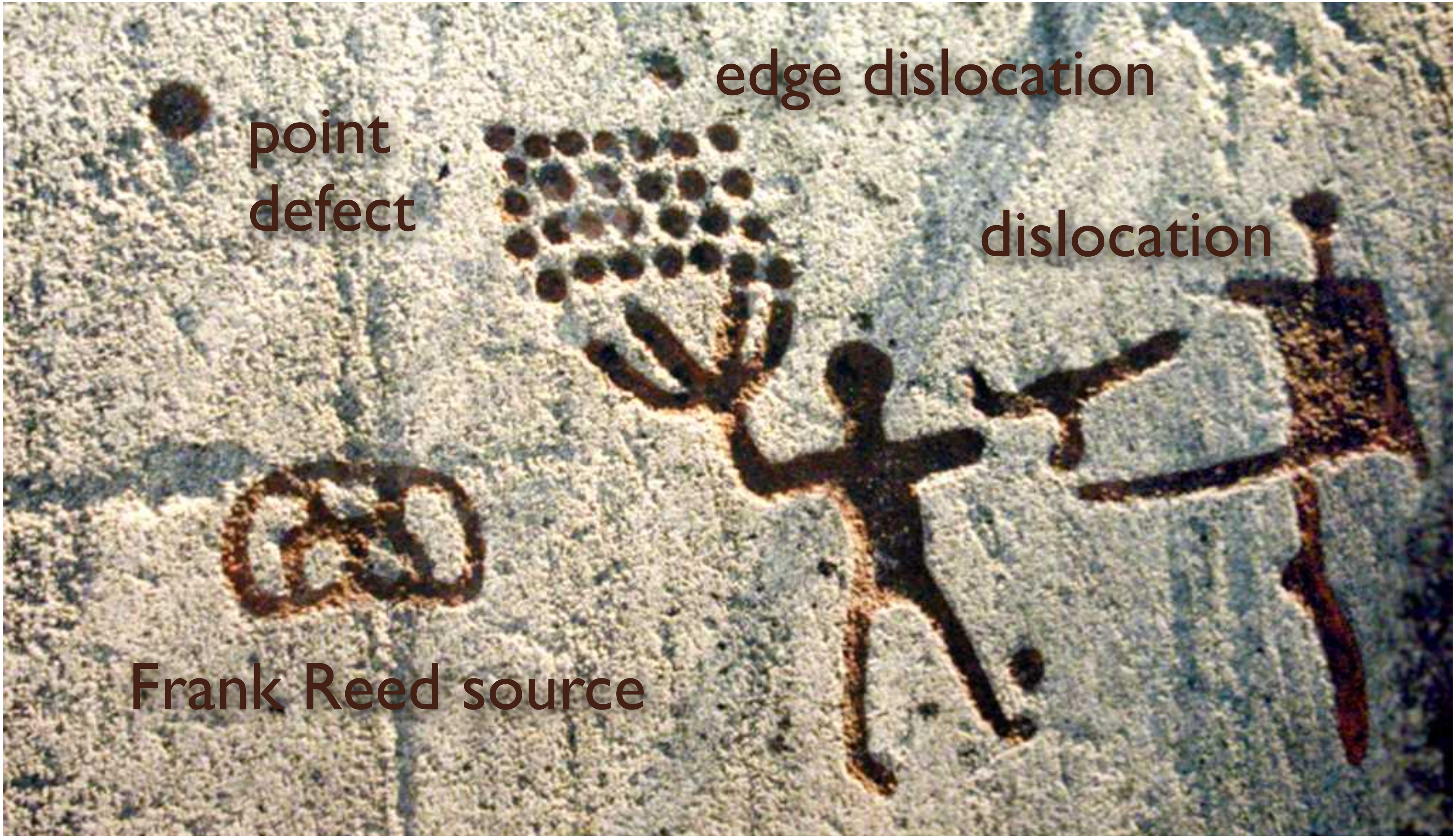
Burger's vector

Bewegungsrichtung

moving & creating dislocations



oldest dislocations



dislocation speed: supersonic

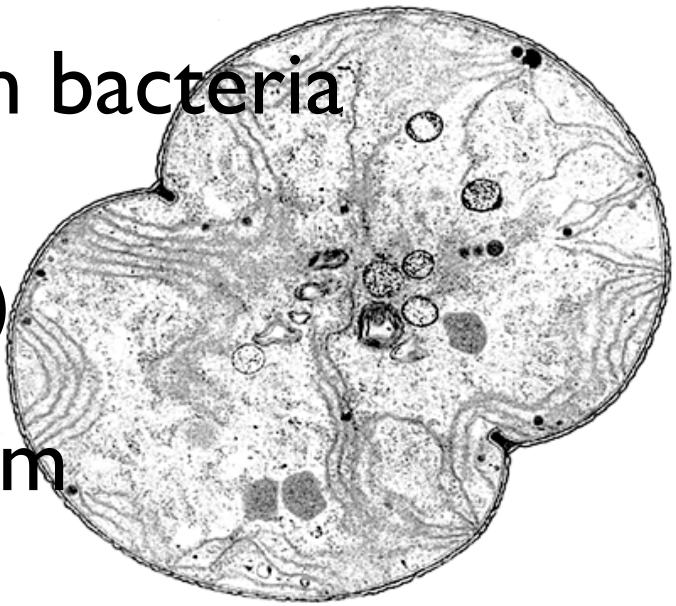
$$v = \sqrt{C_{ij} / \rho}$$

speed of sound in air = 355 ms^{-1}

in minerals ~ 6000 ms^{-1}

(in rubber ~ 60 ms^{-1})

Vergleich:

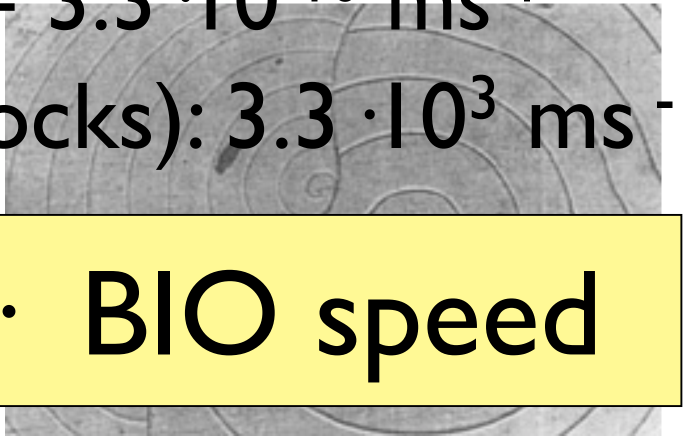


The speed of DNA replication in bacteria
$\approx$ 1000 nucleotides / s
(in humans $\approx$ 50 nucleotides / s)

Length of nucleotide unit: 0.33 nm

$\Rightarrow$ replication speed (in ms^{-1}):

$1000 \cdot 0.33\ \mathrm{nm\ s}^{-1} = 330\ \mathrm{pm\ s}^{-1} = 3.3 \cdot 10^{-10}\ \mathrm{ms}^{-1}$



Assume dislocation speed (in rocks): $3.3 \cdot 10^{3}\ \mathrm{ms}^{-1}$

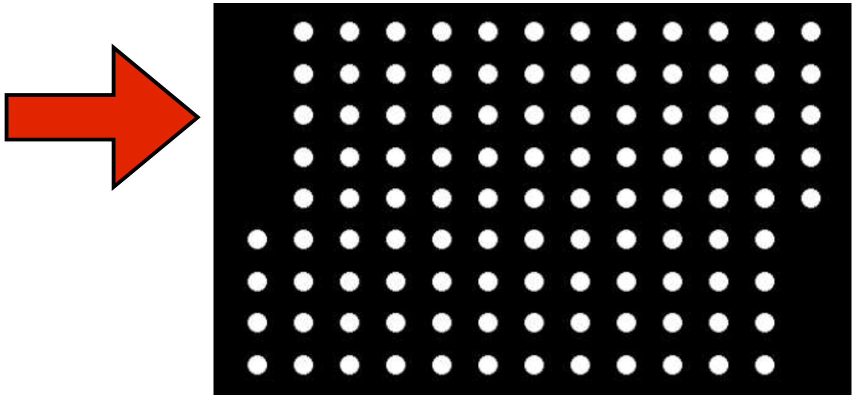
$\Rightarrow$ GEO speed $\approx 10^{13} \cdot$ BIO speed

www.dnareplication.info/speedofdnareplication.php en.wikipedia.org/wiki/DNA

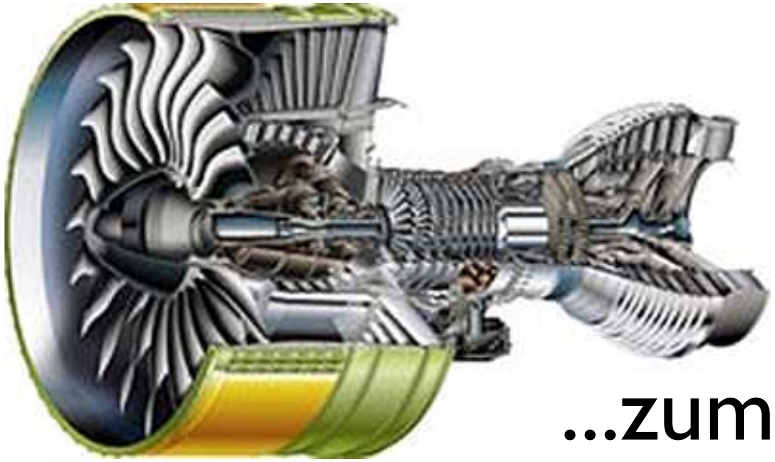
plastische Verformung von kristallinen Festkörpern (Aggregaten)

warum ergeben viele
schnelle Versetzungen
eine grosse Langsamkeit ?!

0. Es ist gar nicht so einfach Dislokationen zu erzeugen !



so einfach
geht's nicht

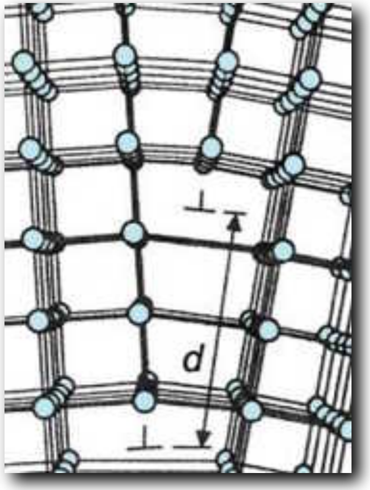


...zum Glück !

1. Nicht jede Richtung im Kristallgitter eignet sich zum Gleiten (dislocation glide), es gibt "harte" und "weiche" Gleitsysteme.

$$v = \sqrt{C_{ij} / \rho}$$

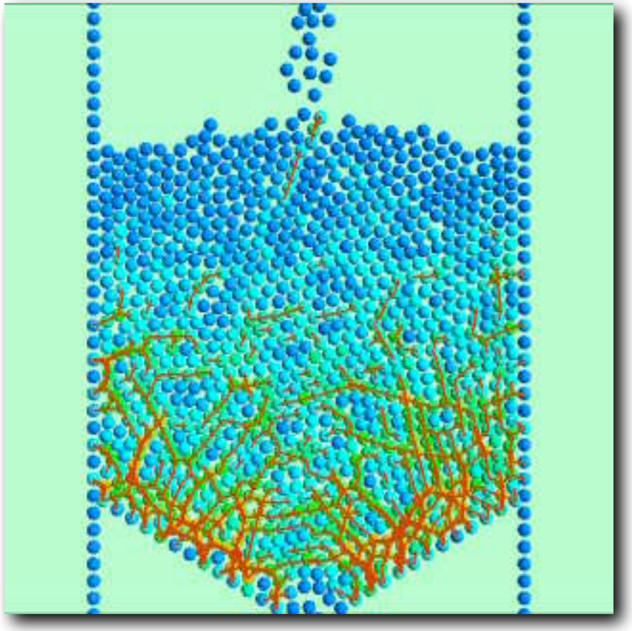
2. Dislokationen werden behindert (dislocation pile-up). Geschwindigkeits-bestimmender Schritt ≠ Dislokationsgleiten, sondern die Diffusion (Beseitigung) der Dislokationen.

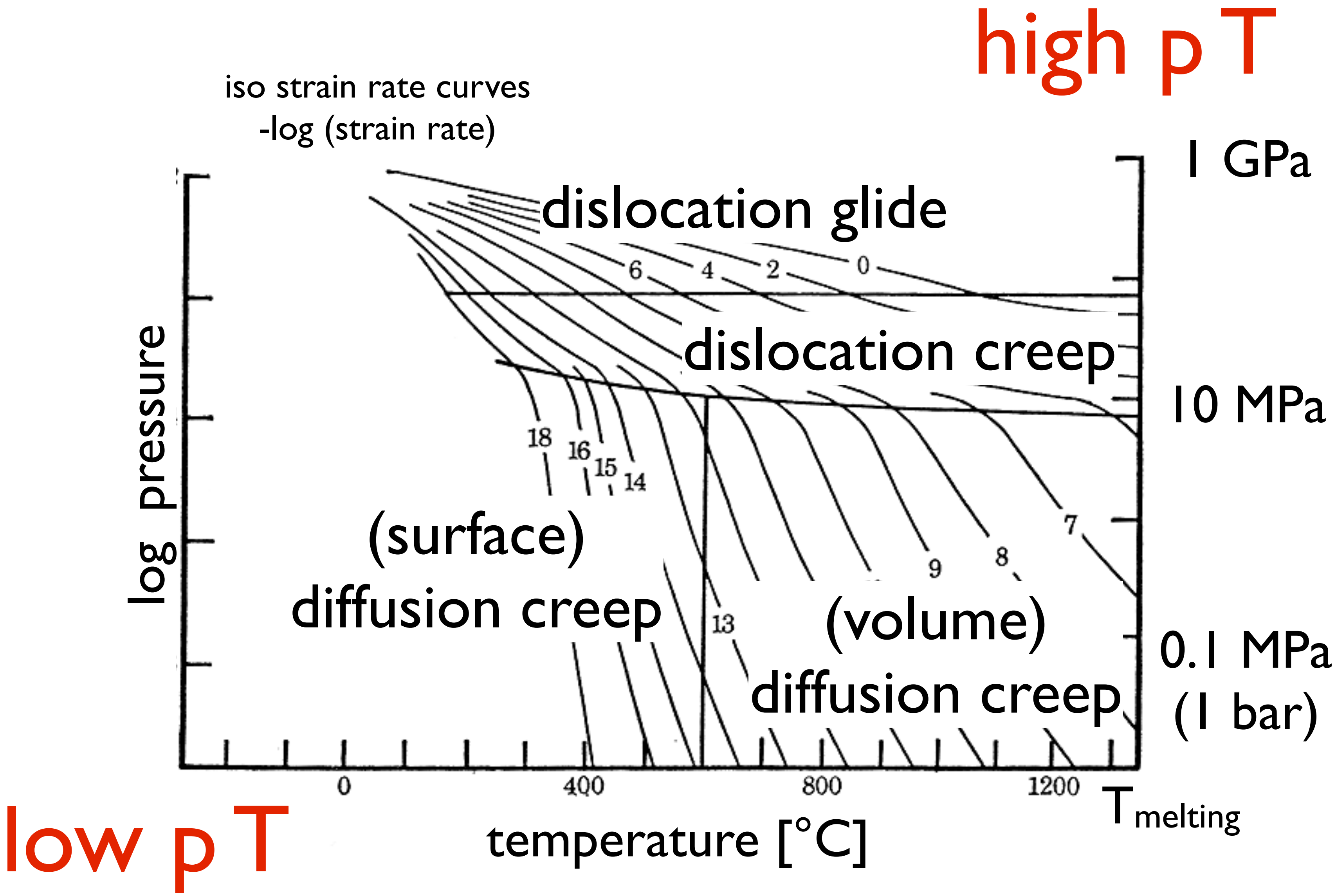


=> dislocation creep

3. Verformung weicht aus auf schwächere Phasen, ± kein Dislokationsgleiten, Korn gleitet oder diffundiert als Ganzes.

=> g boundary sliding, granular flow, diffusion creep





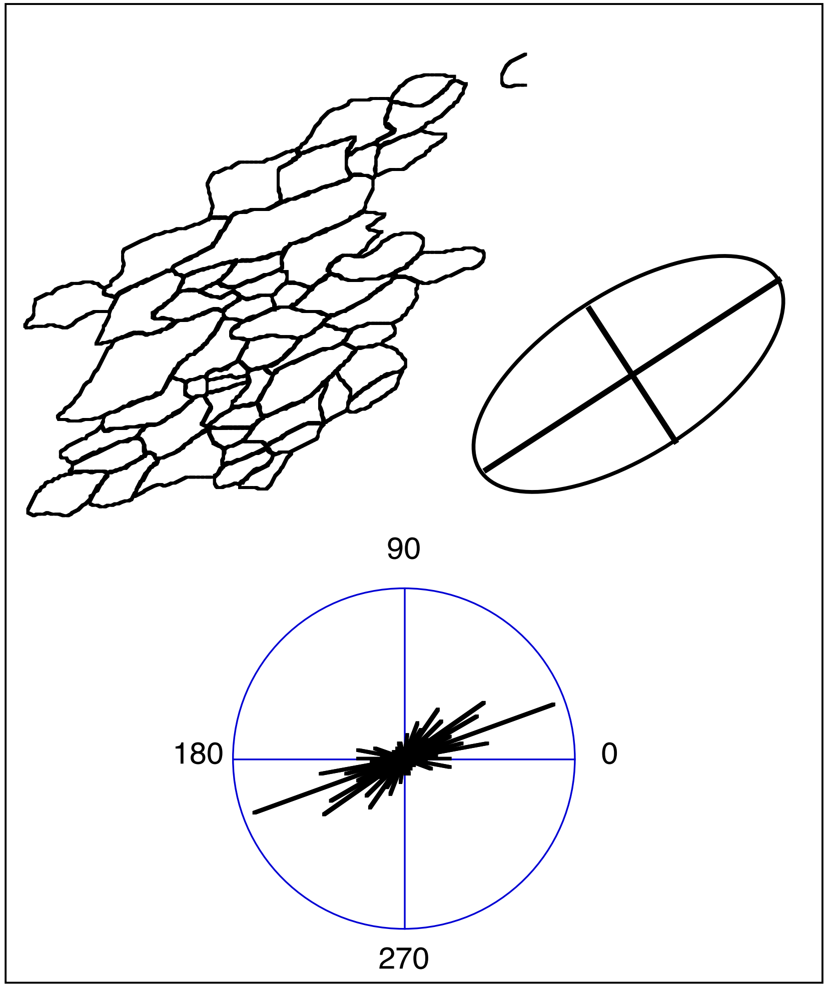
deformation mechanism map for calcite d = 100 µm

und wie erkennen wir,
ob es sich um...

dislocation glide
dislocation creep
diffusion creep

... handelt ?

microstructure of dislocation glide

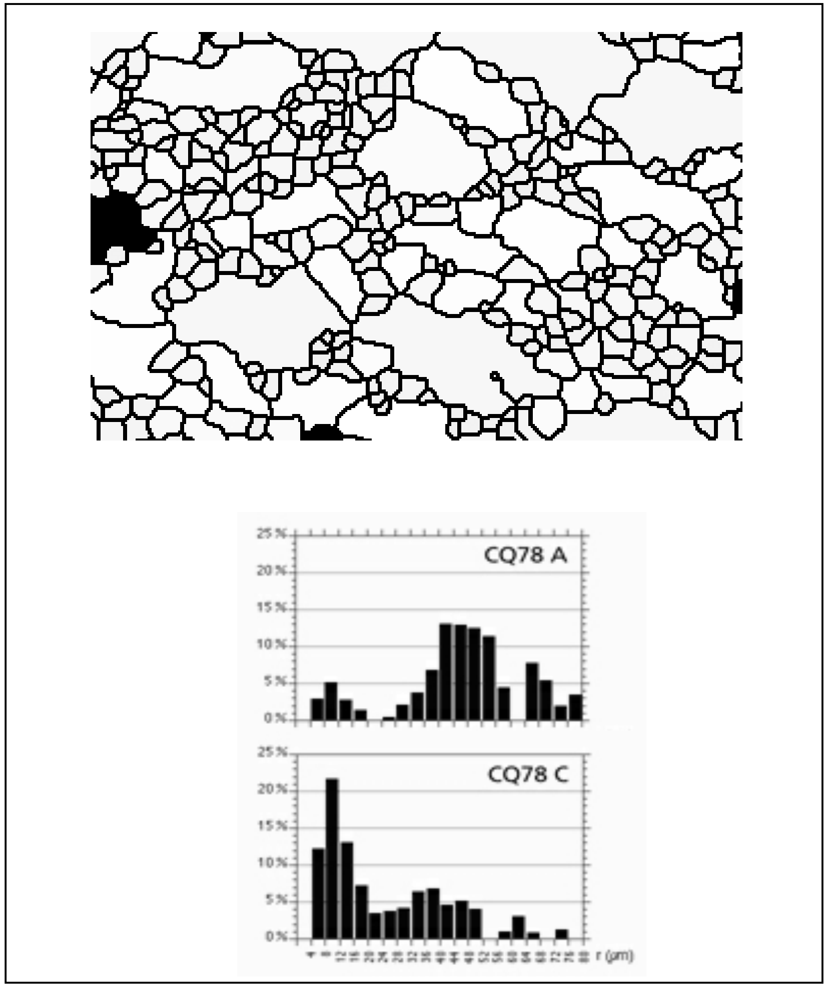


shape change = strain
strain markers,
homogeneous
deformation

typical for:

intracyrstalline plasticity
dislocation glide with 5
slips systems (van Mises)

microstructure of dislocation creep diffusion creep

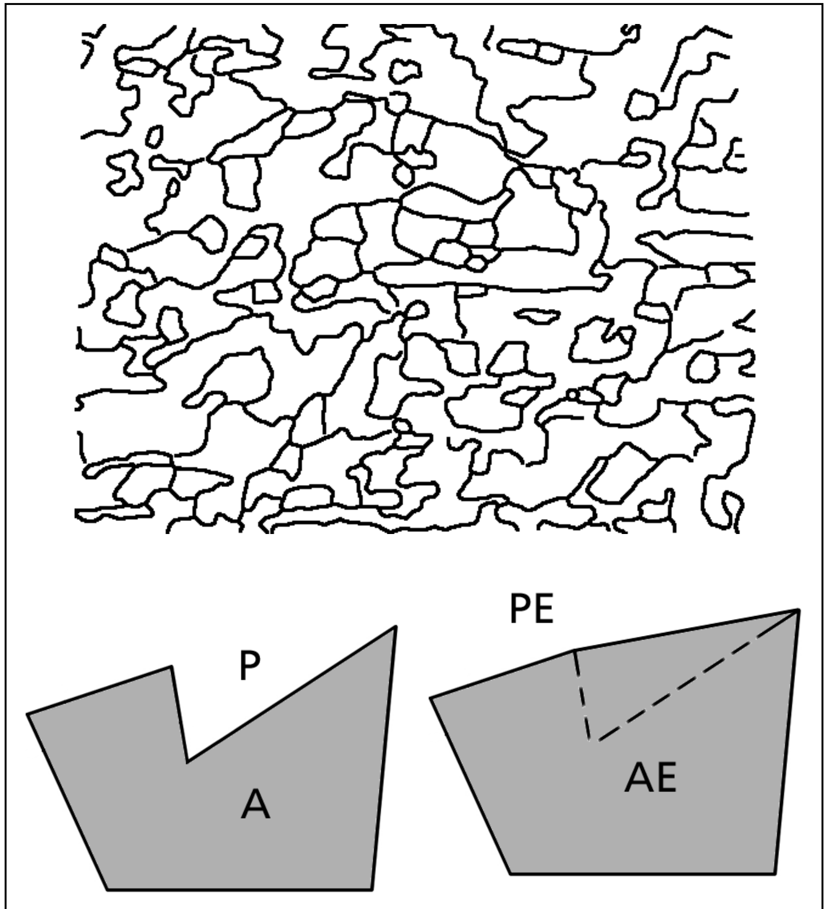


change of size
grain size distribution

typical for:

recrystallization, grain growth, nucleation

microstructure of dislocation creep diffusion creep



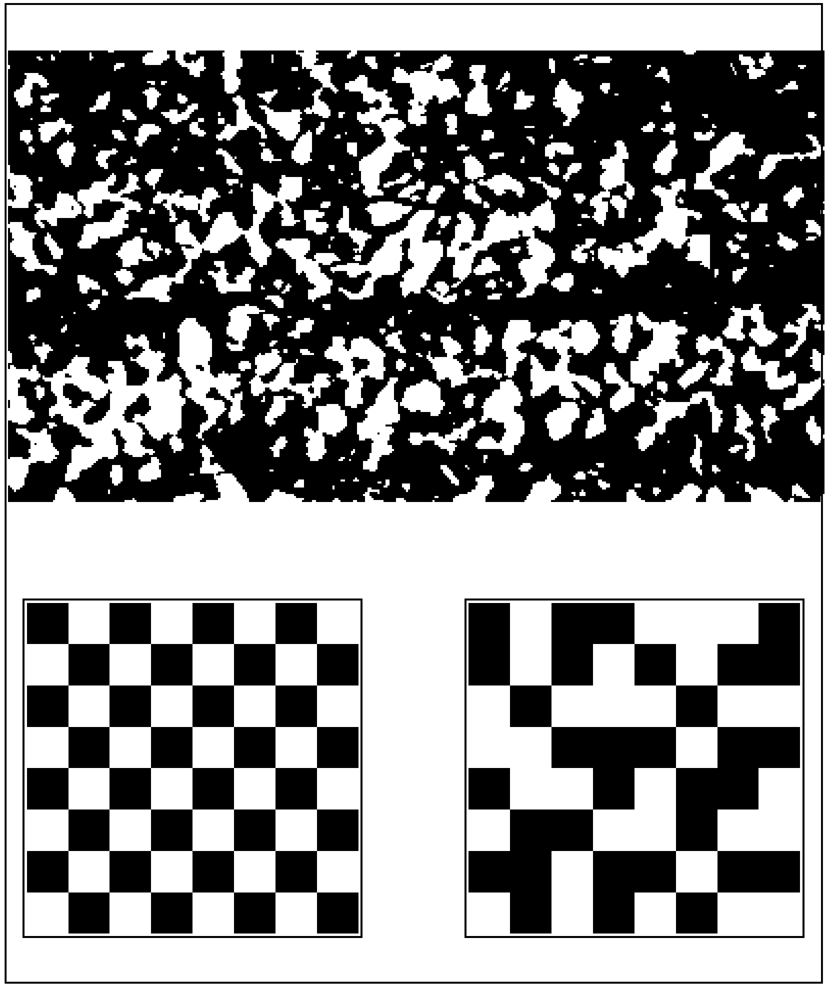
PARIS(%) factor = 2 · ((P-E) / E) · 100

shape change ≠ strain
lobate boundaries
convex-concave
angularity, etc.

typical for:

grain boundary migration
annealing, cataclasis

microstructure of diffusion creep

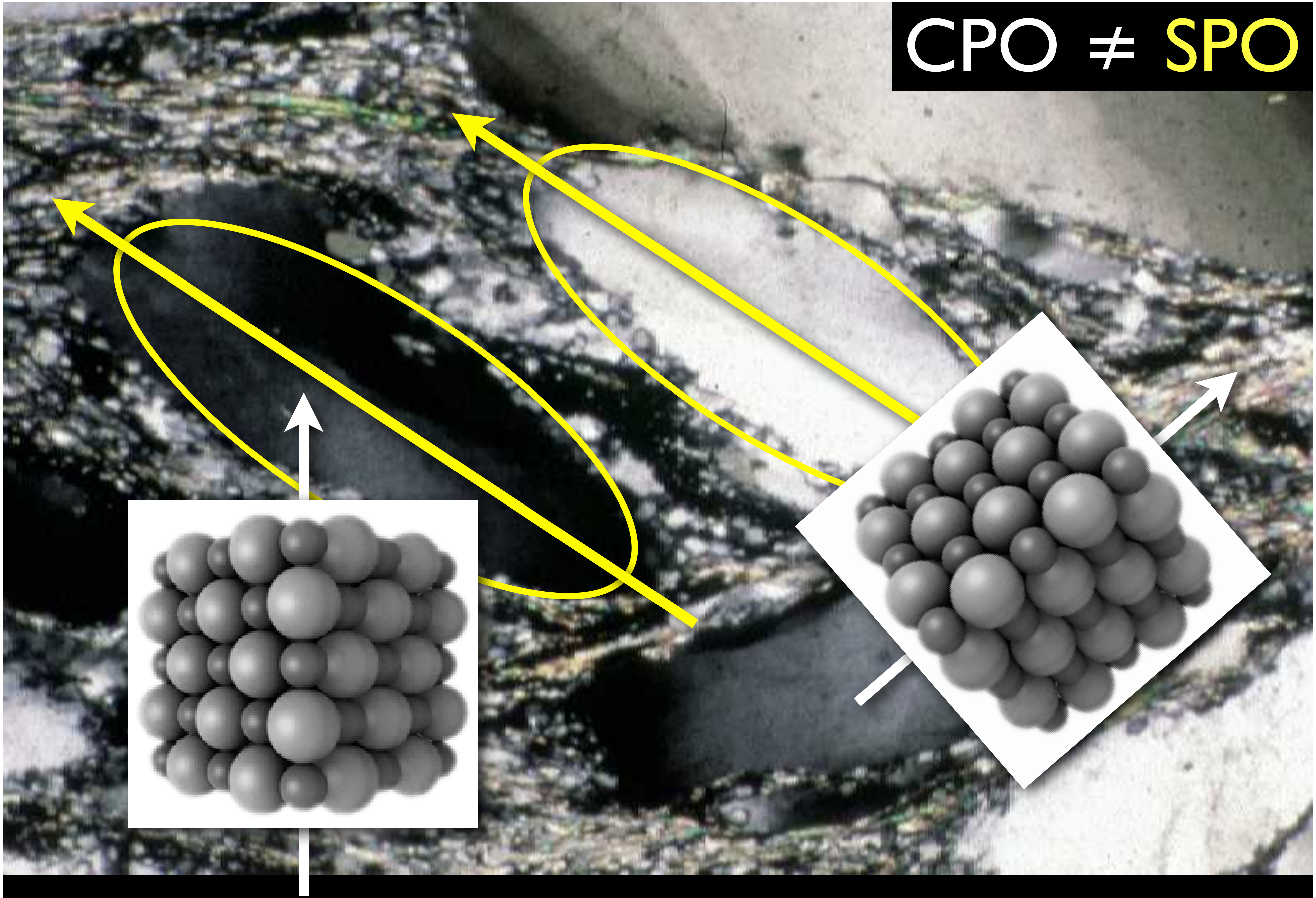


spatial distribution
grain contact frequency

typical for:

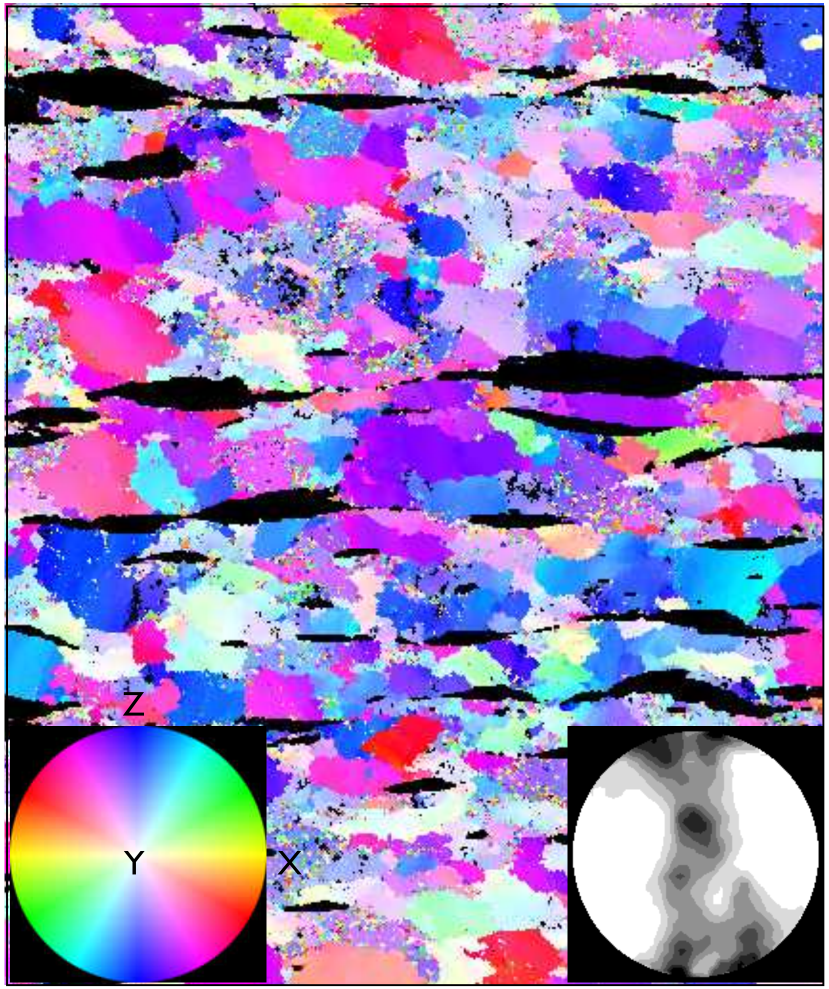
grain boundary sliding
granular flow

CPO ≠ SPO



crystal orientation ≠ shape orientation

CPO of dislocation creep



map of crystallographic orientation
(orientation image)
c-axis pole figure

typical for:

dynamic recrystallization,
shear sense

workshops

>>> BASEL UNIVERSITY SCIENCE FACULTY (PHIL II)
>>> BASEL UNIVERSITY LIBRARY
>>> BASEL UNIVERSITY Vorlesungsverzeichnis
>>> BASEL UNIVERSITY PERSSEARCH

ROCK DEFORMATION HOME | address | lectures | workshops | software | SXM macros | manuals | projects | publications

Texas A&M

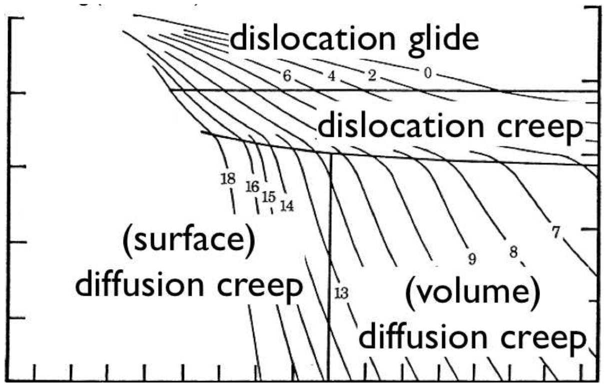
Paläontologin !!

ROCK DEFORMATION HOME | address | rock deformation lab | pictures | miscellaneous | -impressum-

>>> TROMSØ HARD ROCK HOMEPAGE
>>> TROMSØ GEOLOGY HOMEPAGE
>>> TROMSØ UNIVERSITY HOMEPAGE

>>> TROMSØ WEBGEOLOGY

3 Dissertationen

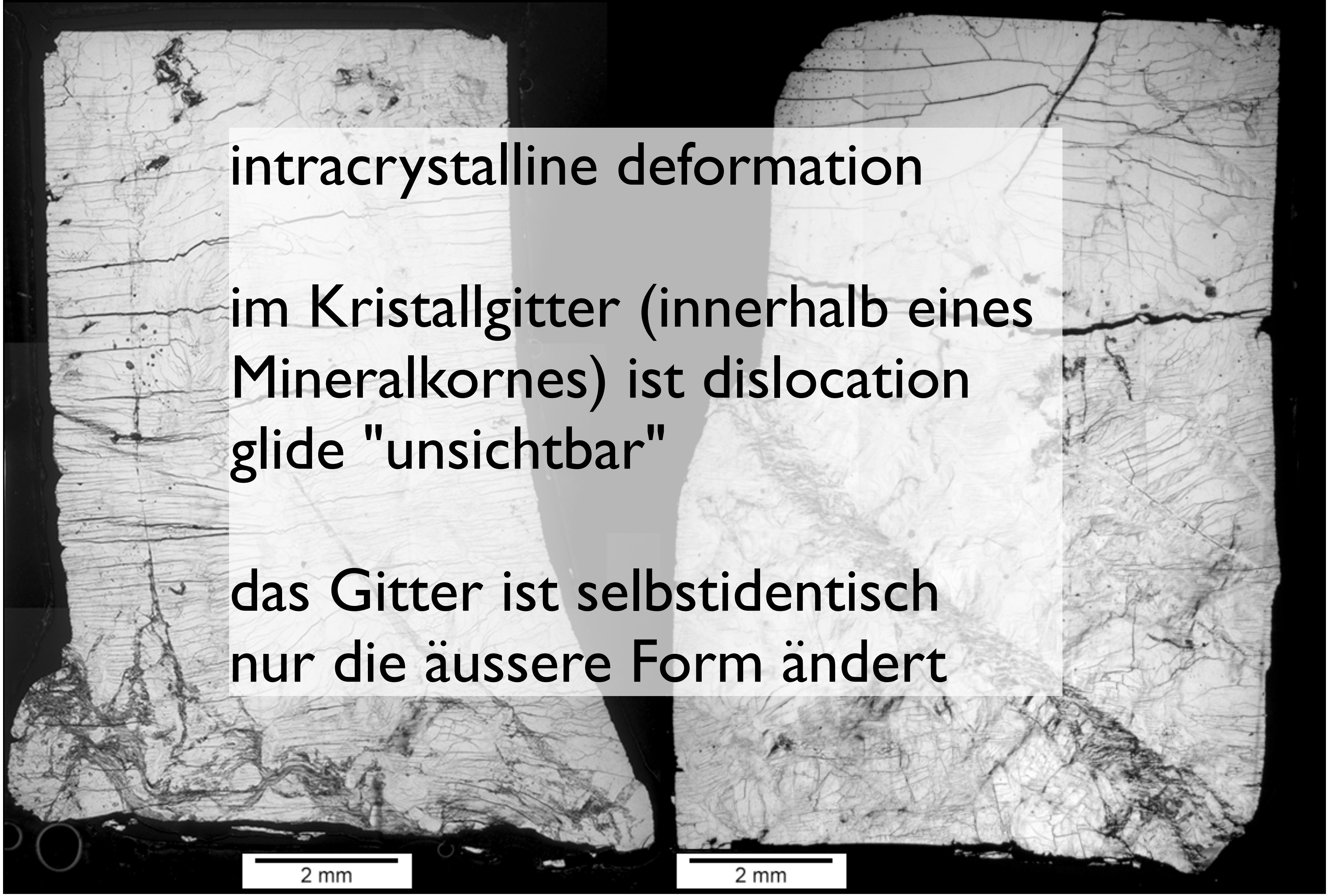


1. dislocation glide
   Anja Thust : Untersuchungen an Quarz Einkristallen
   Festigkeit der verschiedenen Gleitsysteme

2. dislocation creep - diffusion creep
   Rüdiger Kilian : Deformationsmechanismen von Quarz in polyphasen Gesteinen

3. diffusion creep
   Matěj Peč : Rheologisches Verhalten von fault rocks in Natur und Experiment.

Diss zu dislocation glide

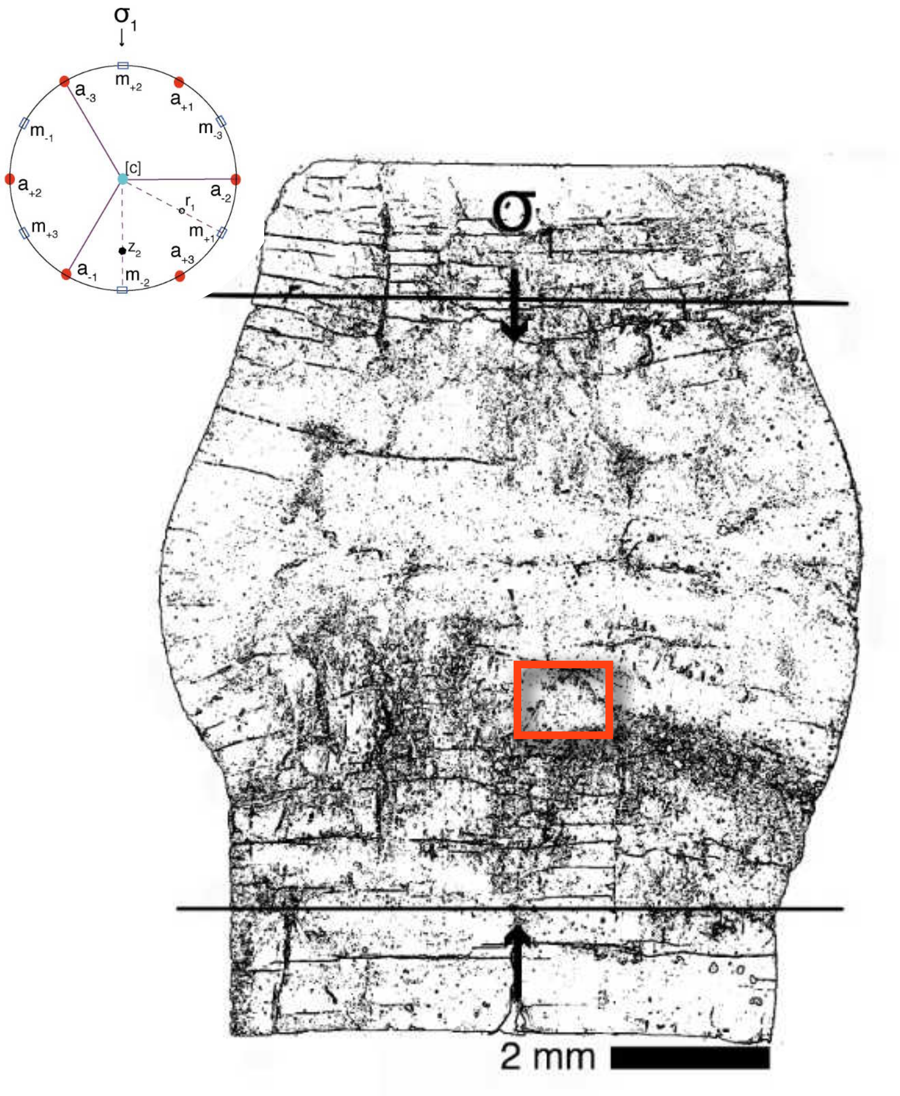


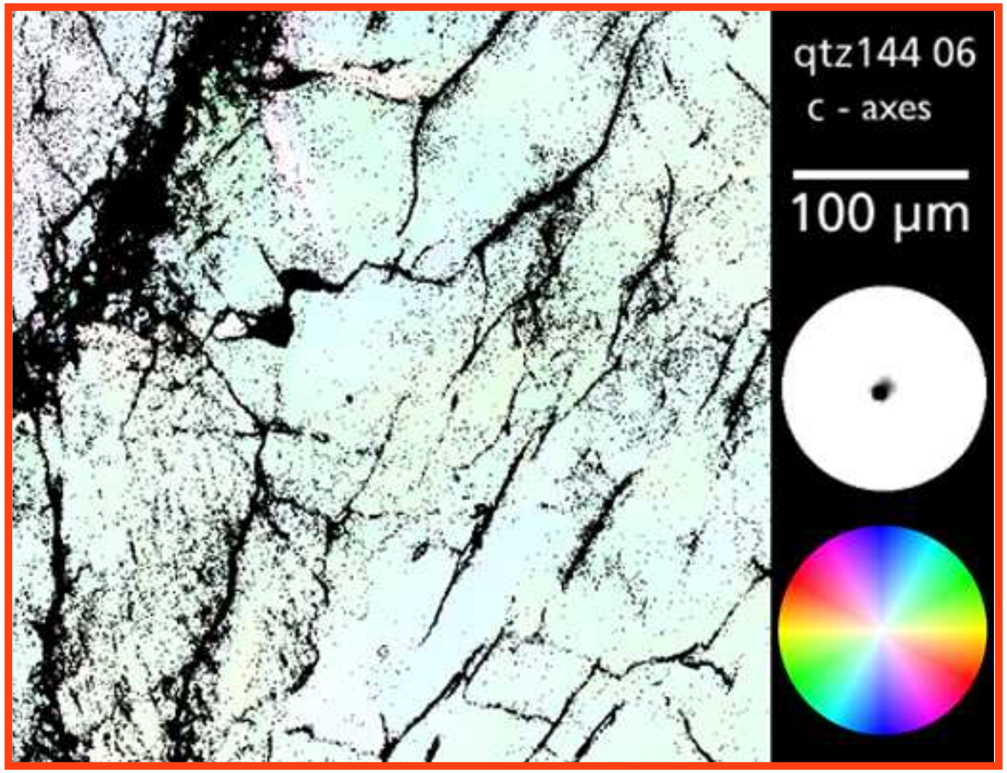
intracrystalline deformation

im Kristallgitter (innerhalb eines Mineralkornes) ist dislocation glide "unsichtbar"

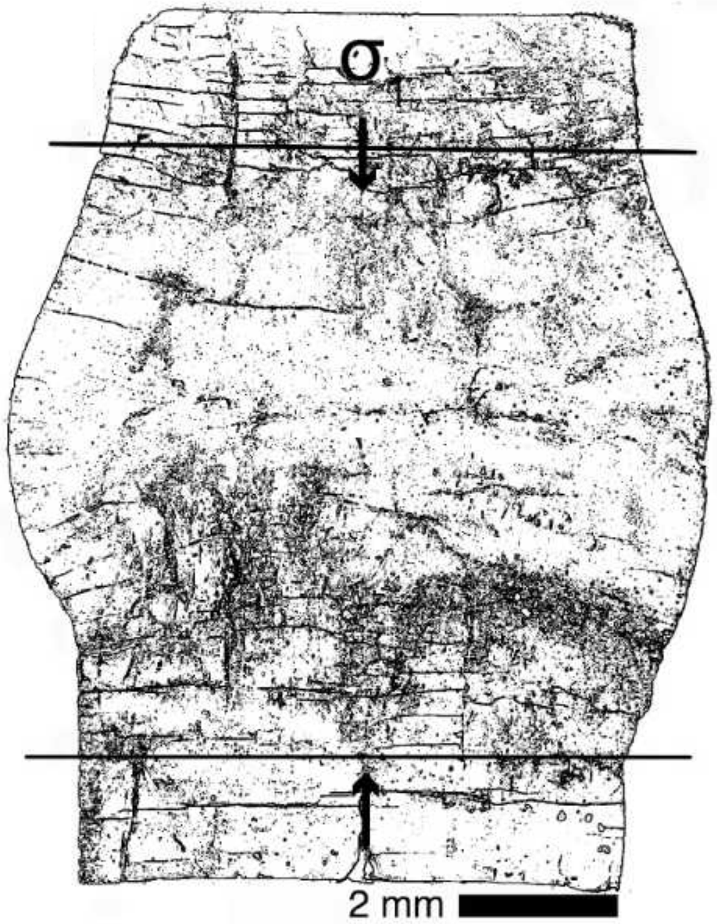
das Gitter ist selbstidentisch
nur die äussere Form ändert

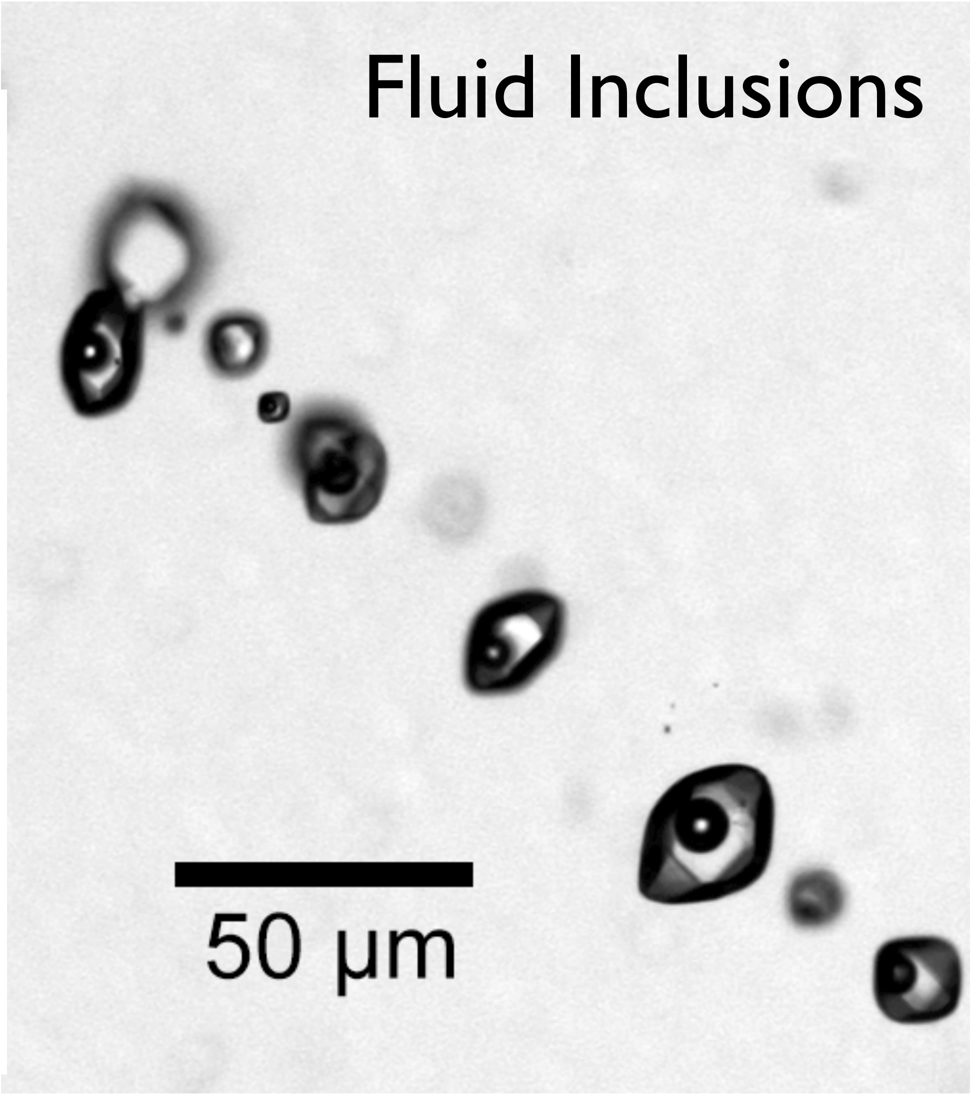
Anja Thust : Quarz - Einkristalle



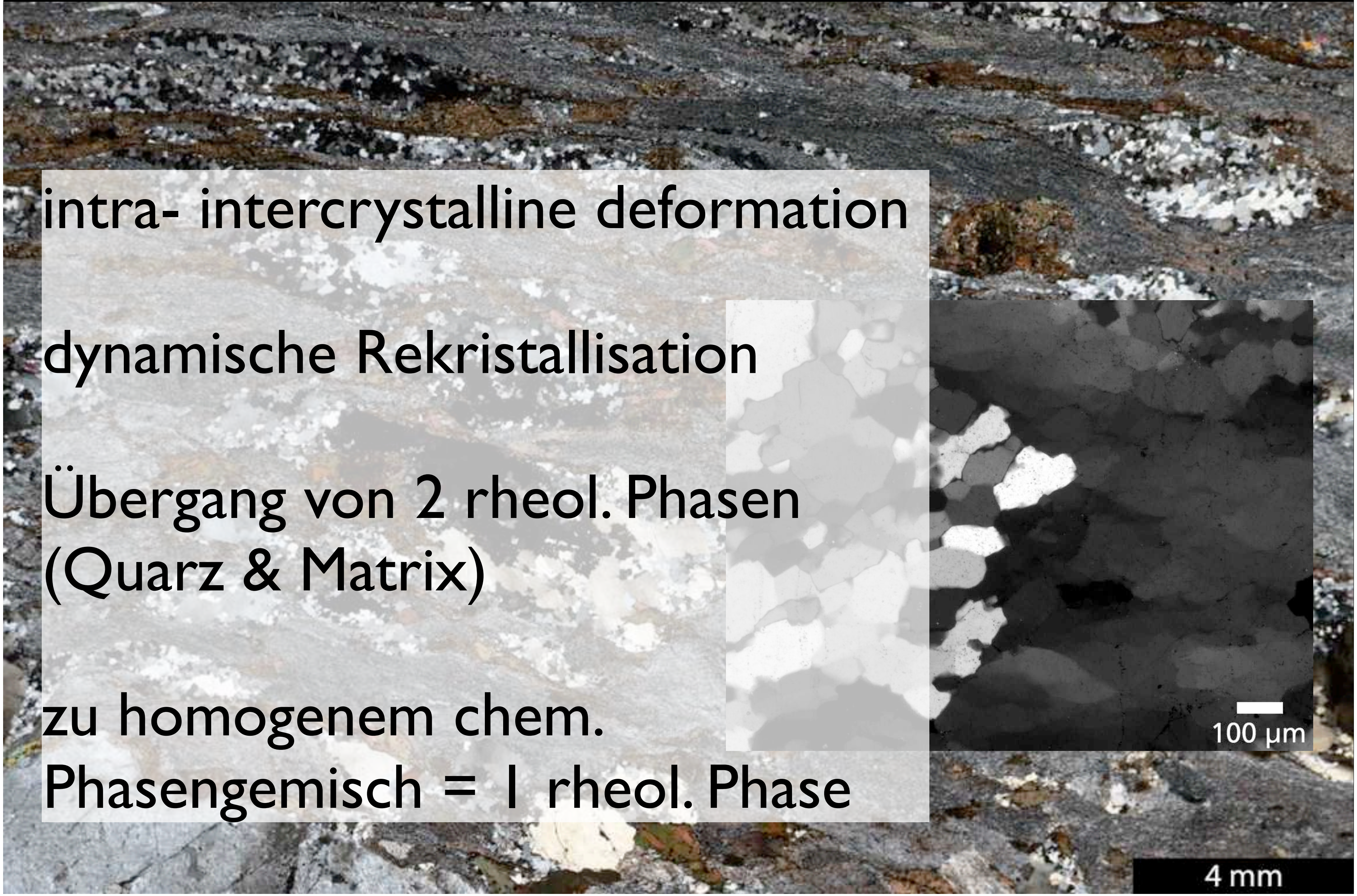


Anja Thust : Quarz - Einkristalle





Diss zu dislocation creep



intra- intercrystalline deformation

dynamische Rekristallisation

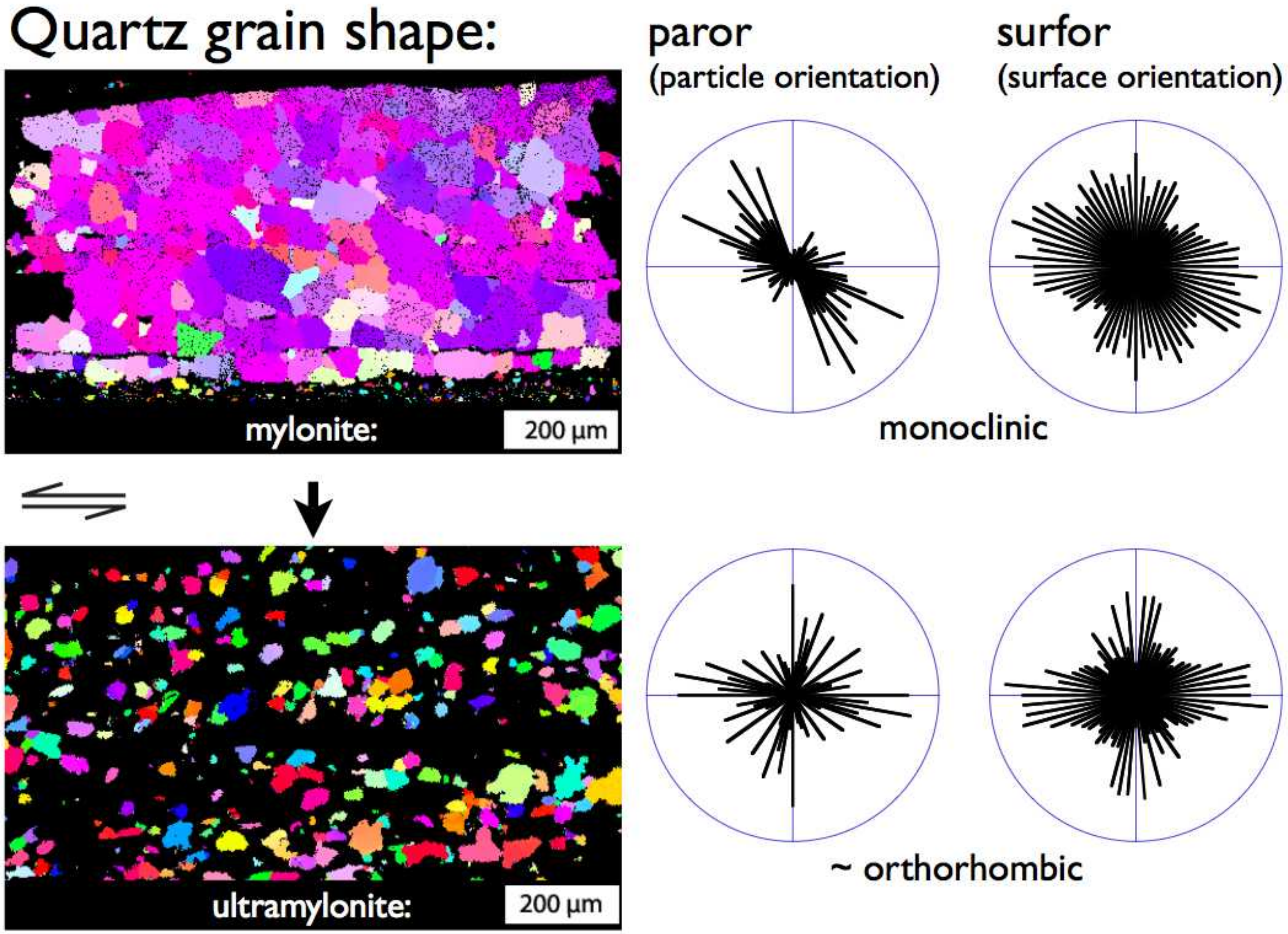
Übergang von 2 rheol. Phasen (Quarz & Matrix)

zu homogenem chem. Phasengemisch = 1 rheol. Phase

Rüdiger Kilian : Quarz in Polyphasen

dislocation creep

diffusion creep

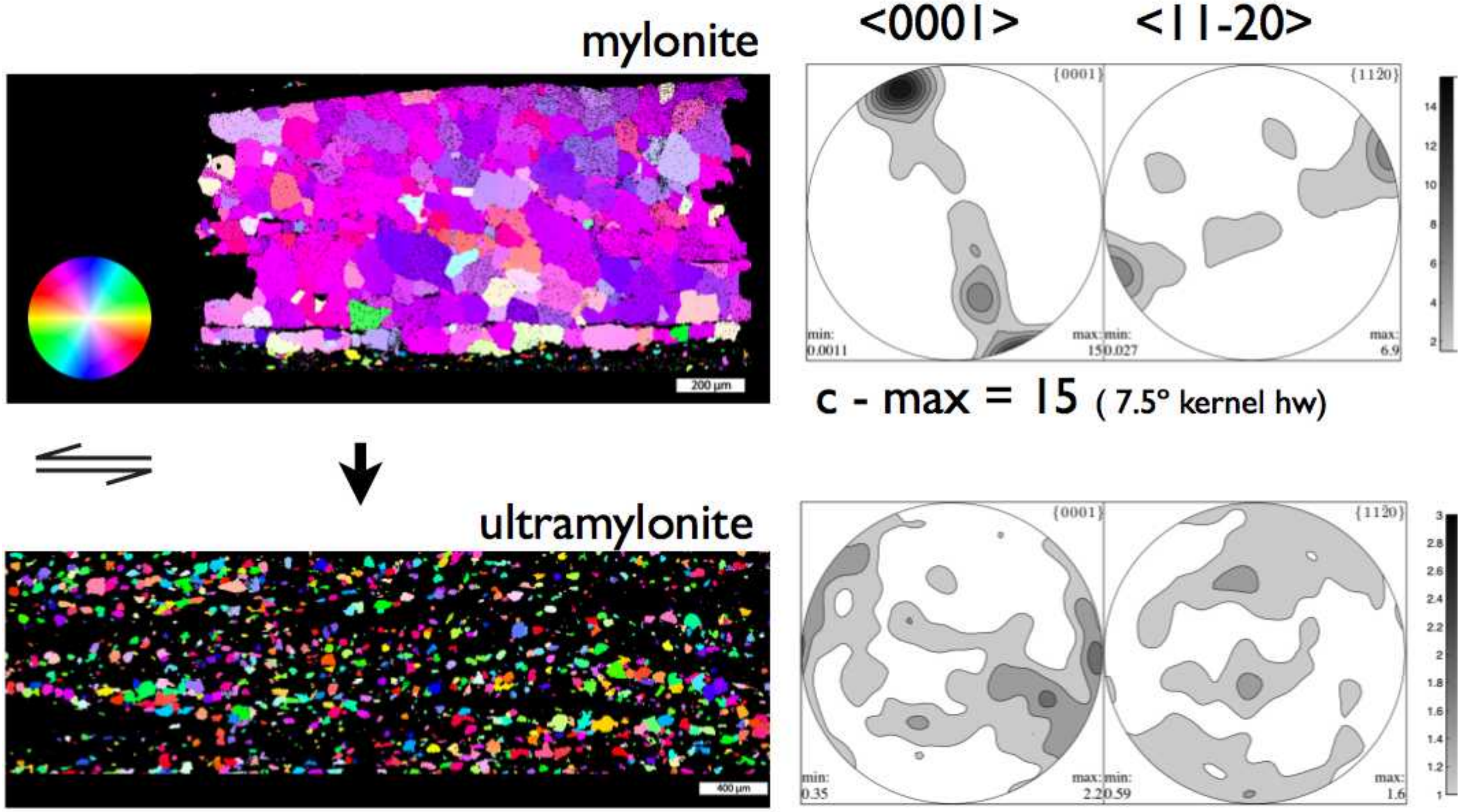


Rüdiger Kilian : Quarz in Polyphasen

Quartz texture:

dislocation creep

diffusion creep



c - max = 15 (7.5° kernel hw)

EBSD data with CIP c-axes orientation colour coding

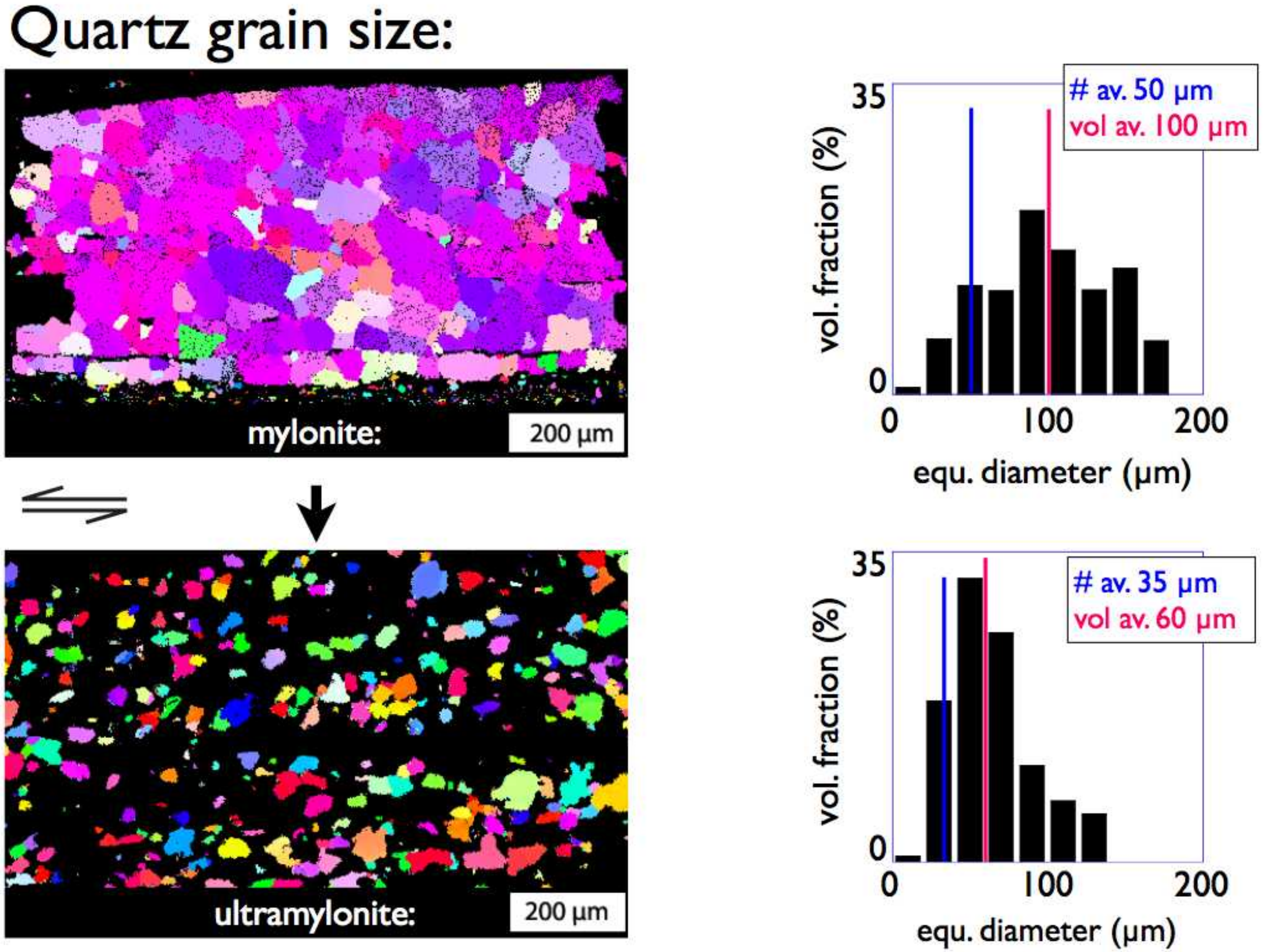
c - max = 2.2 (7.5° kernel hw)

calculated with MTEX (Hielscher & Schaeben, 2008)

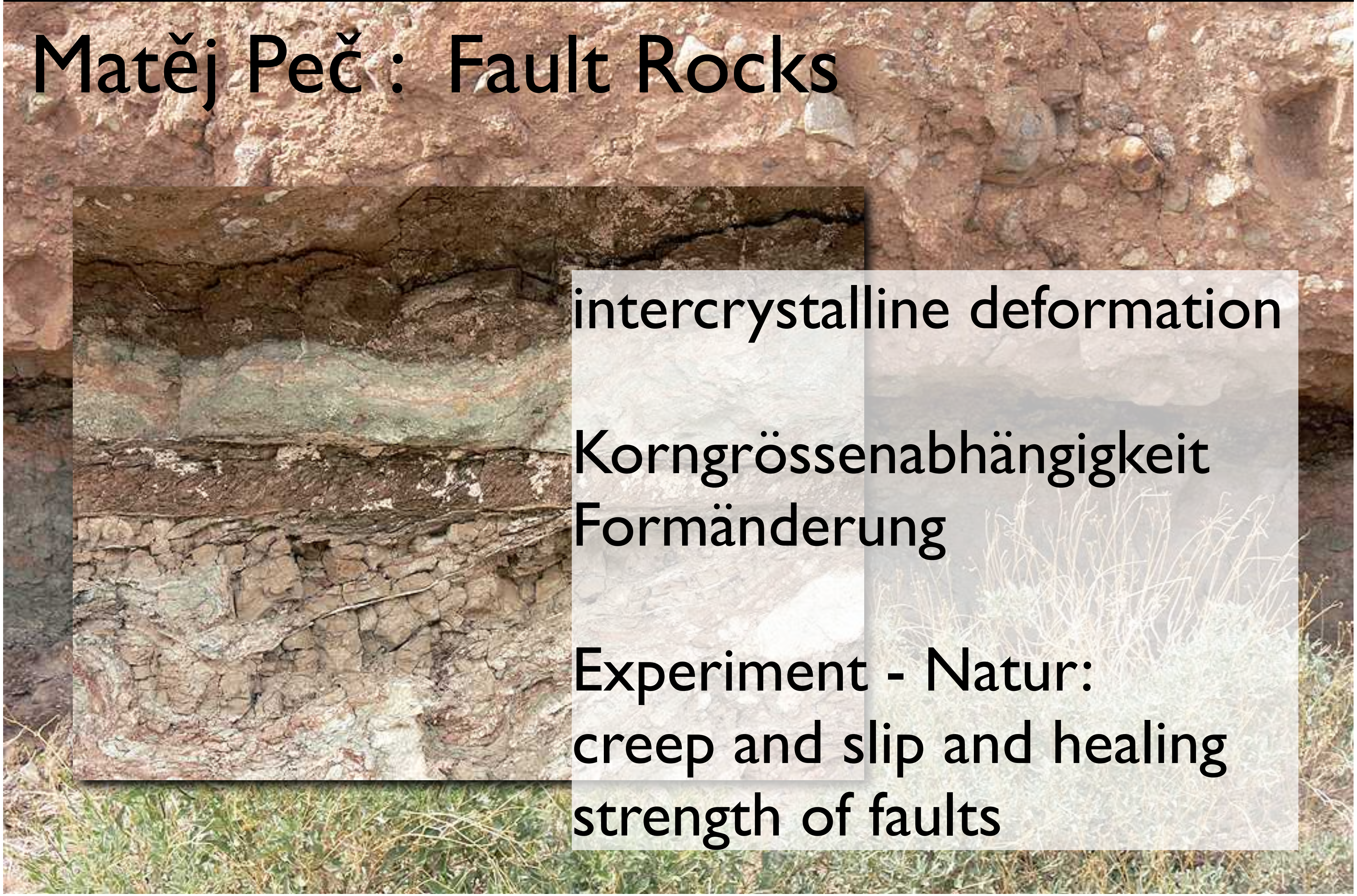
Rüdiger Kilian : Quarz in Polyphasen

dislocation creep

diffusion creep



Diss zu diffusion creep



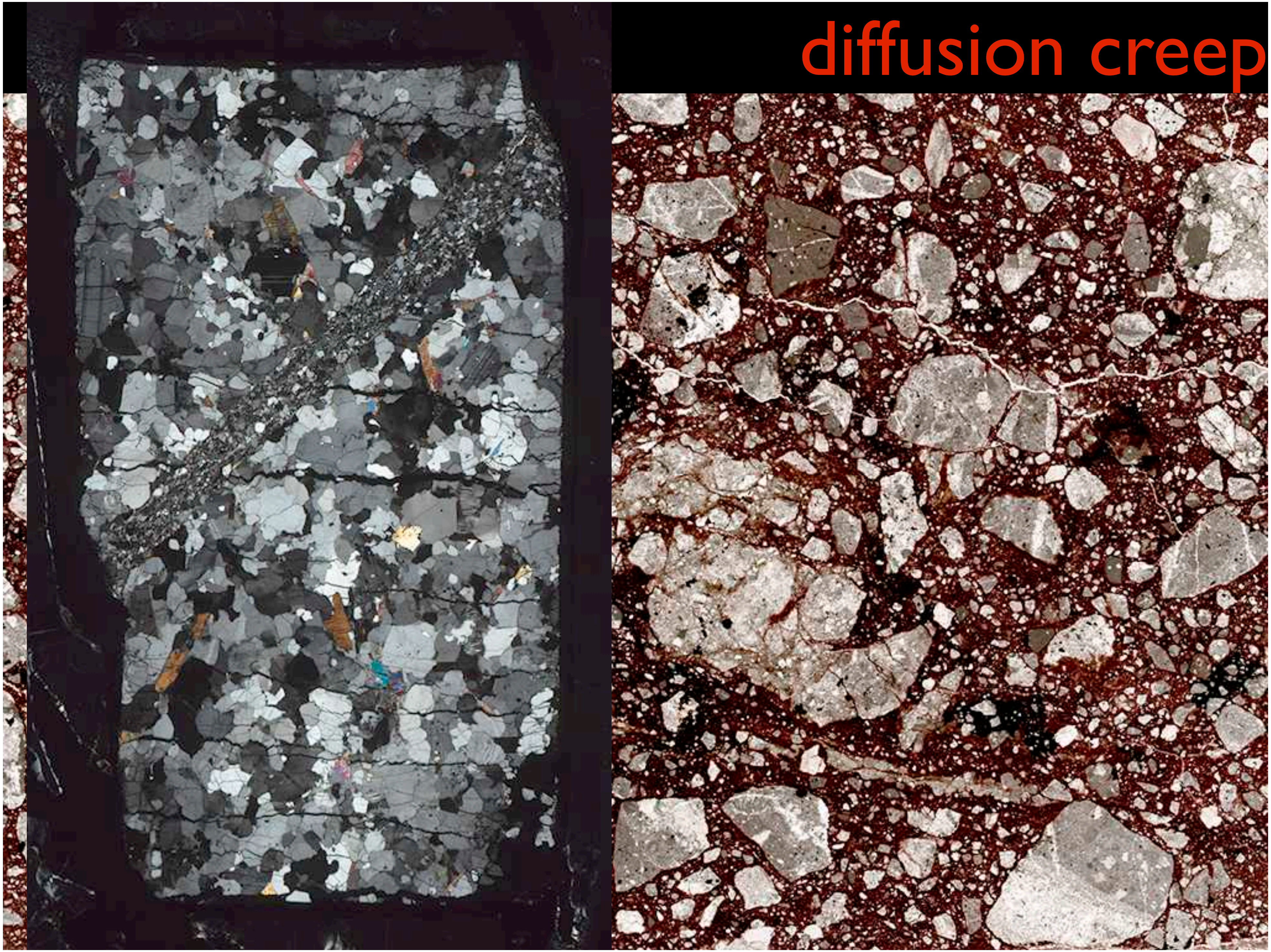
Matěj Peč : Fault Rocks

intercrystalline deformation

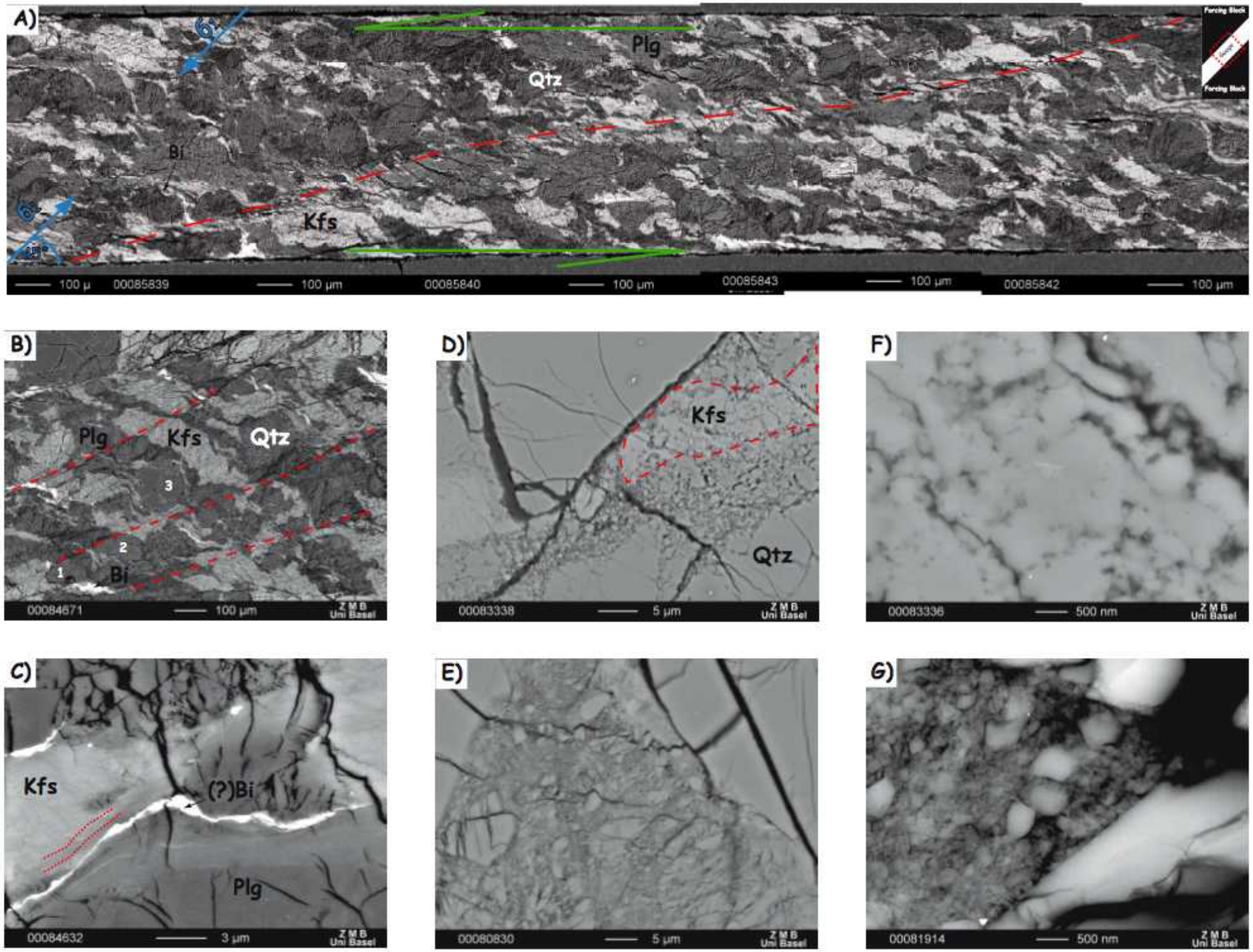
Korngrössenabhängigkeit
Formänderung

Experiment - Natur:
creep and slip and healing
strength of faults

diffusion creep

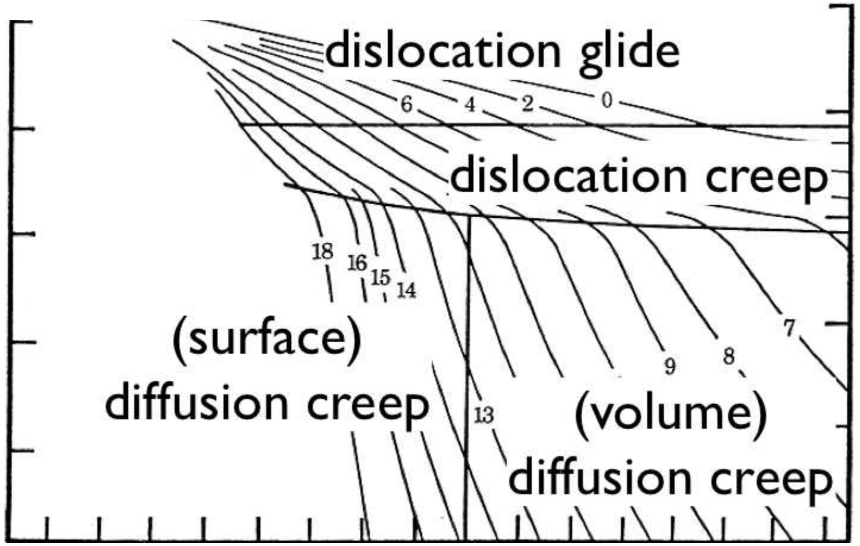


Matěj Peč : Fault Rocks



Moral und Nutzanwendung

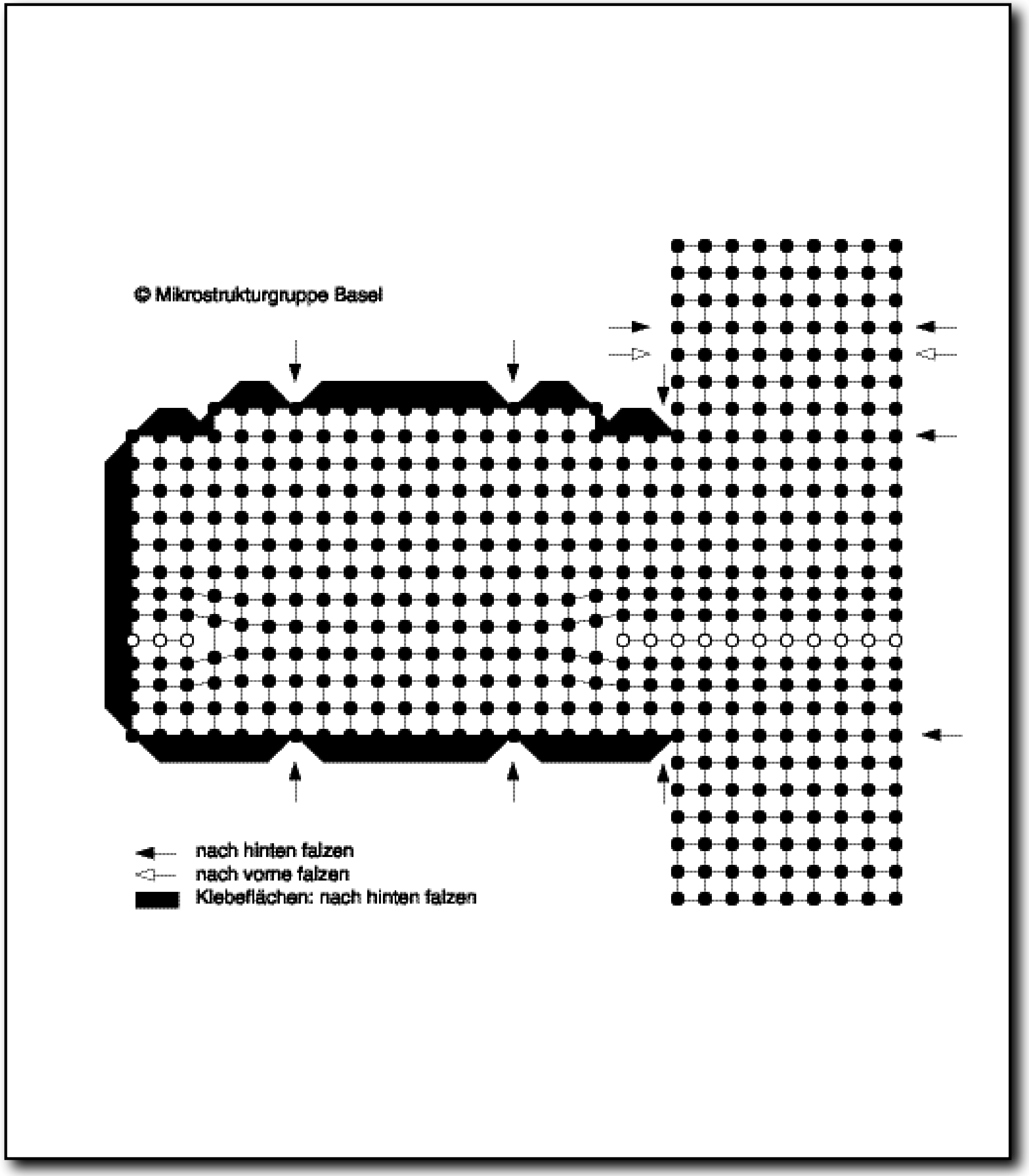
wie aus vielen schnellen Versetzungen eine grosse Langsamkeit entsteht



Moral und Nutzanwendung

- es braucht Fehlstellen
- noch besser Korngrenzen
- noch besser Zweit-/Drittphasen
- Wasser hilft auch

zum Schluss:
slow dislocations
... zum Heimnehmen



the end