

Aspects of Earth Sciences

Prof. Dr. Ulrich A. Glasmacher

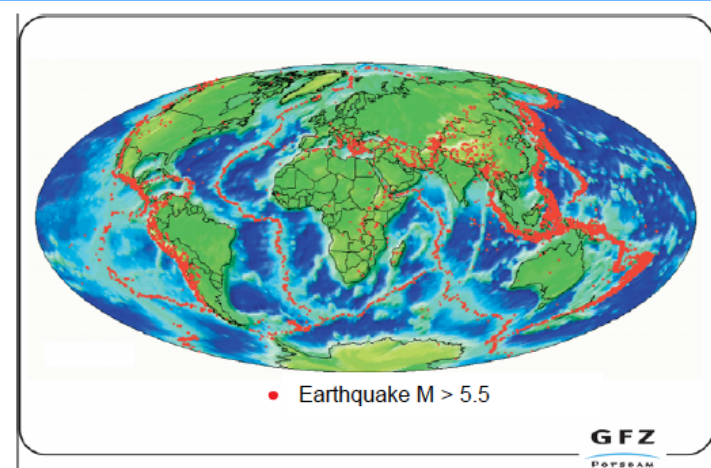
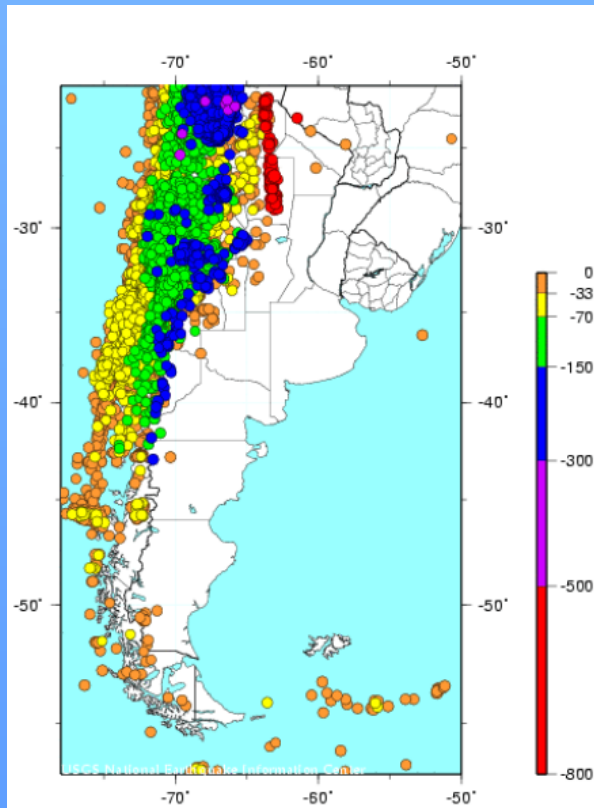
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Representing a group of scientists from HD-Uni, KIT,
and Argentine cooperation partner

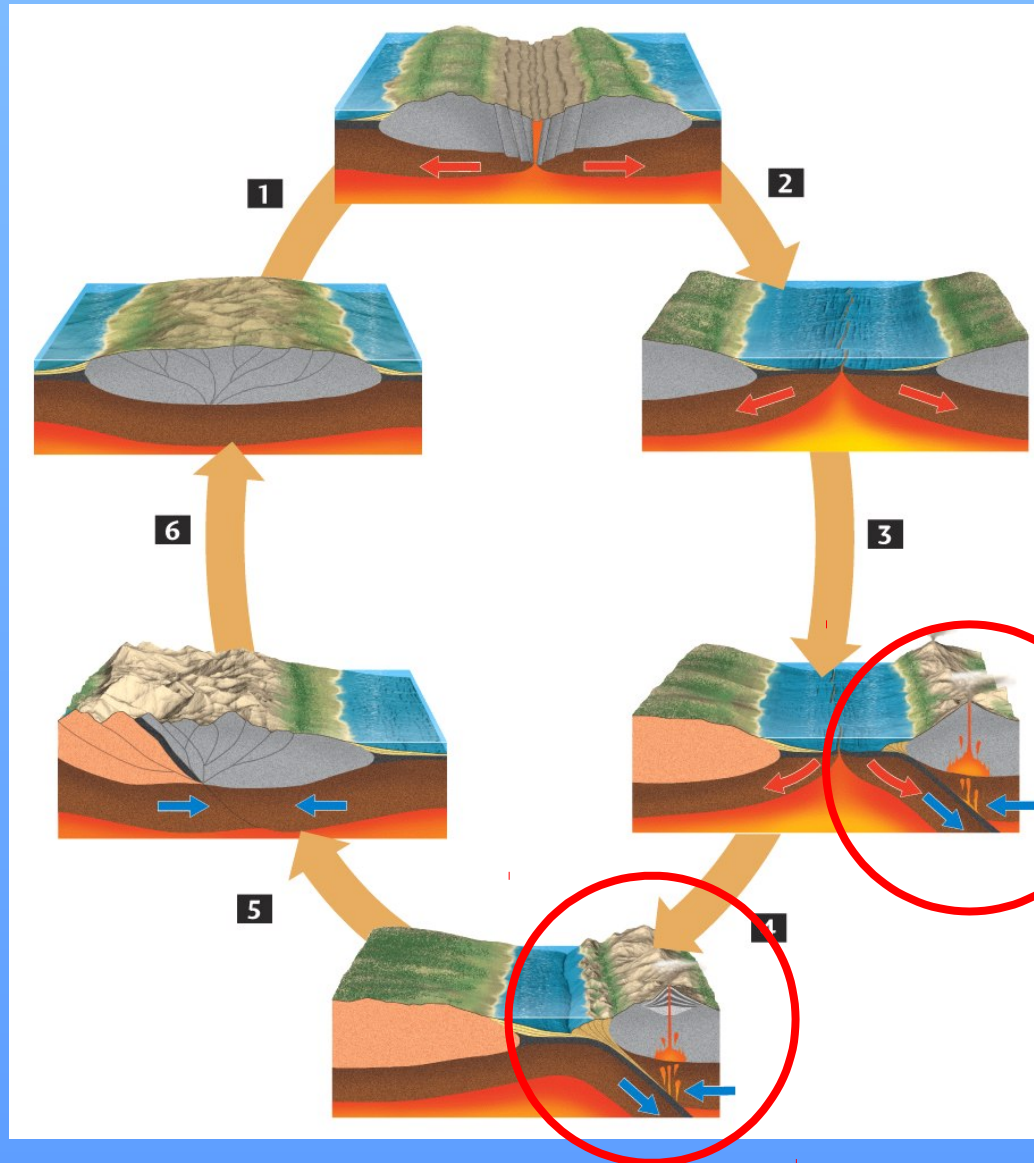
Why is the Tunnel and the ANDES Underground Laboratory
so important for Earth Sciences?

It opens the opportunity to perform Earth Science Research
along a **transect** and along **time** in an **Active Orogeny**.



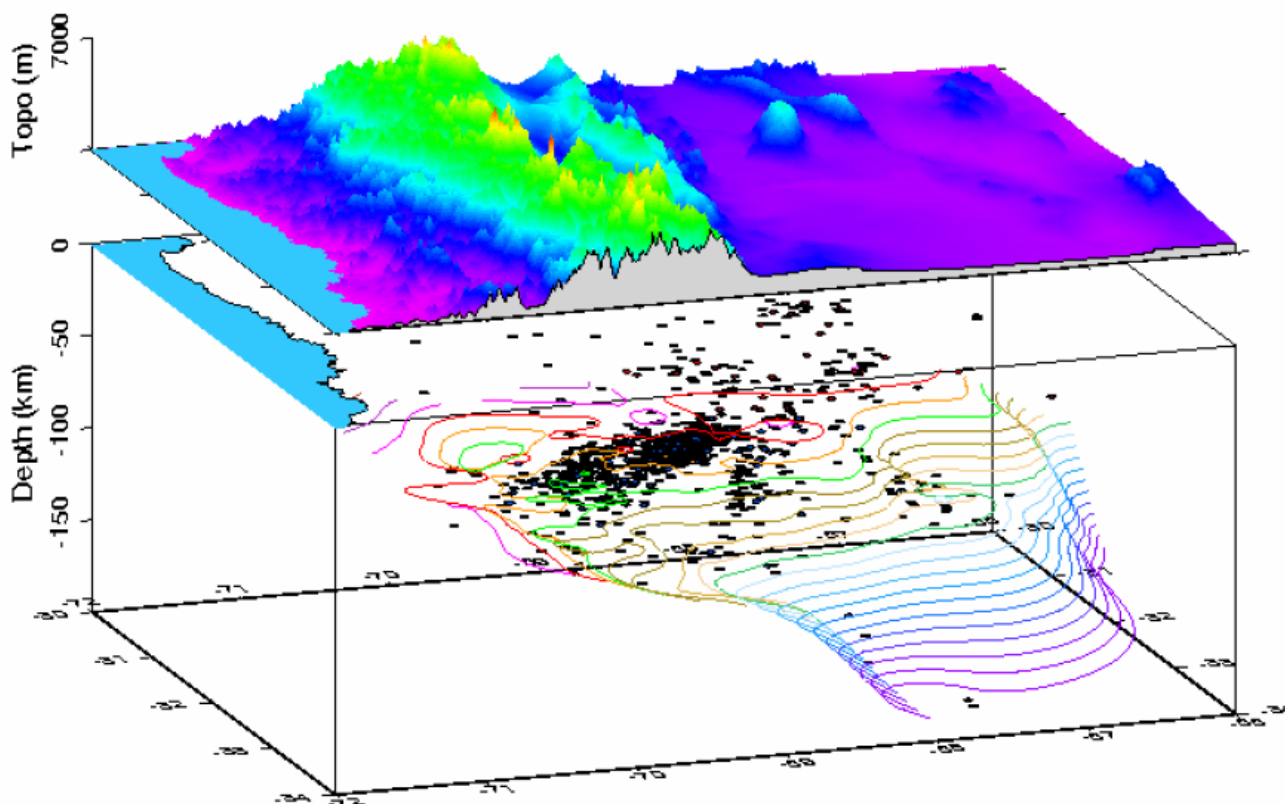
Earthquake between 1973-2011 with $M > 4$.
NEIC-USGS catalog.

Background: Plate Tectonic Theory

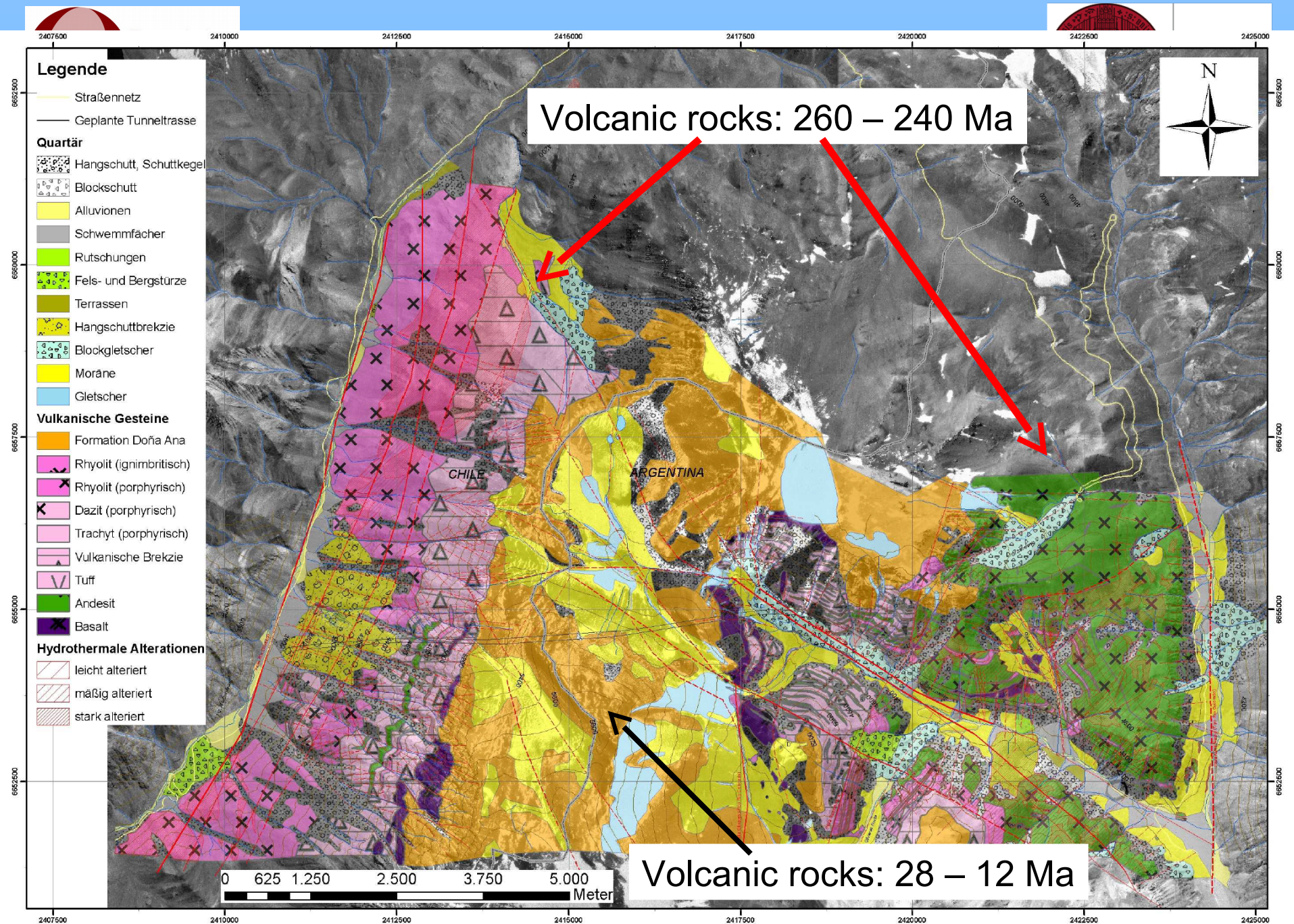


The Andes: An active Orogeny.

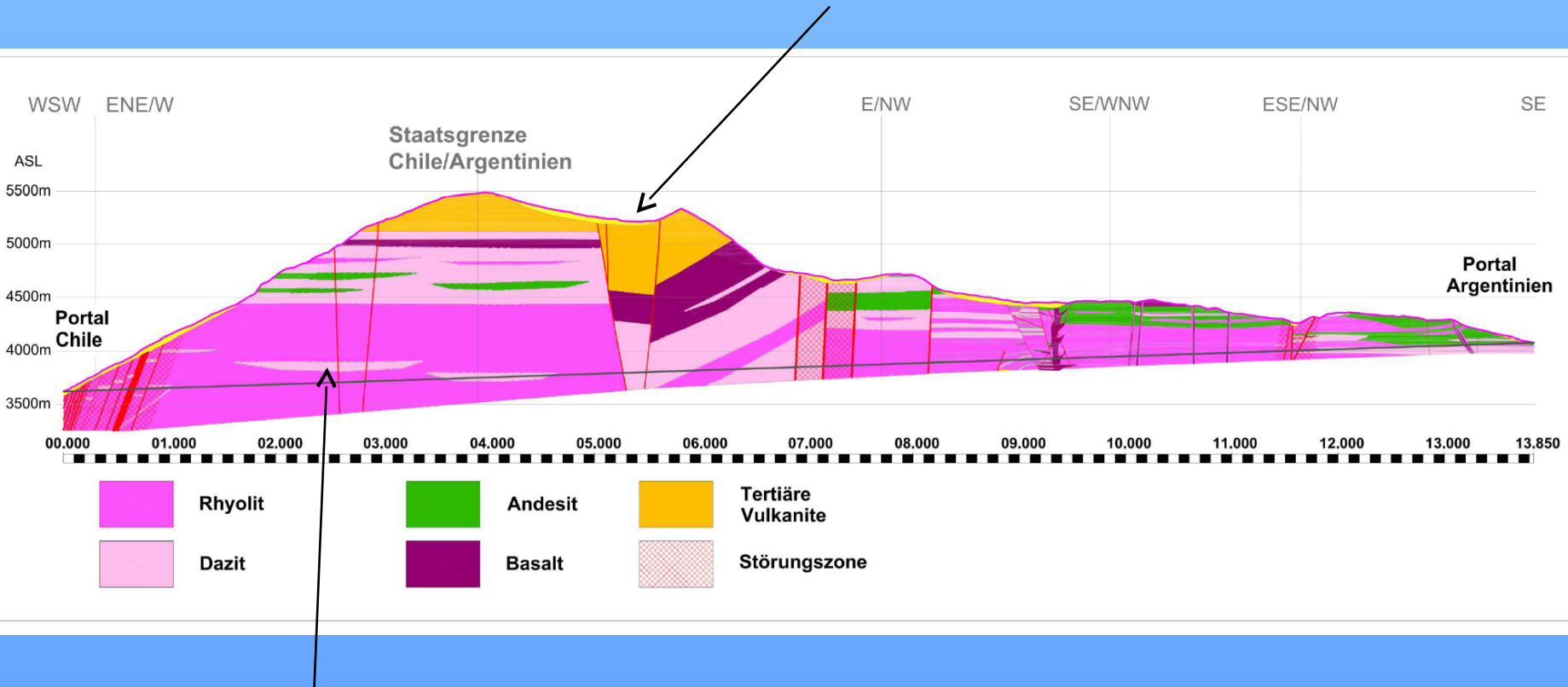
Nazca Plate Morphology & Surface Topography



Furlani & Triep 2007



Upper Oligocene to Middle Miocene: about 28 – 12 Ma



Upper Permian to lower Triassic: about 260 - 240 Ma

Calculated temperature within the ANDES are about 50 °C

The suggested Earth Sciences Research is two-fold:

A. During the excavation of the tunnel and the AUL

B. During the Life time of the ANDES Underground Laboratory (AUL).

What do we learn from the Tunnel ?

- **Past Geodynamic movements**

by analysing and dating the deformation (structures/faults).

- **Past Fluid movement and chemistry**

by analysing and dating rock alterations (Mineral changes).

- **Past thermal histories, rock uplift, and erosion**

by analysing thermochronometers and applying numerical simulations.

- **Dynamic of Permian-Triassic and Tertiary volcanic eruptions**

by analysing and dating fresh volcanic rocks.

All in Millions of Years

What do we learn from long-term experiments in the ANDES Underground Laboratory

- **Recent Geodynamic movements** by analysing geophysical parameters.
- **Determination of Stress fields** and their changes
- **Recent Fluid movement and chemistry** by analysing fluids.
- **Recent Gas movement and chemistry** by analysing rock gas.
- **Crystallization of melts** without influence of Cosmic rays and spallation products.

Continuous Records

Important to mention:

Fluid, Gas data are correlated with geophysical data.

Therefore, monitoring of change of physical parameters is **highly important**.

A. During the excavation of the tunnel and the ANDES Underground Laboratory.

Suggested Projects:

- Long-term evolution of the Mountain building process using nuclear tracks.
and α -decay (Glasmacher, Krob, Uni Heidelberg)
- Geochemical alteration in damage zones around tectonic faults.
(Hilgers, Busch, Kontny, KIT)
- Monitoring of fluid flow and chemistry?
- Quantification and numerical modelling of structural evolution?

A. During the excavation of the tunnel and the ANDES Underground Laboratory.

Suggested Projects:

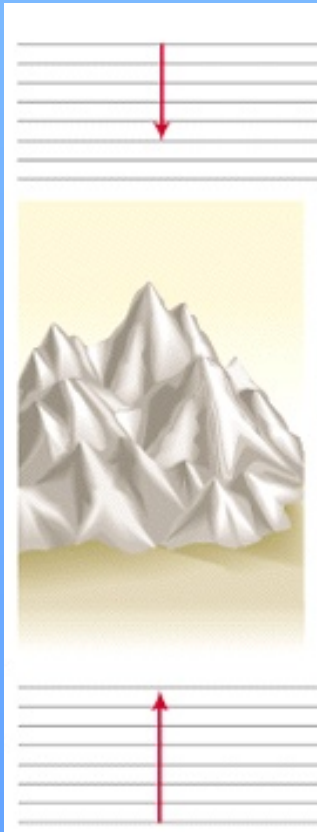
- Long-term evolution of the Mountain building process using nuclear tracks and a-decay (Glasmacher, Krob, Uni Heidelberg)

Objects: rocks from the tunnel and drill cores

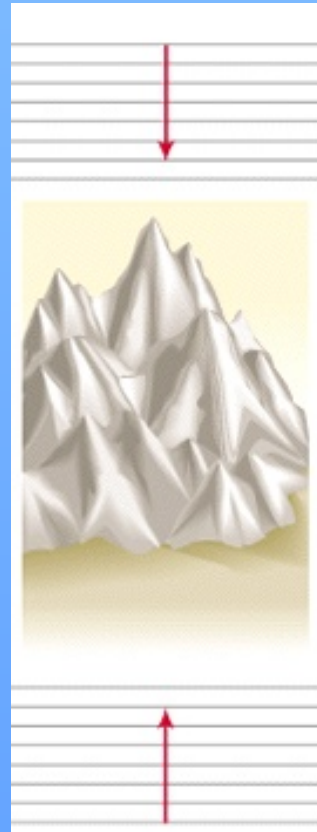
What does “Long-term evolution of the Mountain building process” mean?

Erosion rate
[m/Ma]

Rock uplift rate
[m/Ma]



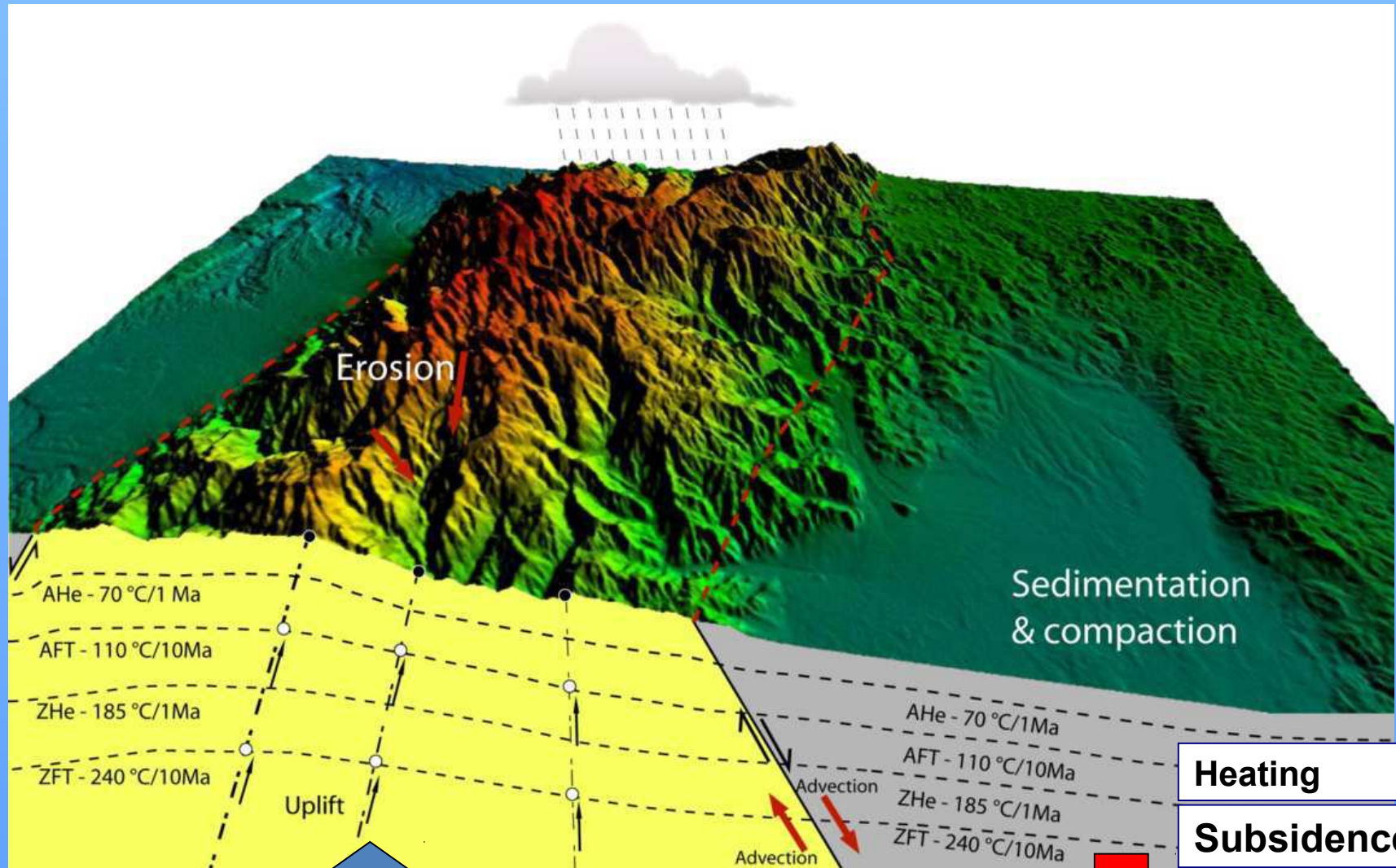
Rock uplift rate
> Erosion rate
= **Surface elevation
rise**



Rock uplift rate
= Erosion rate
= **No change
of surface elevation**



Rock uplift rate
< Erosion rate
= **Surface elevation
decrease**



Exhumation

Cooling

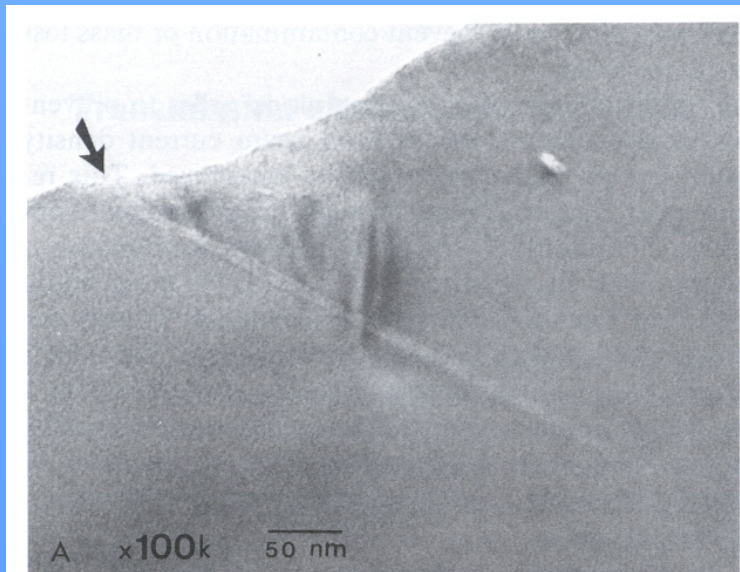
All at a constant geothermal gradient!

Heating

Subsidence

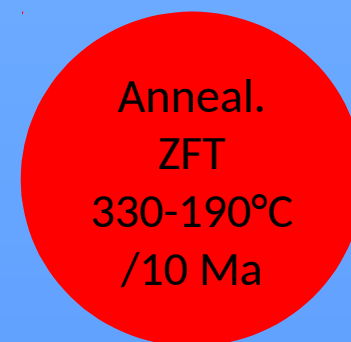
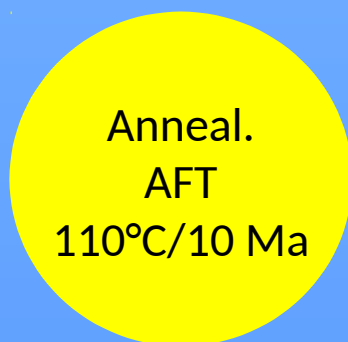
How can this be achieved: **nuclear tracks** and **a-decay**?

- Rocks bear Apatite and Zircon with ^{238}U and ^{232}Th isotopes.
- Apatite and Zircon are archives of time-temperature evolution of rocks/crust.
- Two possible decays: Fissioning and a-decay
- Natural fissioning of ^{238}U creates linear crystal defects (nuclear tracks) in apatite (AFT) and zircon (ZFT).



How can this be achieved: **nuclear tracks** and **a-decay**?

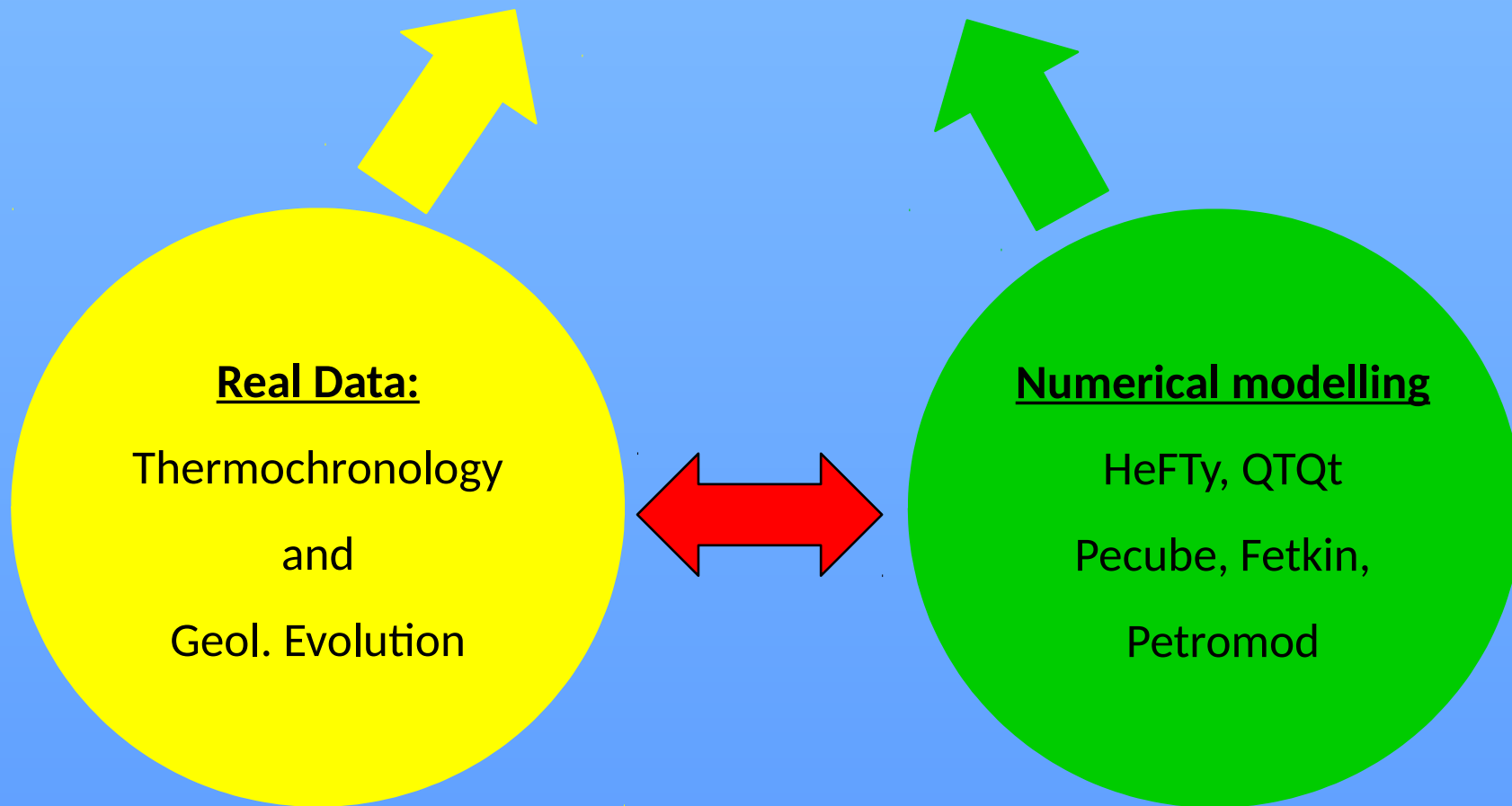
- The linear defects are metastable.
- Increase of temperature erase the tracks (Annealing).
- The annealing process (t-T) is described by equations and t-T evolution numerical modeled.
- a-decay creates ^4He -isotope in apatite (AHe) and zircon (ZHe).
- The diffusion process (t-T) described by equations and t-T evolution numerical modeled.



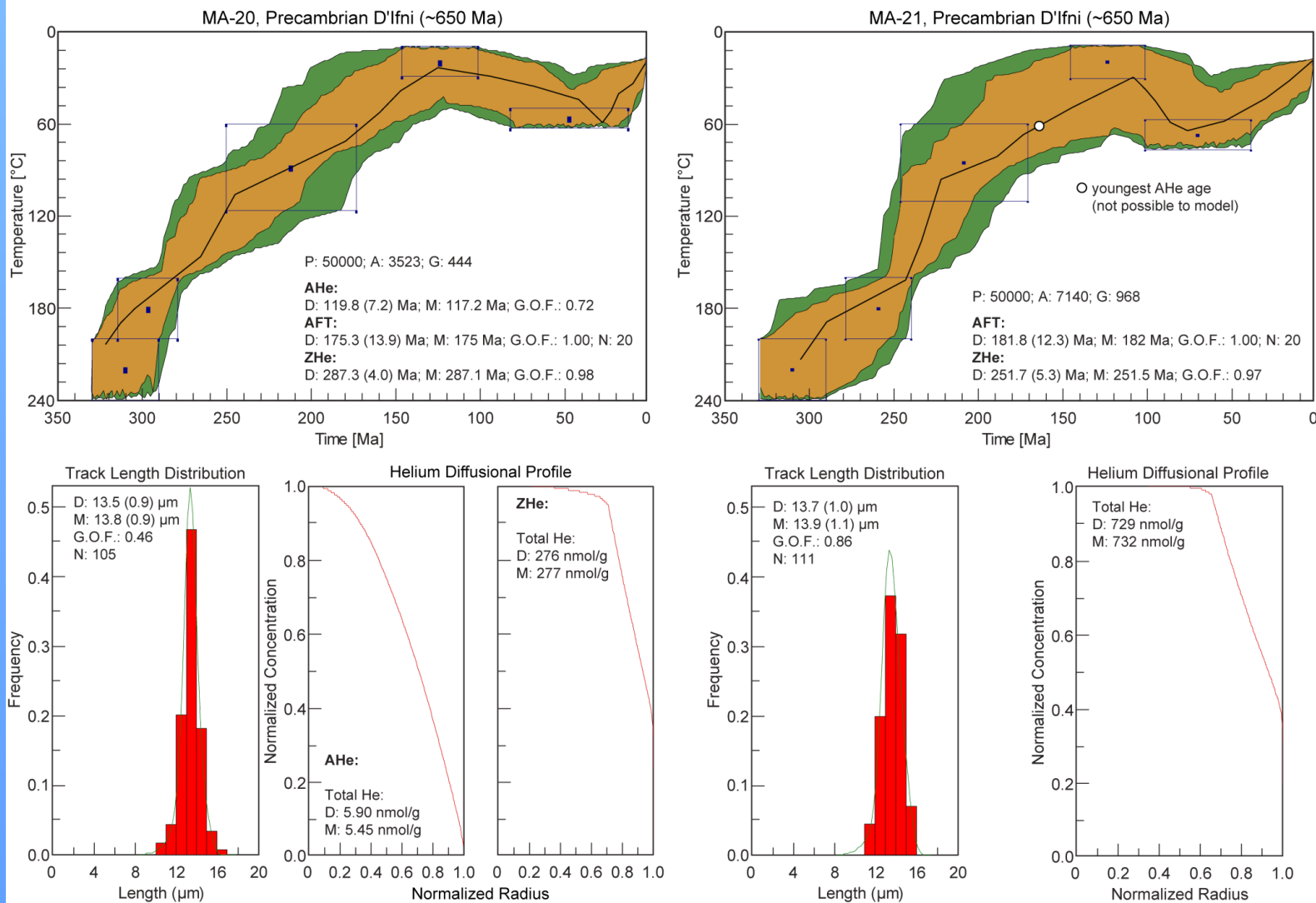
Increase of Rock Temperature



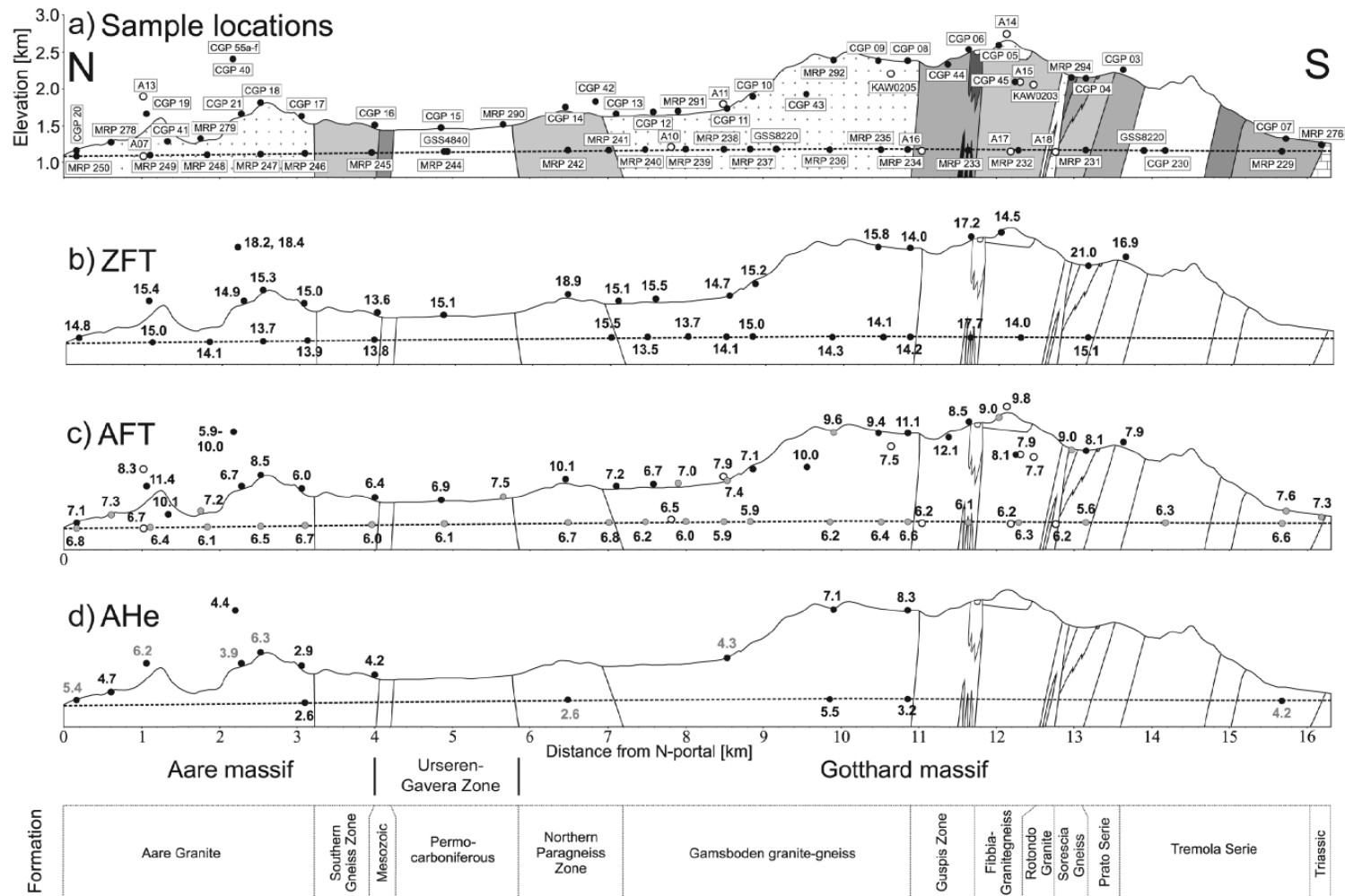
Long-term Landscape Evolution

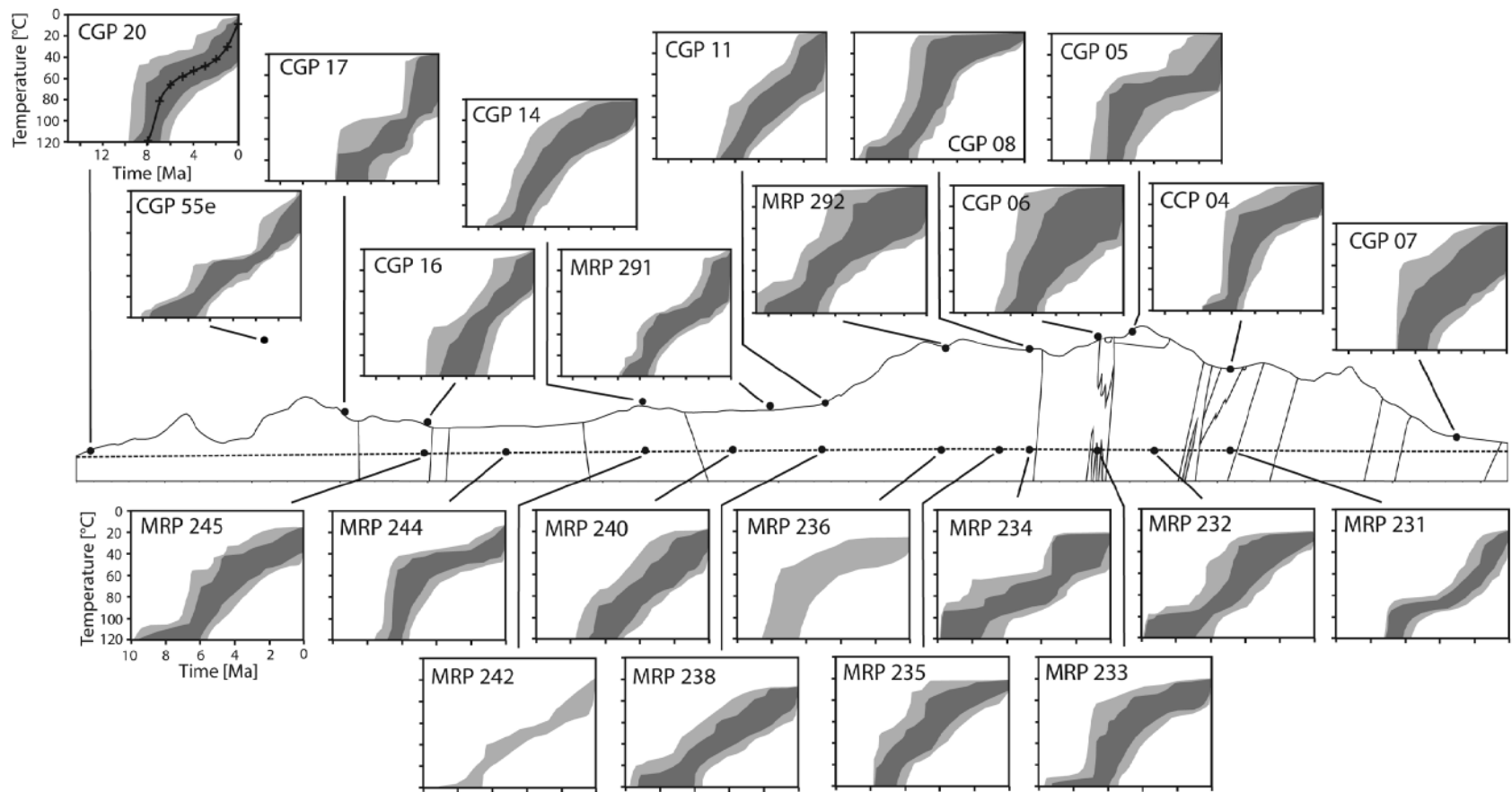


Ifni inlier



Similar research was performed in the Alps at the Gotthard Tunnel.





B. During the **Life time** of the **ANDES Underground Laboratory (AUL)**.

Suggested Projects:

- Controlled crystallization of amorphous thin films without cosmic irradiation
(Burchard, Glasmacher, Lattard, Uni Heidelberg)
- Long-term monitoring of geogenic gases
(Keppler, Glasmacher, Uni Heidelberg)
- Long-term monitoring of magnetic susceptibility of rocks under in-situ stress
(Kontny, KIT)
- Long-term rheological and geochemical investigation of host rock integrity
in damage zones (Hilgers, Busch, KIT)
- Long-term monitoring of chemical composition of geogene fluids?

Requirements: to the ANDES Underground Laboratory (AUL).

Long-term monitoring of geogenic gases (CO_2 , N_2 , He, H_2 etc.

(Keppler, Glasmacher, Uni Heidelberg)

- One small room with open rock surface for the measuring equipment.
Preferred in zones of damaged rocks
- One small room for computer, power supply.

Requirements: to the ANDES Underground Laboratory (AUL).

Long-term monitoring of magnetic susceptibility of rocks under in-situ stress
(Kontny, KIT)

- Open rock surface. Preferred in zones of damaged rocks

Requirements: to the ANDES Underground Laboratory (AUL).

Long-term rheological and geochemical investigation of host rock integrity
in damage zones (Hilgers, Busch, KIT)

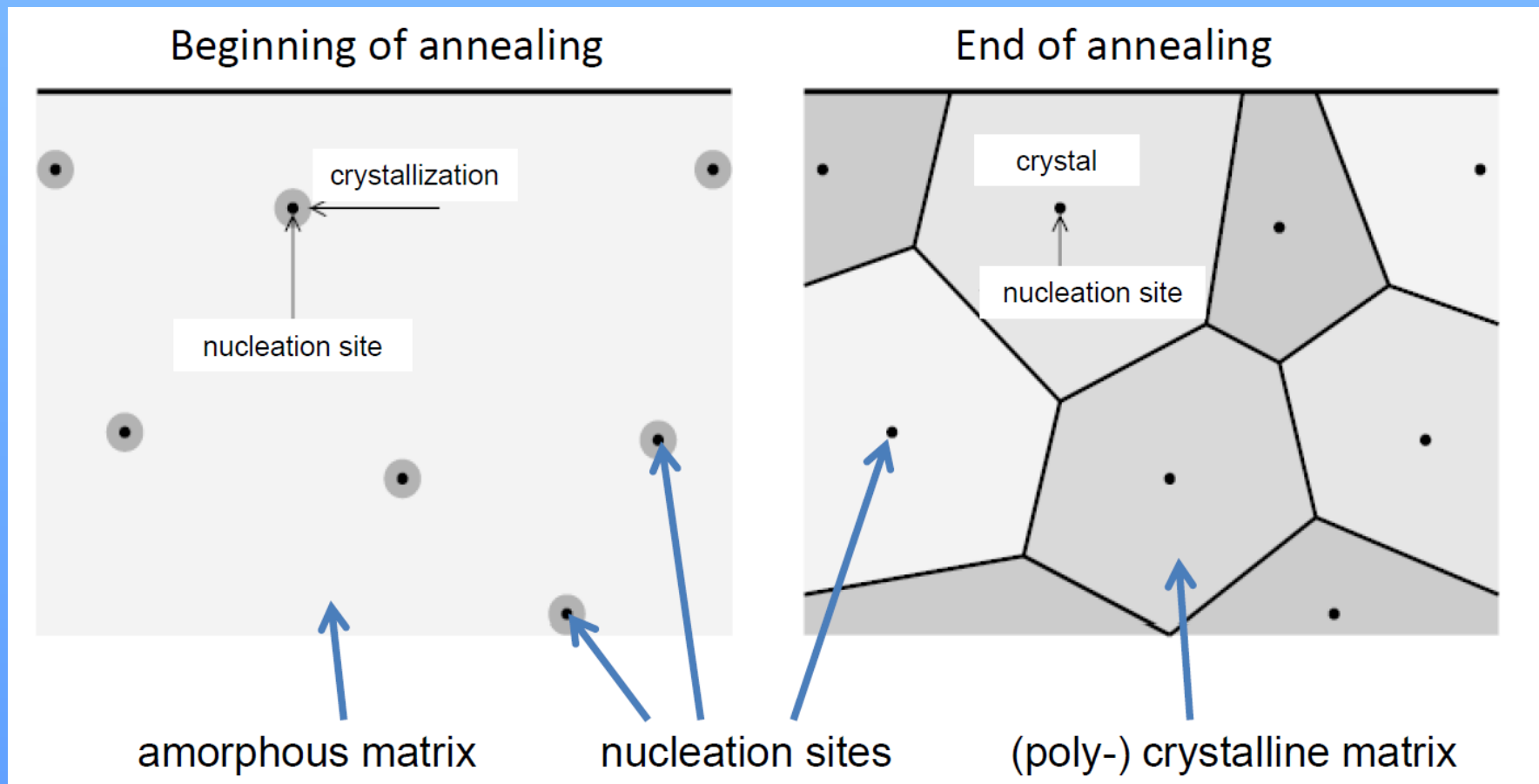
- Open rock surface. Preferred in zones of damaged rocks

Controlled crystallization of amorphous thin films without cosmic irradiation (Burchard, Glasmacher, Lattard, Uni Heidelberg)

Experiments performed in the past

- Create a amorphous thin film using an Eximer-laser.
- Analyse by different techniques: Truly amorphous, no nano-crystals.
- Stored for a certain time.
- Fast reheat the amorphous thin film to start slow crystallization (annealing).
- Analyse by different techniques: Shape and distribution of crystals.

Theory: Ideal crystallization of amorphous materials



The crystal growth is described by: Johnson-Mehl-Avrami-Kolmogorov equation (JMAK)

simple form:

$$f(t) = 1 - \exp(-At^n):$$

A = kinetic crystallization information ✉ **important material constant**

t = time

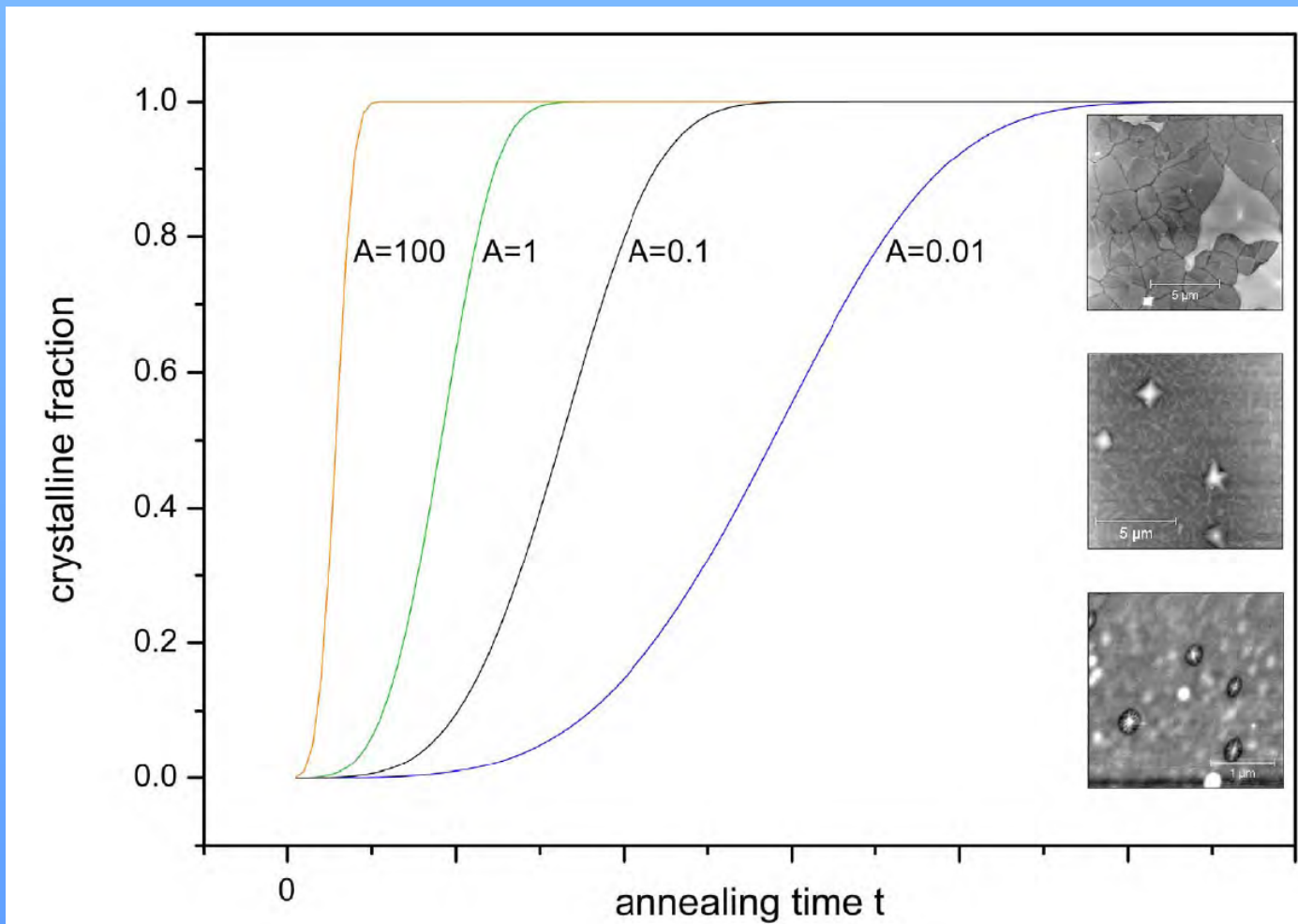
n = process constant = q d + B

B = type of seed formation

q = function representing the linear or nonlinear character of the process

d = dimension of seed growth

JMAK parameter A (B q d = constant)

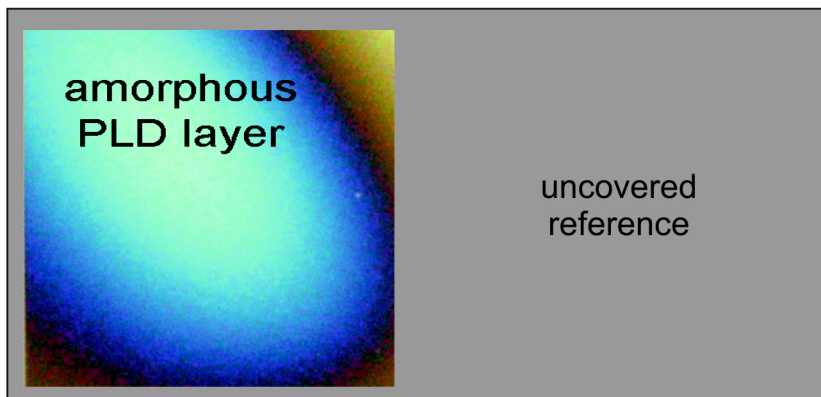


Characterization of 2D crystallization

By atomic force microscopy (AFM), difference interference contrast microscopy (DIC), scanning electron microscopy (SEM), fourier transform IR spectroscopy (FTIR)

Thin film on (111) Si-wafer (substrate)

top view

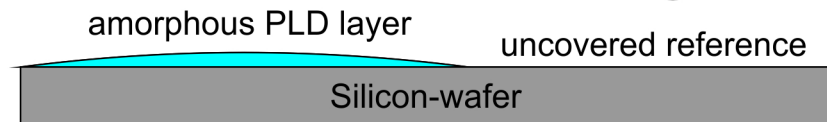


before annealing

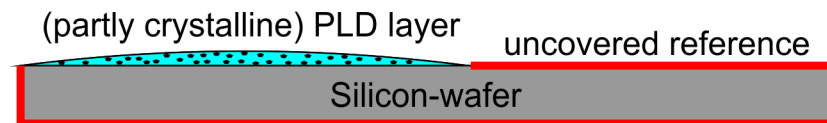
Thin film thickness: ~150 nm

lateral view

before annealing



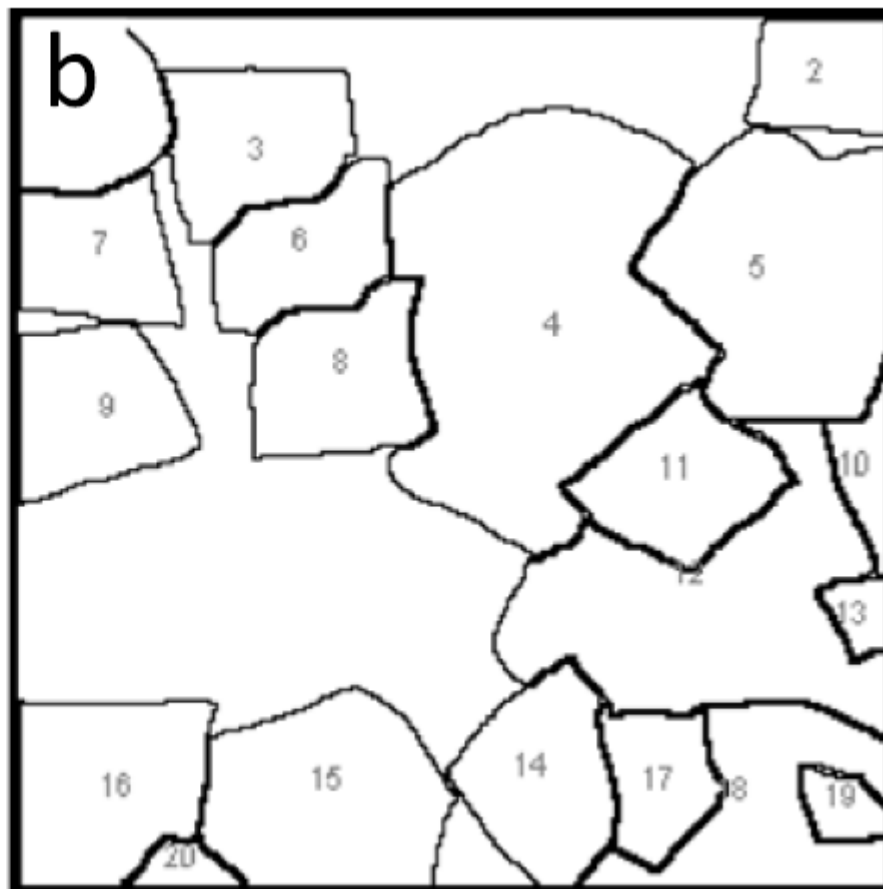
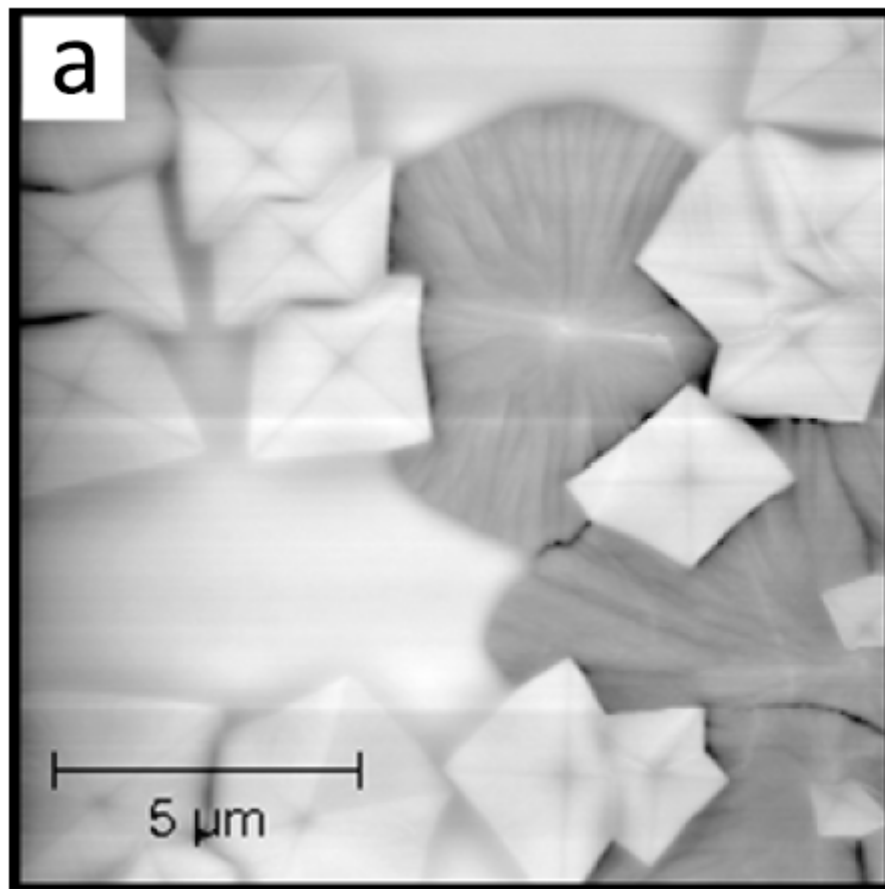
after annealing



Oxidation layer (SiO_2) on wafer surface

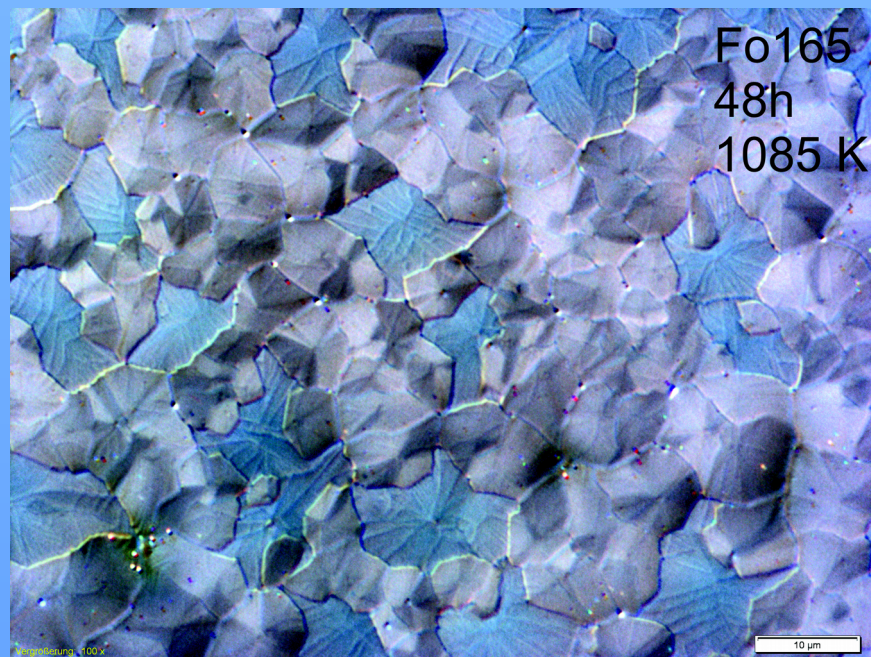
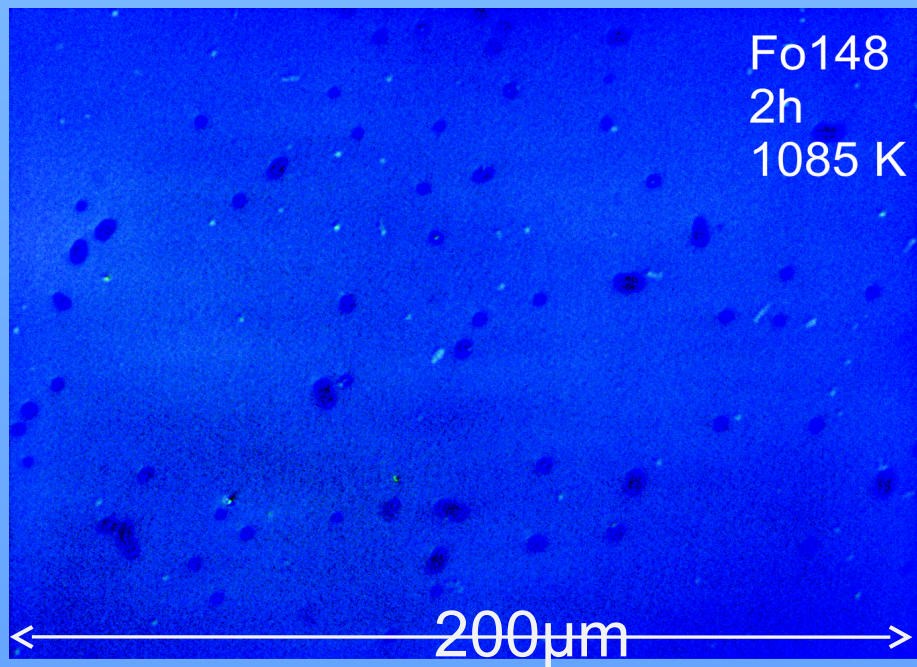
Characterization of 2D crystallization

Atomic force microscopy (AFM)



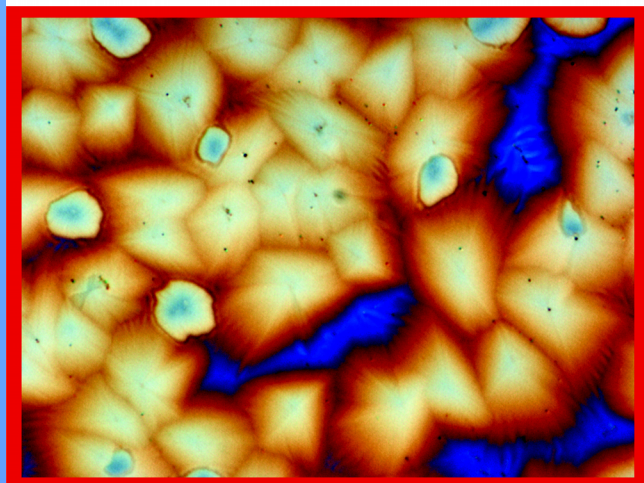
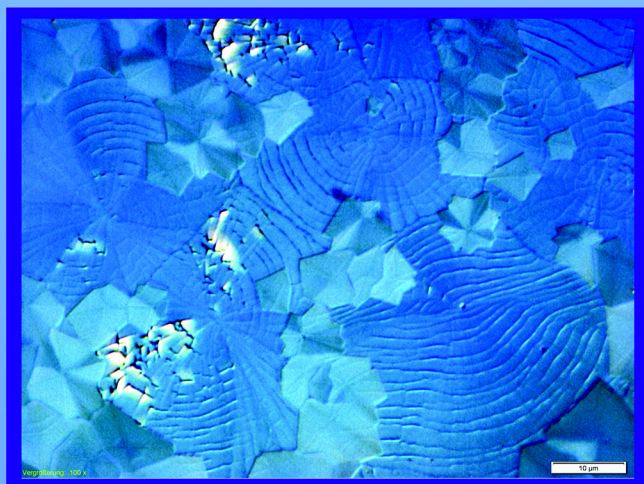
Characterization of 2D crystallization

Difference interference contrast microscopy (DIC)

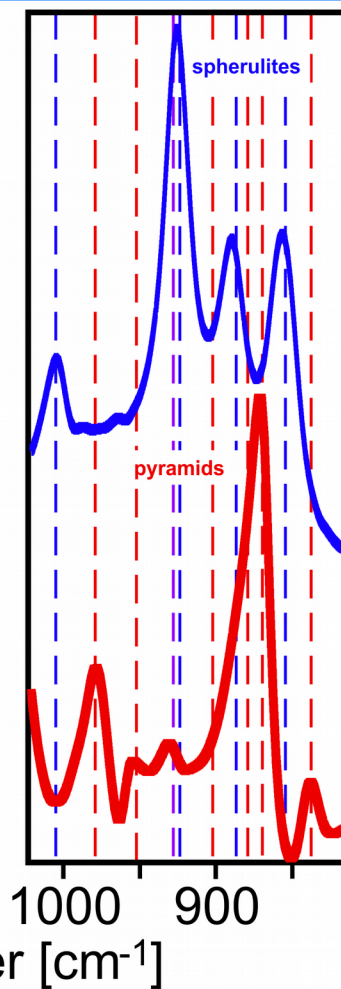
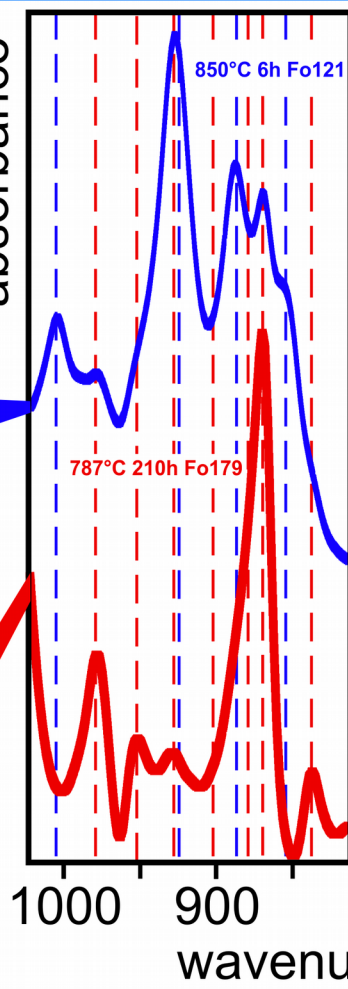


Characterization of 2D crystallization

Fourier transform IR spectroscopy (FTIR)



absorbance



Simple time dependent experiments ?

Crystallizing thin films ($d = 2$) of homogenous amorphous material at the same controlled experimental conditions but with variable time should result in simple to evaluable structures.

Based on these data parameter A can easily be calculated.

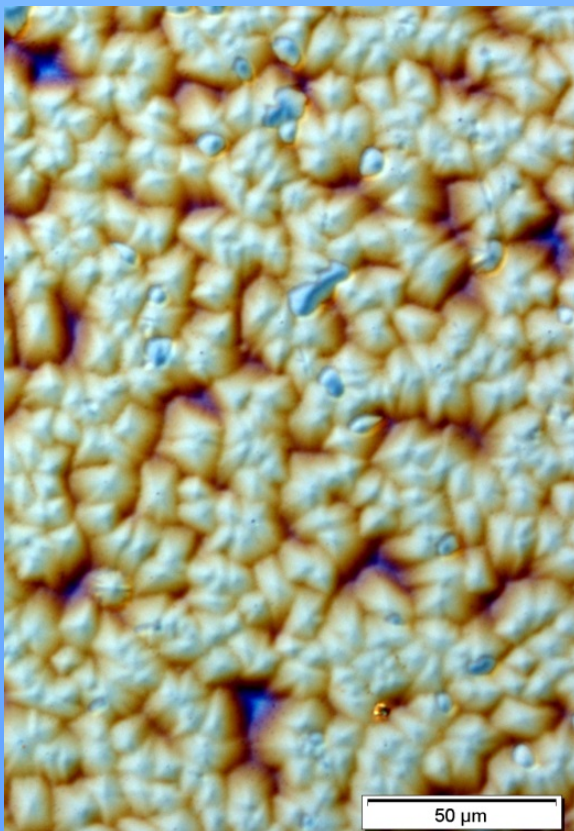
BUT

All observed experimental parameters are constant.

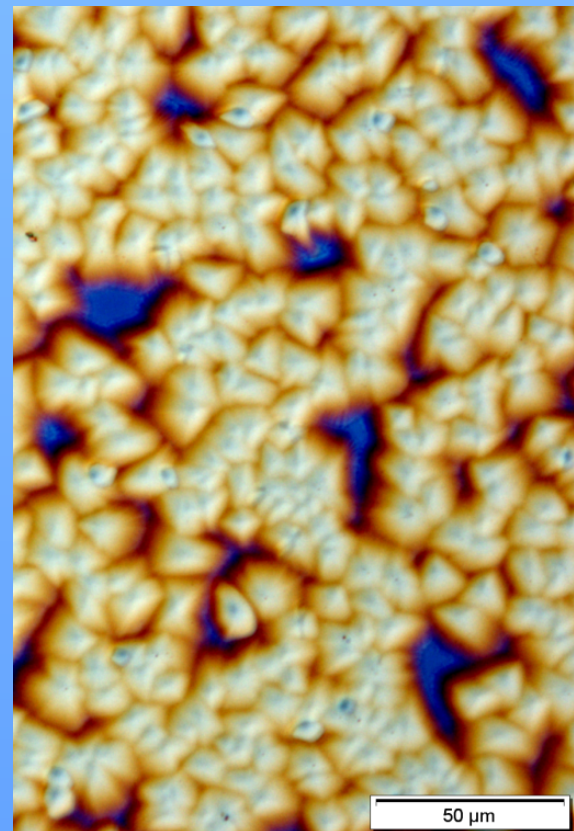
Crystallization structures is significant different.

The expected

Fo177



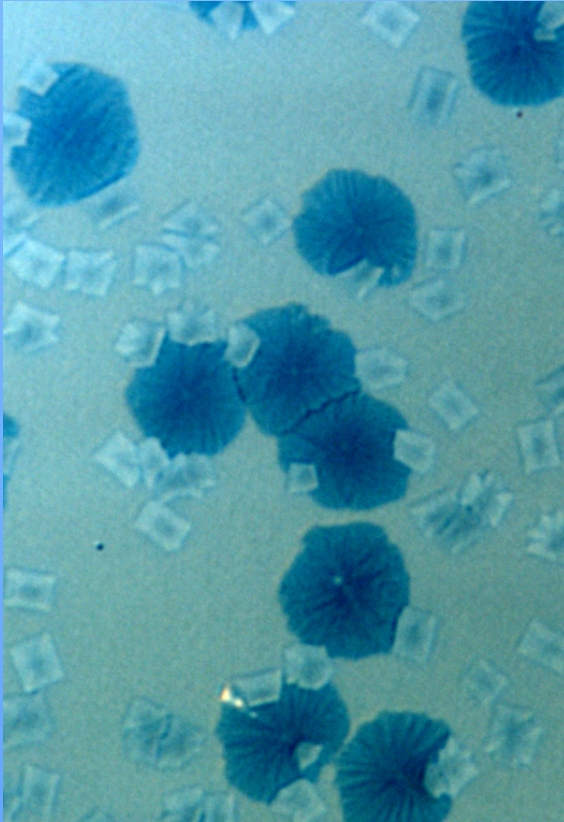
Fo178



Slightly different Forsterite thin both crystallized 144h at 1060K.

The unexpected

Fo138



Fo139



Extremely different Forsterite thin films both crystallized 8h at 1098K.

Fo139 is completely recrystallized.

Fo139 was stored several month before used for the experiment.

The Results of the Past Experiments

The crystallization structures are statistically related to:

- the storage time of the thin amorphous films before crystallization experiment.
- and not associated with the H_2O / CO_2 contend. (quantified by IR-spectroscopy).

The cause?

The crystallization structure of the same material is extremely sensitive to the formation of crystal seeds.

Hypothesis: Crystal seeds are related to natural high energy radiation.

Therefore, the different crystallization behavior is to be expected directly connected to the flux of natural high energy radiation.

Conclusion for the ANDES experiments

Experiments with samples produced and processed under low radiation flux conditions are necessary to gain the “real” material crystallization constants.

The Results of these experiments will be compared with results from crystallization runs performed under natural flux conditions

Requirements: to the ANDES Underground Laboratory (AUL).

Controlled crystallization of amorphous thin films without cosmic irradiation
(Burchard, Glasmacher, Lattard, Uni Heidelberg)

- An area within the AUL to perform the experiments.
- Equipment:
 - Eximer-Laser, Power etc.: to generate the thin films
 - Storage area
 - Oven: performing the annealing experiments
 - Analyser: First analysing of crystallization structure

B. During the Life time of the ANDES Underground Laboratory (AUL).

Suggested Projects:

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Muchas Gracias!

Thank you very much!