Geological sliding in the field

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EPFL Summer School, Viège, August 2021

Preliminary remarks

-Some basic elements about two geological systems that exhibit sliding contact.

-I’m not a field geologist! I’m just giving you a few theoretical insights and some examples.

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-Outline:

Rock faults

Glaciers

Rock faults

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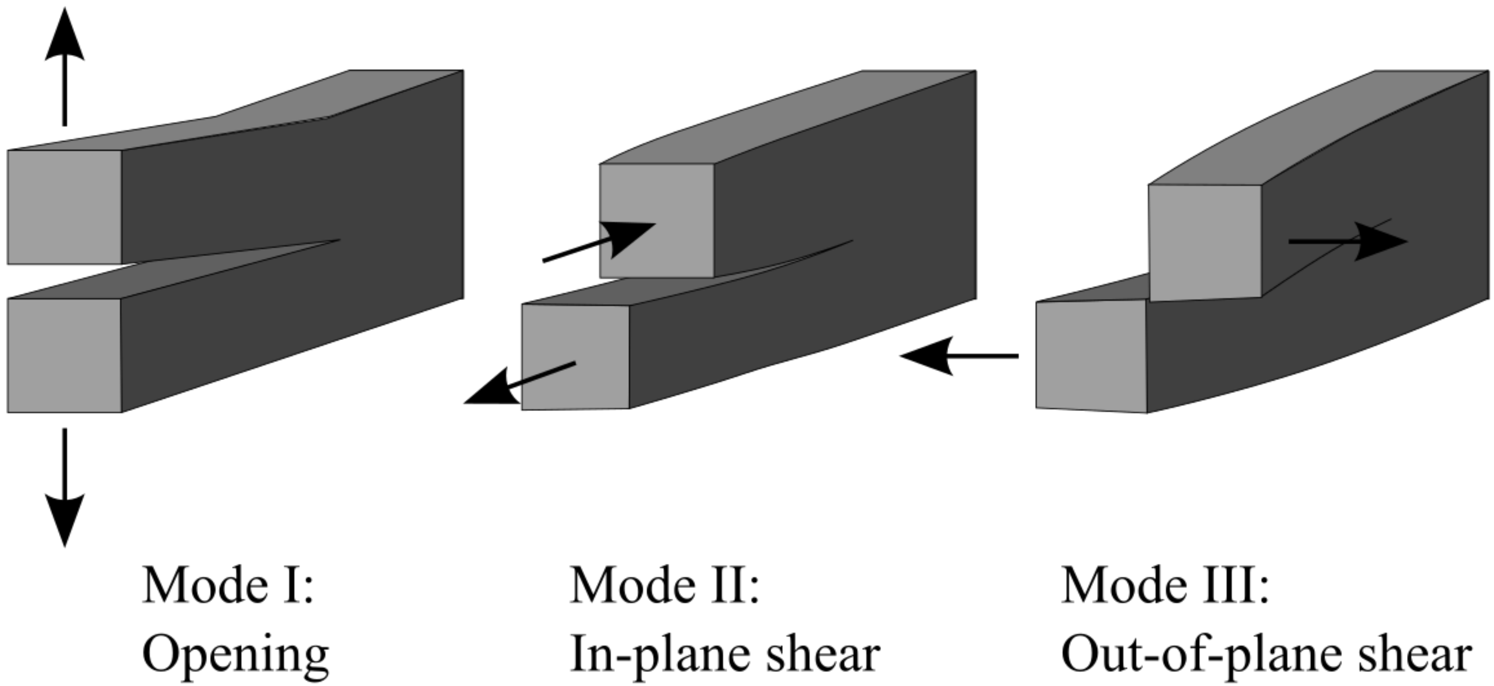
Some elements of Linear Elastic Fracture Mechanics (LEFM)

-Three modes of cracks, named I, II, and III:



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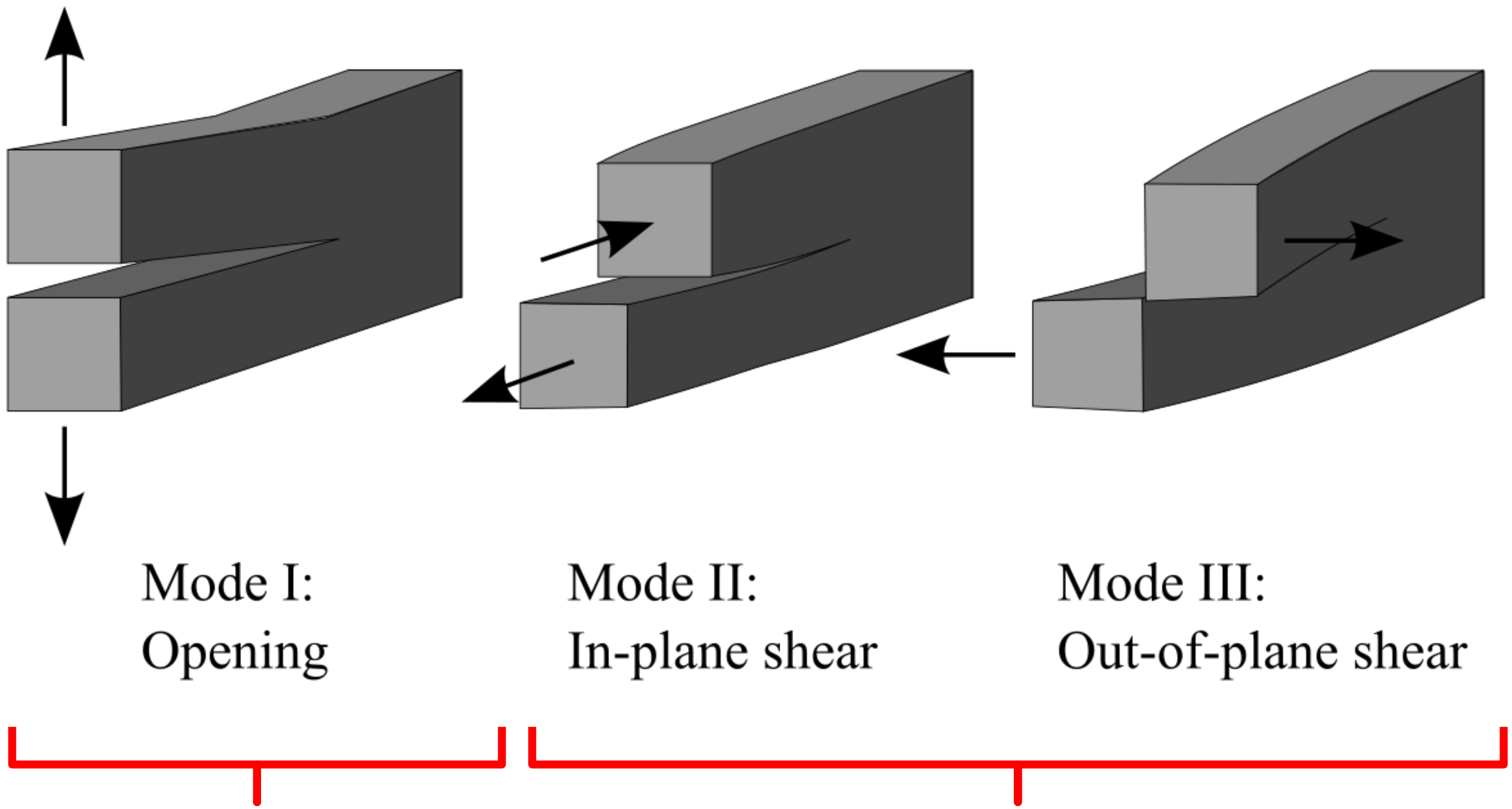

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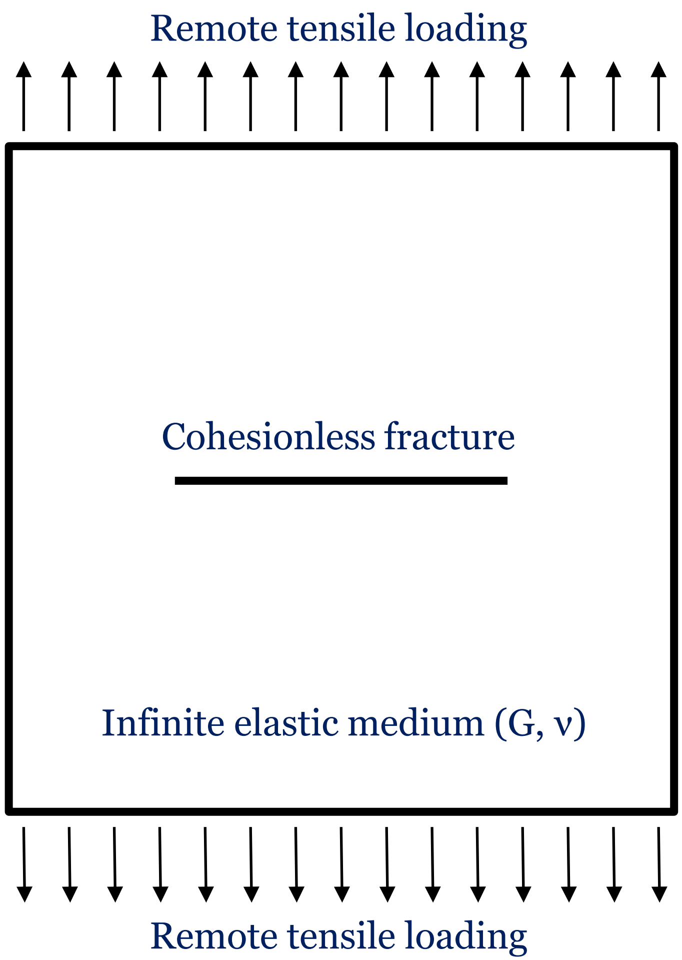
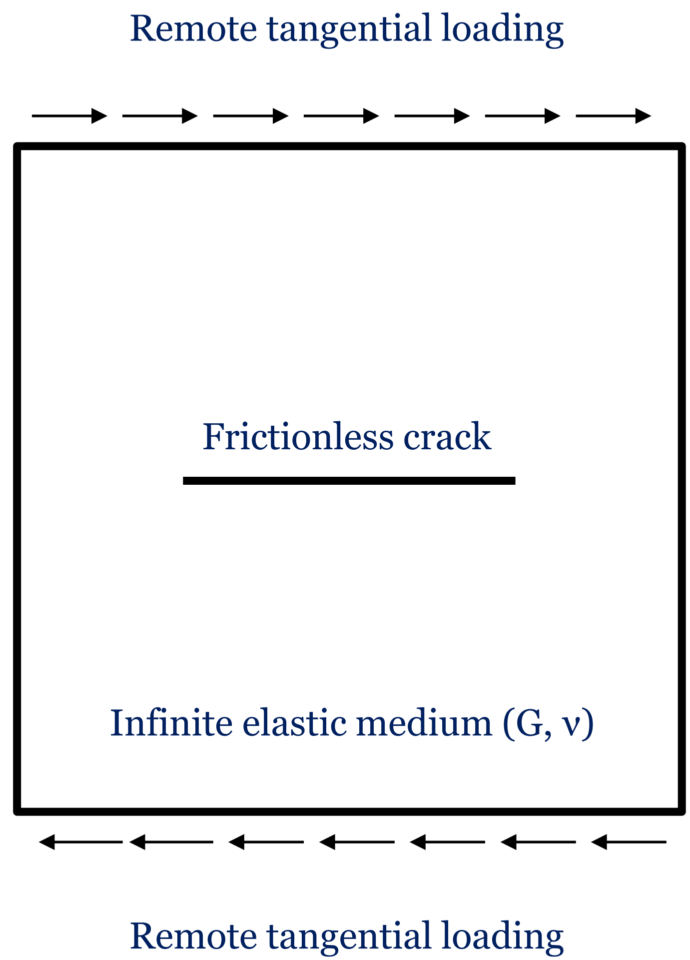
-Canonical models for fractures and faults in 2D:





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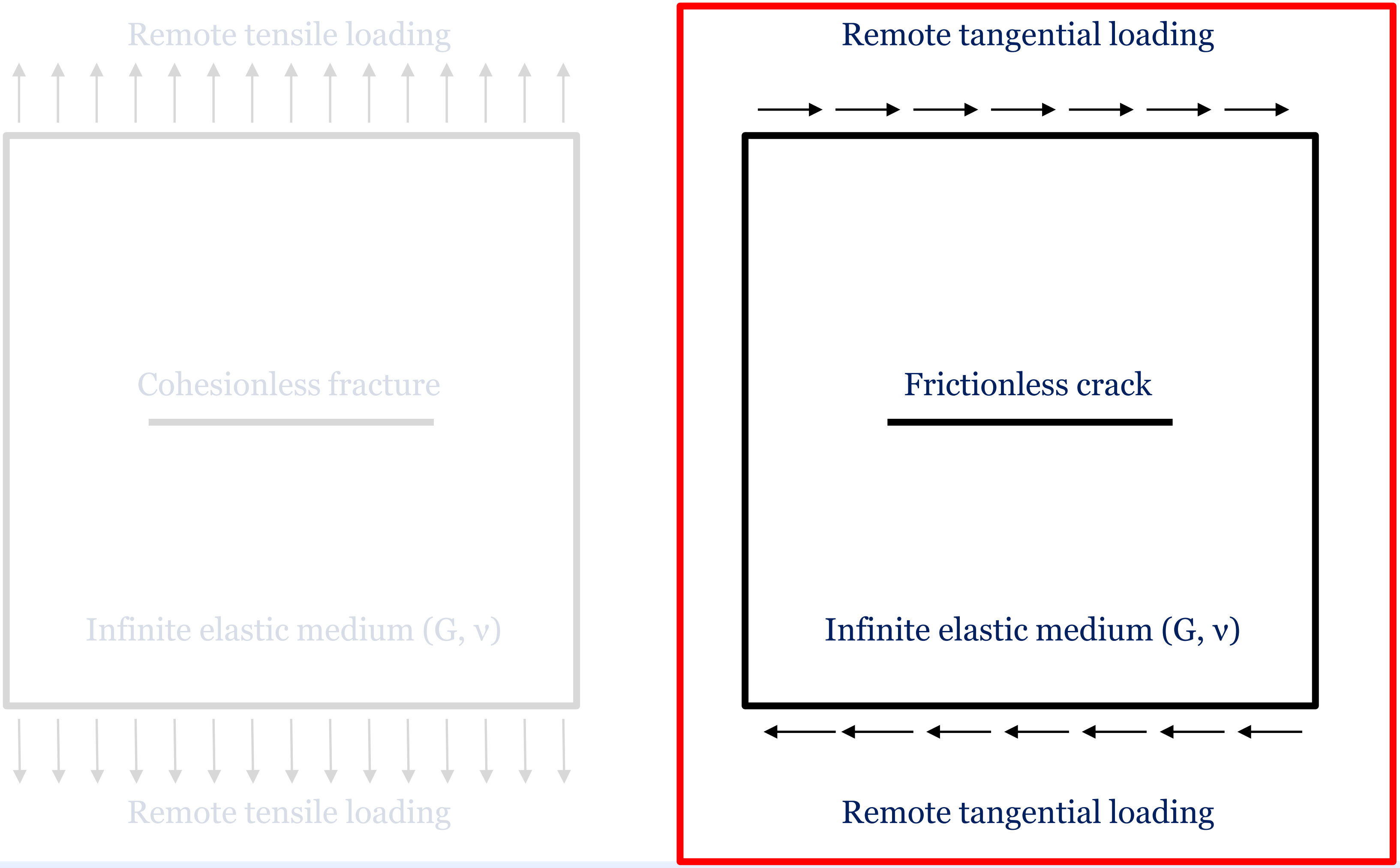
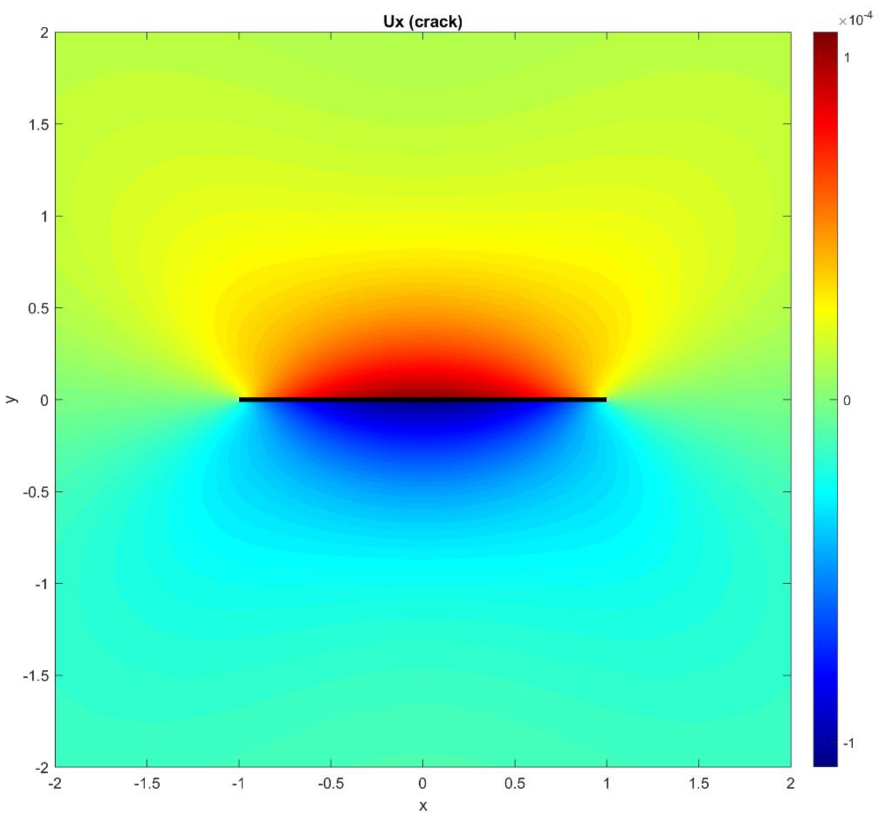


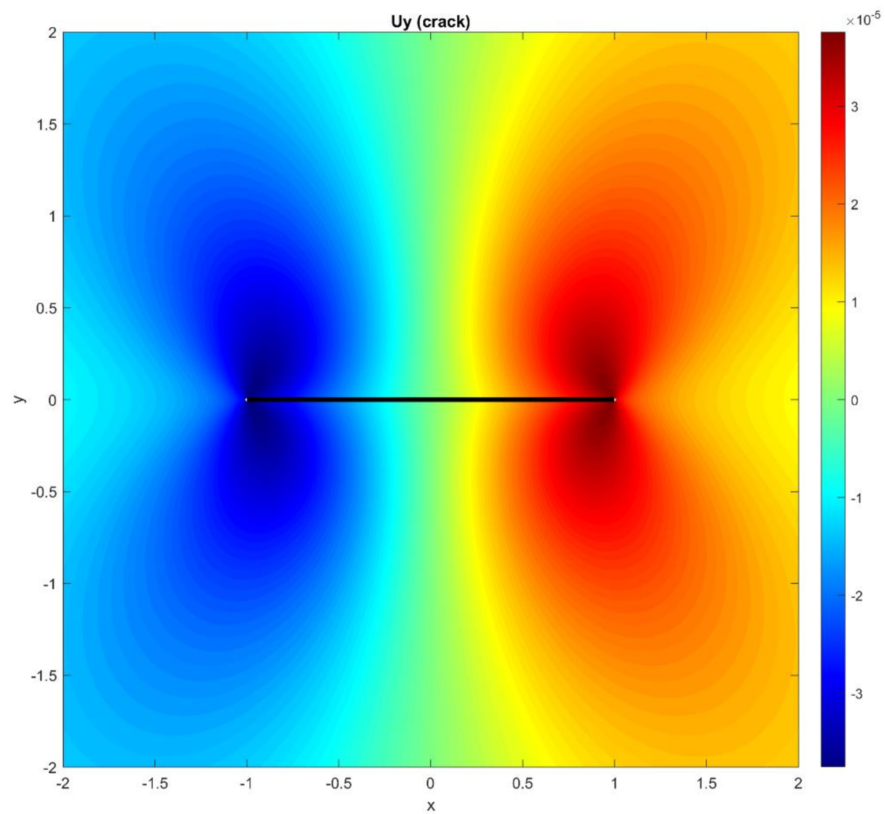
Some elements of Linear Elastic Fracture Mechanics (LEFM)

-Displacement field for the canonical fault model (under the assumptions of LEFM):

-> Normal continuity

-> Tangential discontinuity





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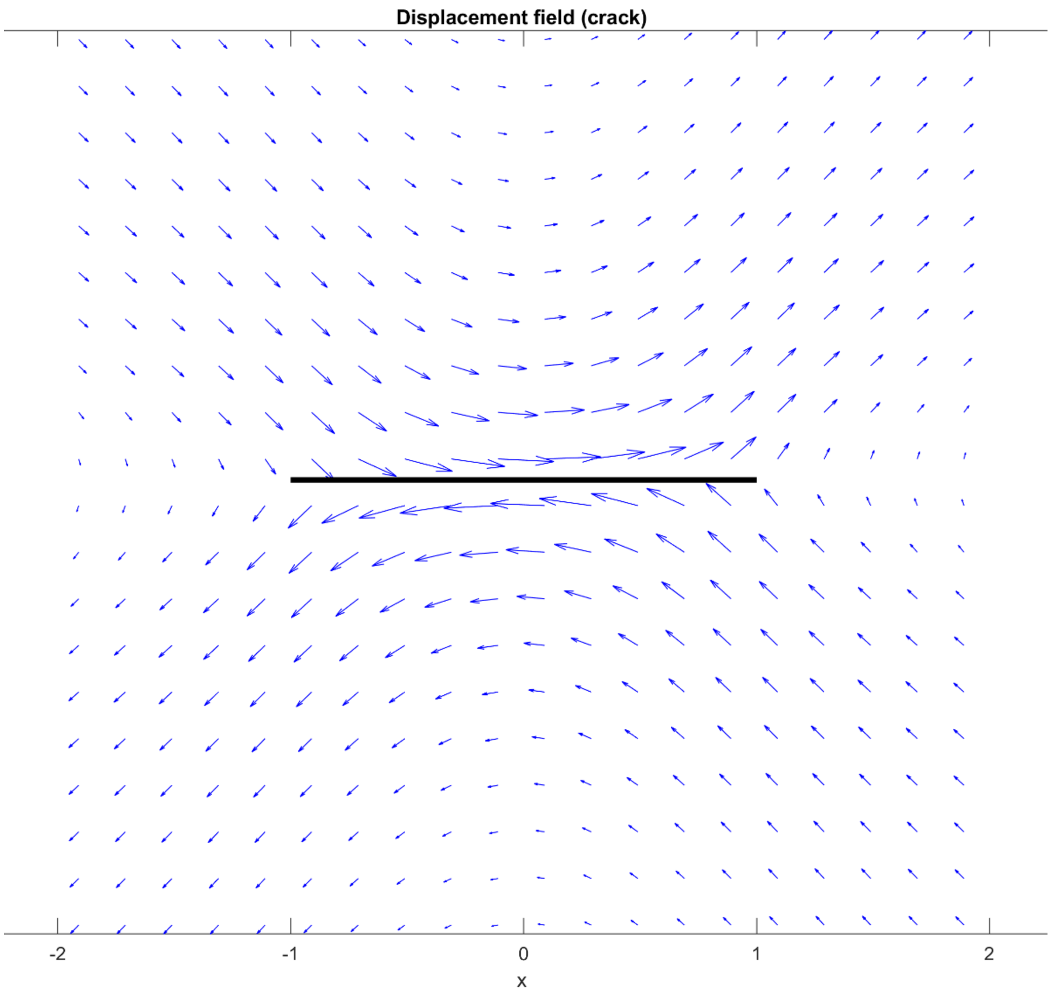
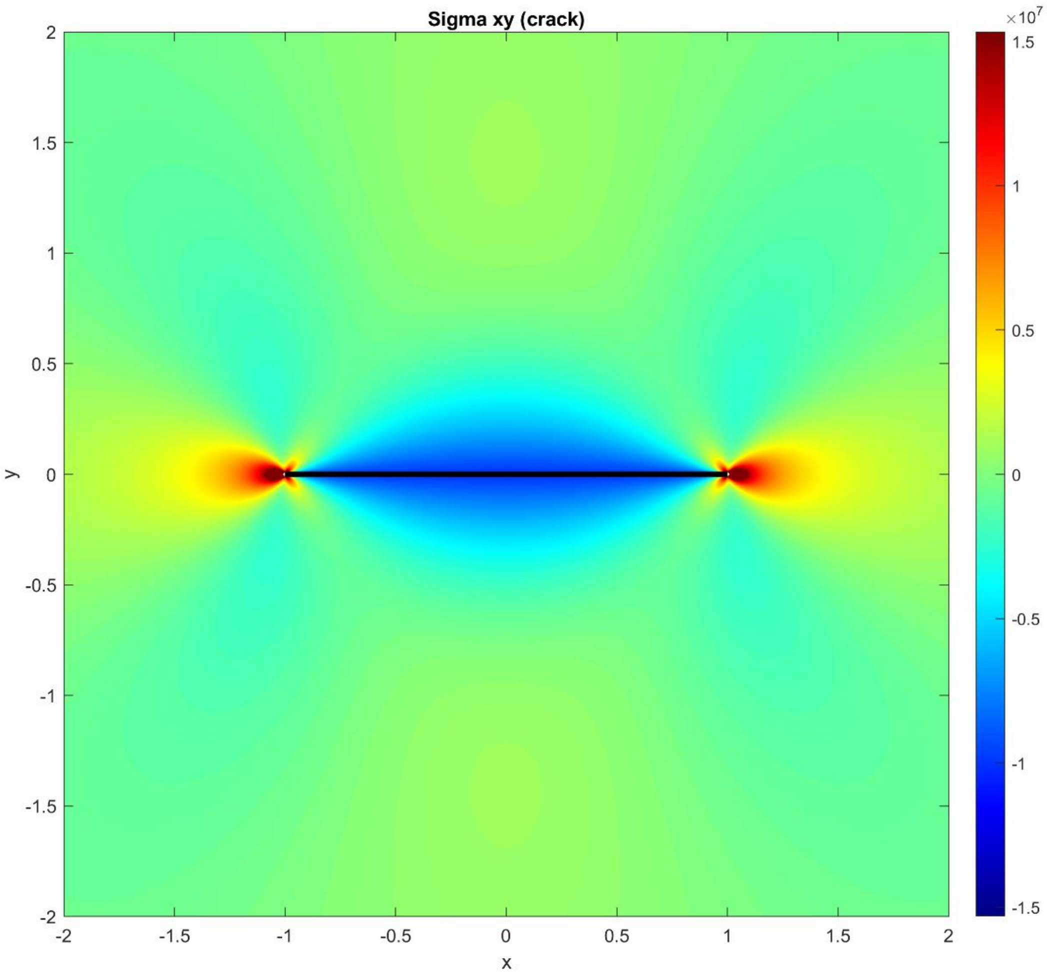


Some elements of Linear Elastic Fracture Mechanics (LEFM)

-Stress field shows interesting features:

-> stress shadow on the sides

-> stress concentration at the tips



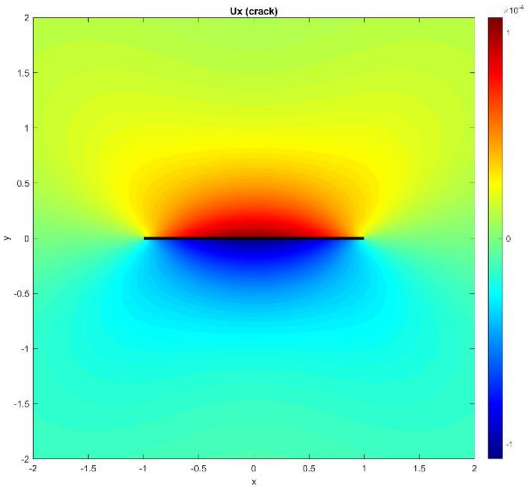
Some elements of Linear Elastic Fracture Mechanics (LEFM)

-Distribution of slip (i.e. tangential discontinuity in displacement) along fault:

-> No slip at the tips

-> Maximum slip in the middle, close to 1% of fault length

-> If a fault wants to slip more, it will have to grow…



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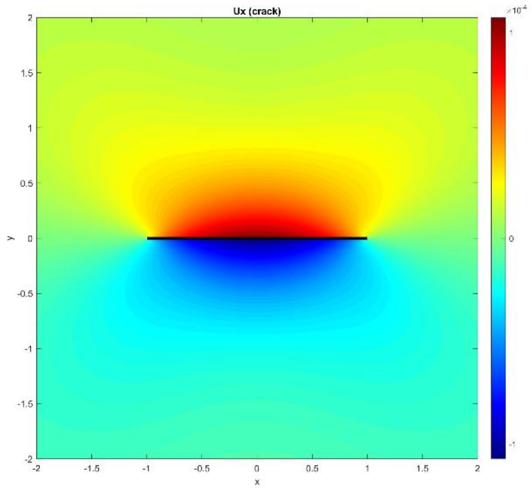

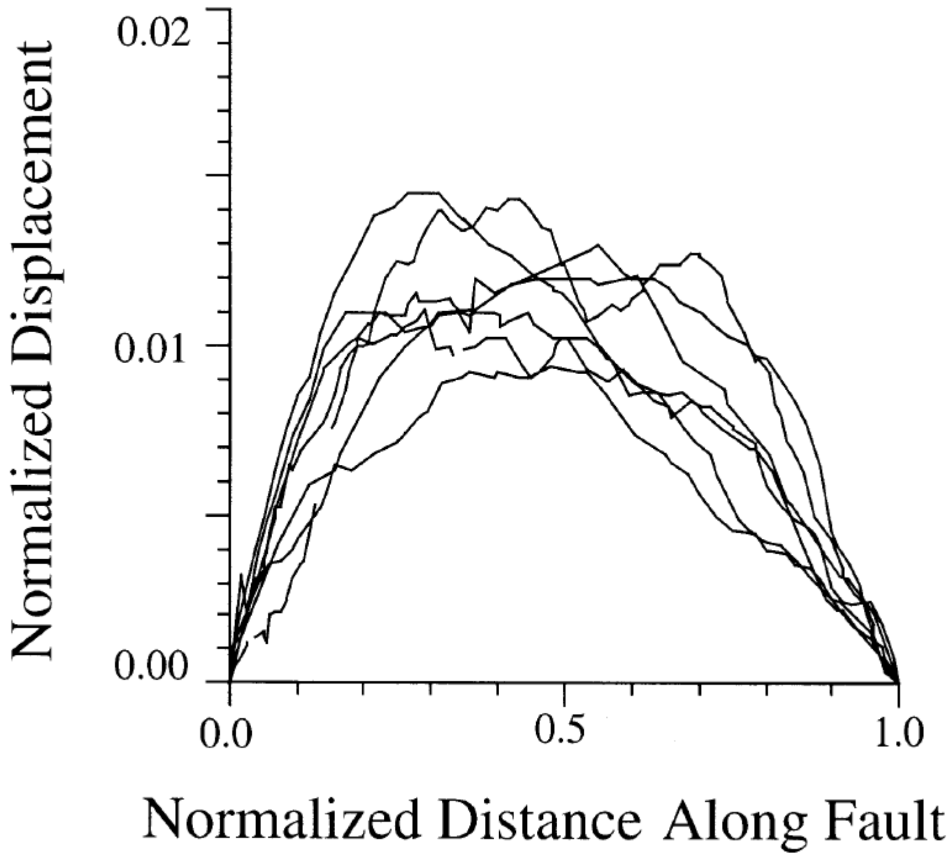

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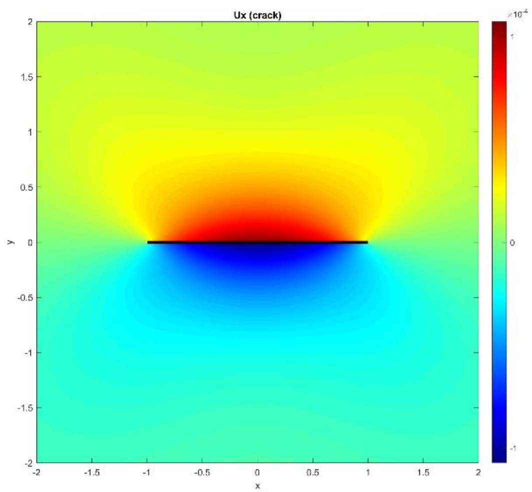
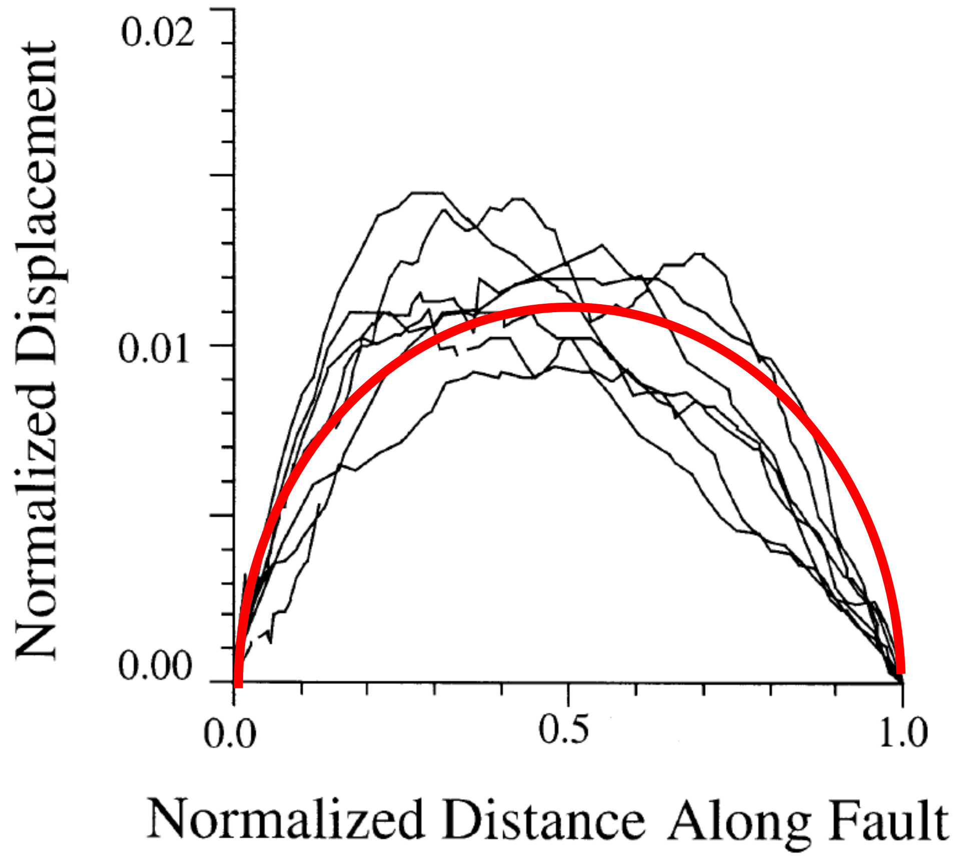
-> Theory predicts elliptical distribution





How to recognize a fault in the field?

-You may first want to look for **offsets**

-> At the regional scale

Piqiang fault, China

San Andreas fault, USA

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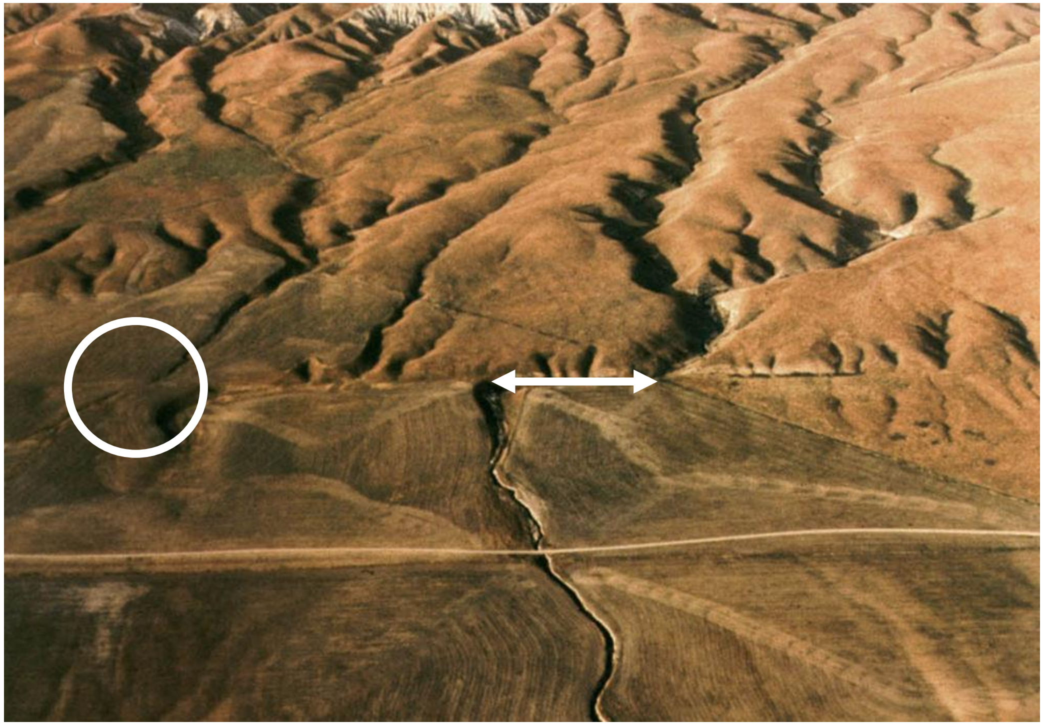


Offsets can provide insights on the chronology of events.

San Andreas fault, USA

How to recognize a fault in the field?

-You may first want to look for **offsets**

-> At the regional scale

-> At the local scale

NB: these offsets are those of single earthquakes, not the total, integrated slip on the fault.

Orders of magnitude :

Single event -> slip = 10^{-6}-10^{-4} fault length

Total discontinuity -> slip = 10^{-3}-10^{-2} fault length

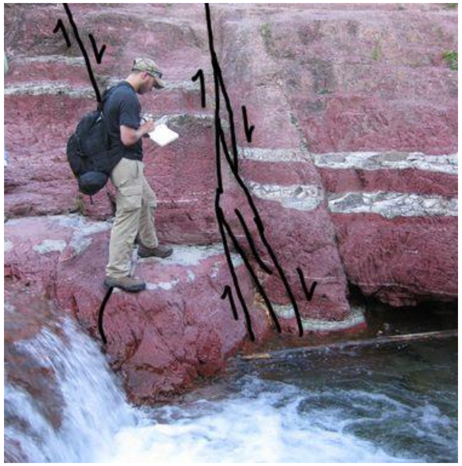
How to recognize a fault in the field?

-You may first want to look for **offsets**

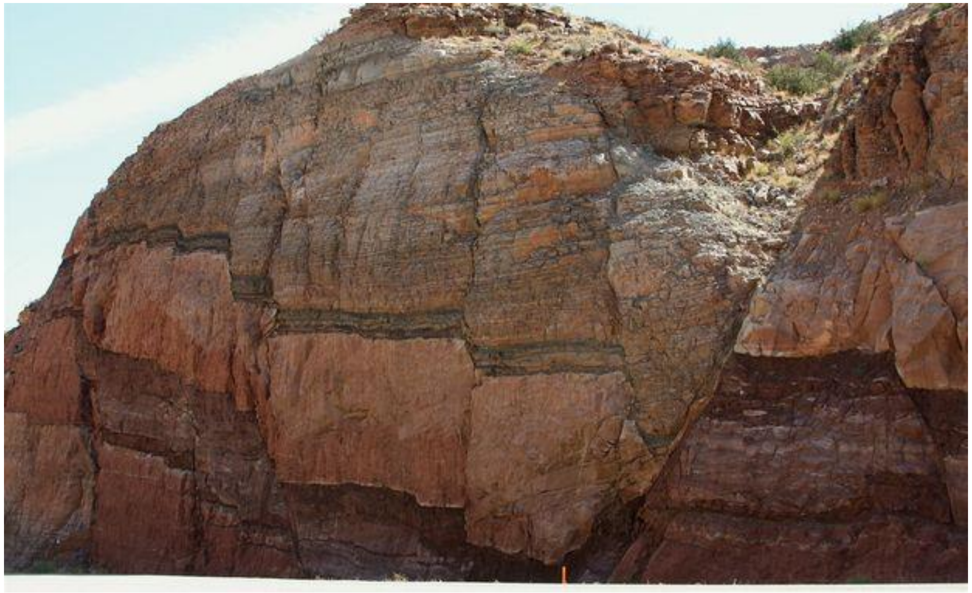
-> At the regional scale

-> At the local scale

-> At the outcrop scale



Offsets are easy to observe and measure when they cross planar features -> sedimentary bedding, magmatic intrusion, etc.



How to recognize a fault in the field? - Some common traps:

-Outcrops are often complex / unclear / damaged / covered with sediments.

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How to recognize a fault in the field? - Some common traps:

-Beware what quantity you measure: offset is different from slip distance

-> You are not sure that the plane of observation contains the slip vector

-> To be sure of that, you need two non-colinear offset measurements!

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What is the offset here?

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What is the offset here?

No offset! This is a fracture, not a fault!

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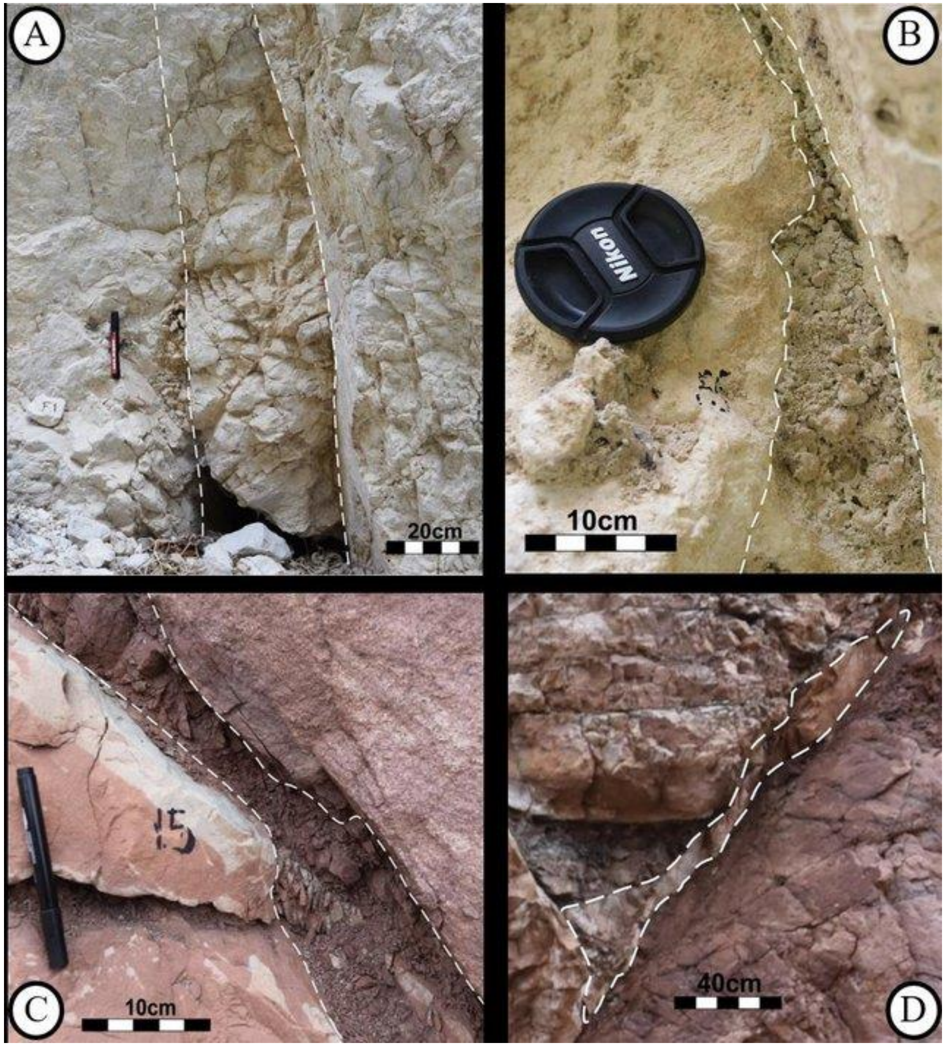
How to recognize a fault in the field?

-Other sliding evidences in faults: third body!

Granular gouge – cataclistic flow – brittle failure



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Mylonites– semi-brittle or ductile failure

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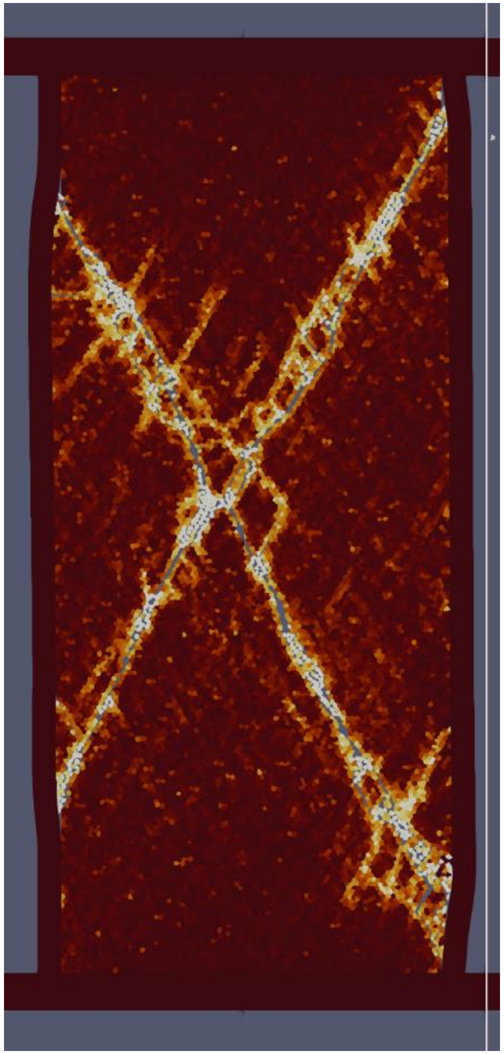
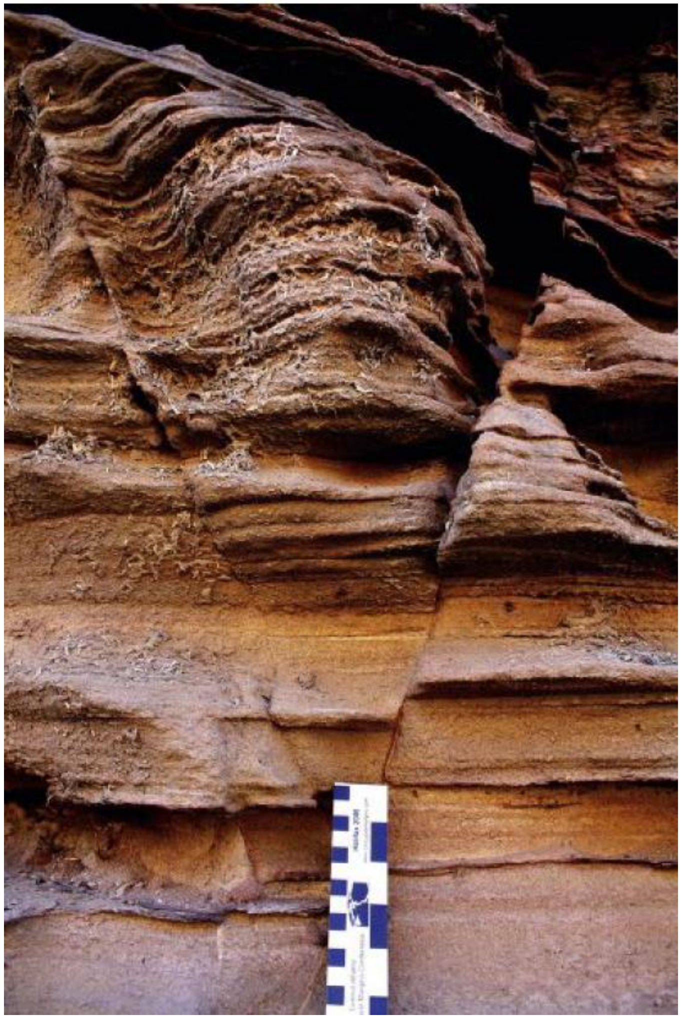
Pseudotachylites – fast and large coseismic slip

How to recognize a fault in the field?

-Other sliding evidences in faults: fracturing patterns



Conjugate faults



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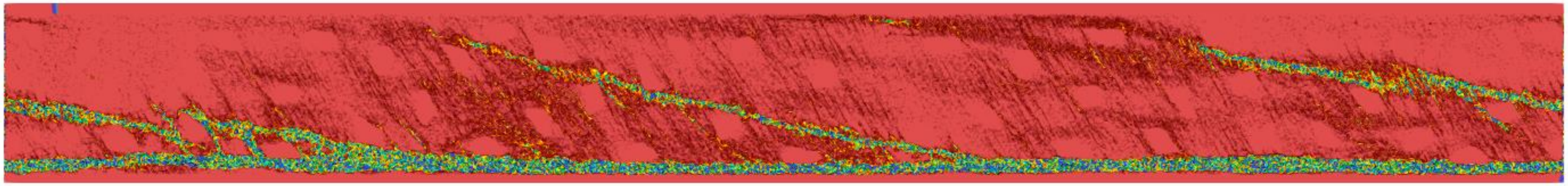
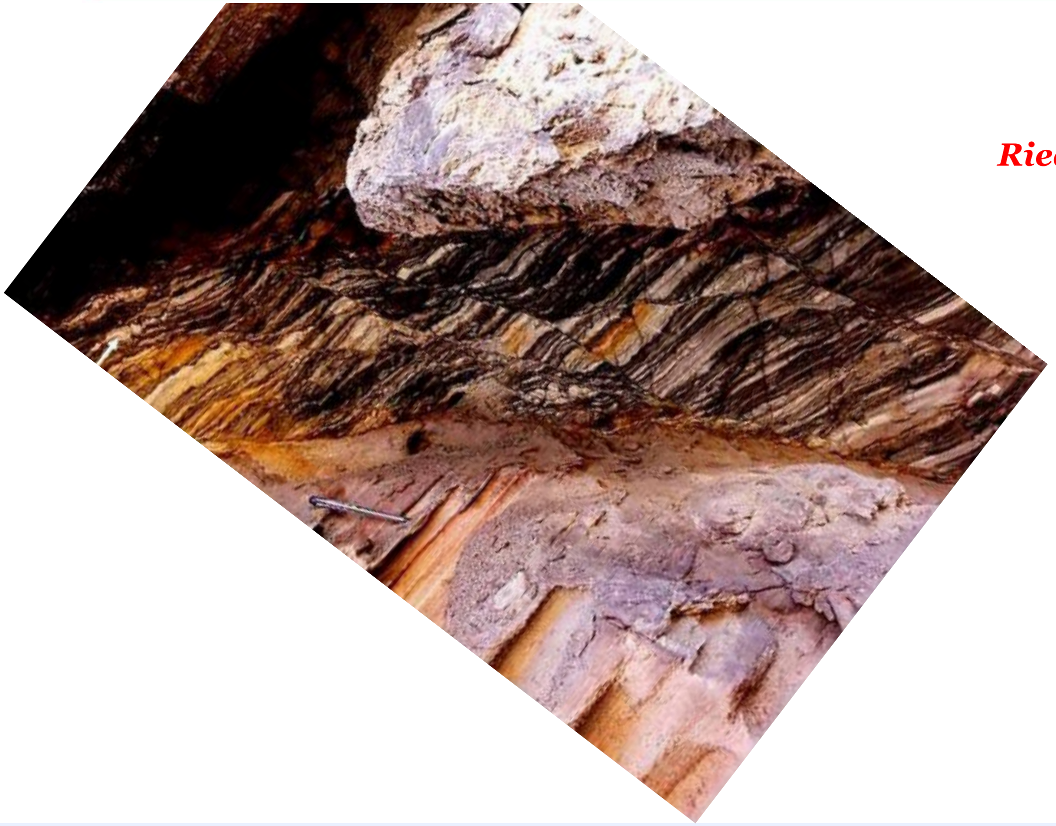




Riedel bands

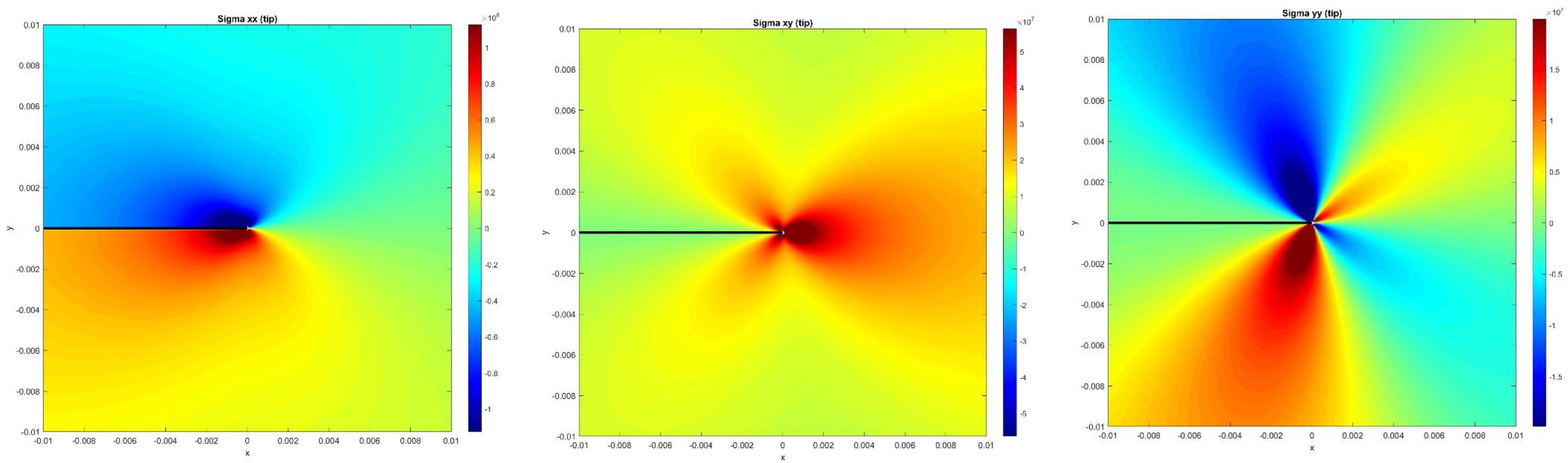
How to recognize a fault in the field?

-Other sliding evidences in faults: crack tip patterns

Infinitely close to the tip, theory predicts two phenomena:

-> Divergence of stress towards infinity (internal violation of elasticity assumptions)

-> Asymmetrical stress distribution at the tip



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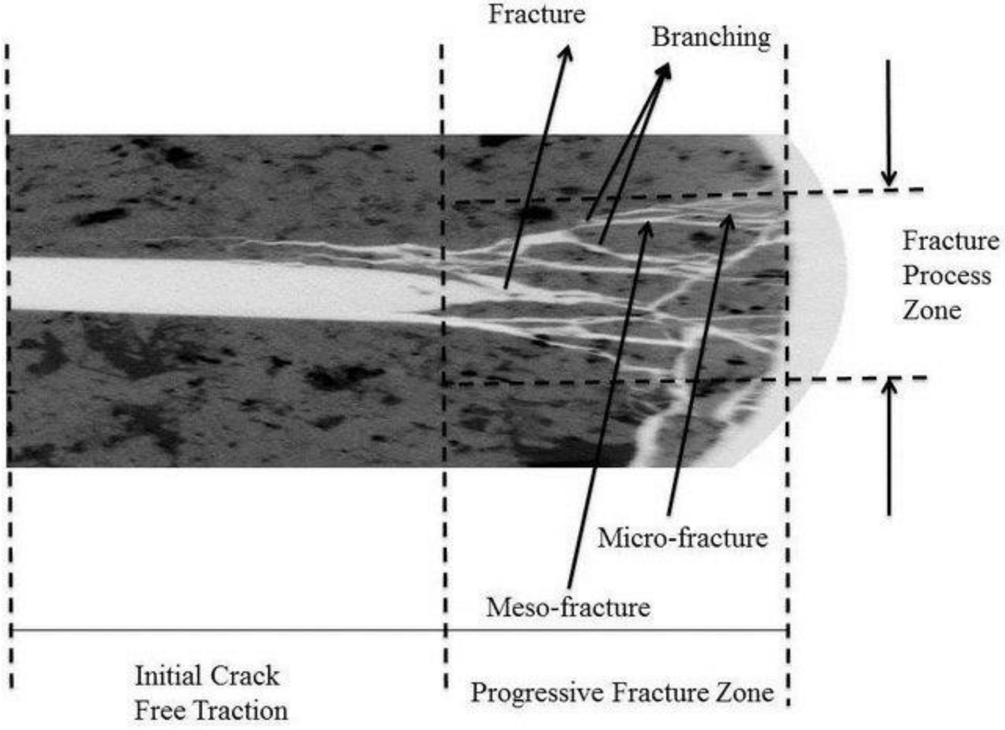
-> Several consequences!

"Process zone" around the fault tip, with damage, plasticity, etc.



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"Wing cracks" at the tip (on the tensile side)

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"Horsetail" patterns at the tip

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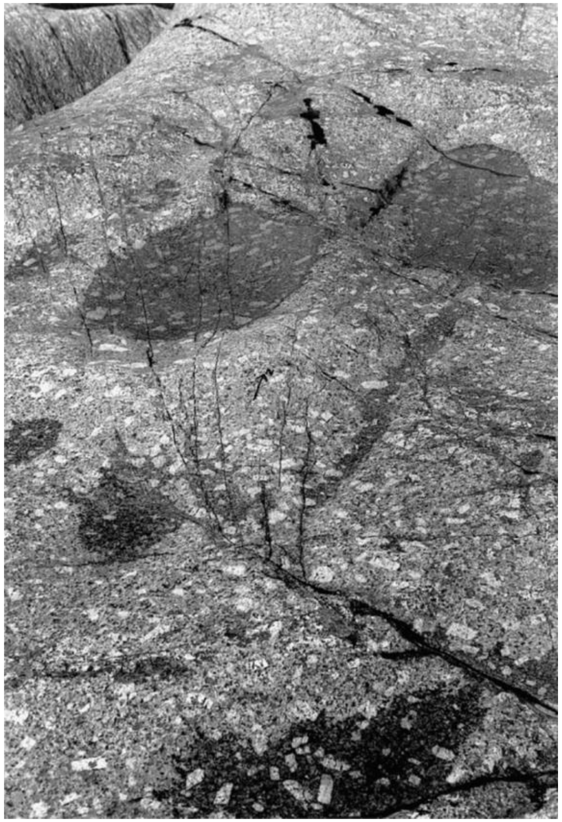

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"Echelon" patterns across several fault segments

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-Other sliding evidences in faults: slickensides.

Rare but interesting observation: the sliding plane!

-> planar, flat, sometimes shiny surfaces

-> may exhibit striations -> sliding vector.

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Glaciers

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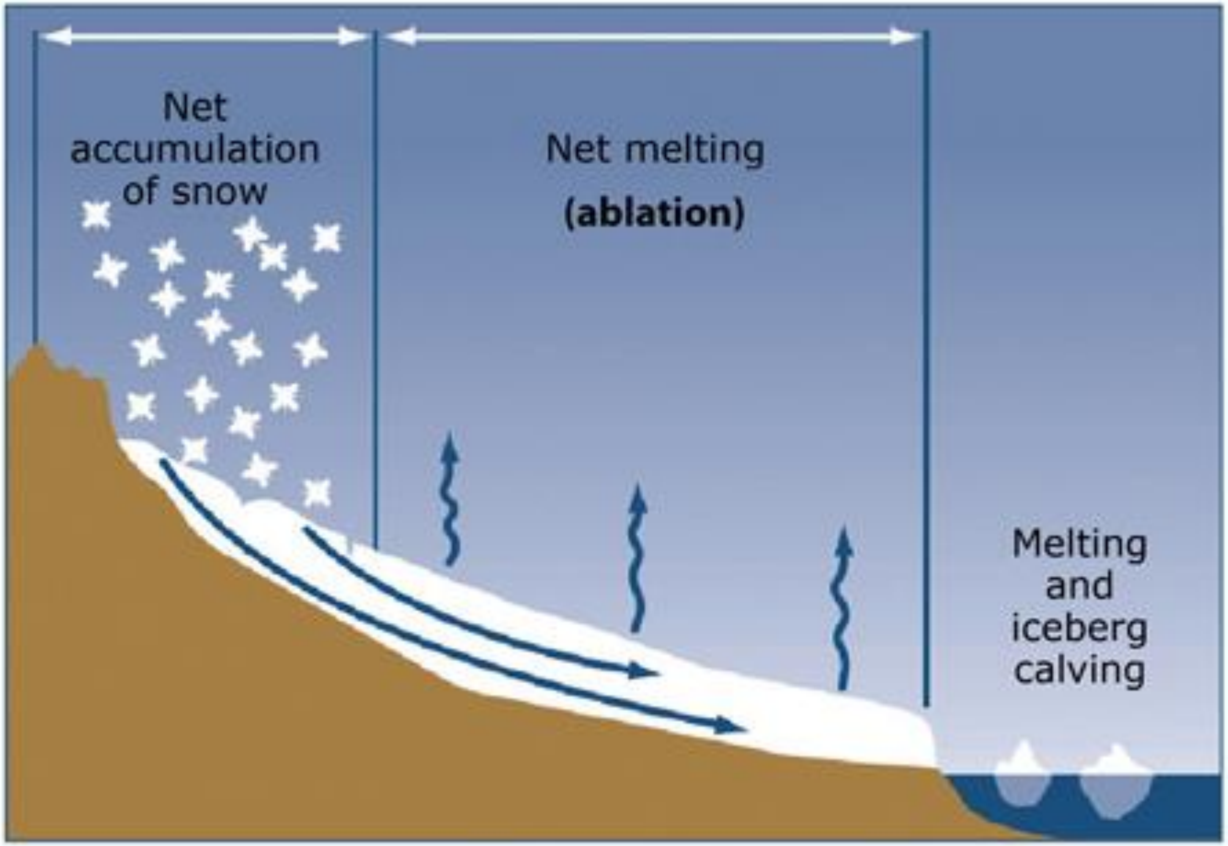
General elements on glaciers

-Typical structure: three zones

-> Accumulation zone

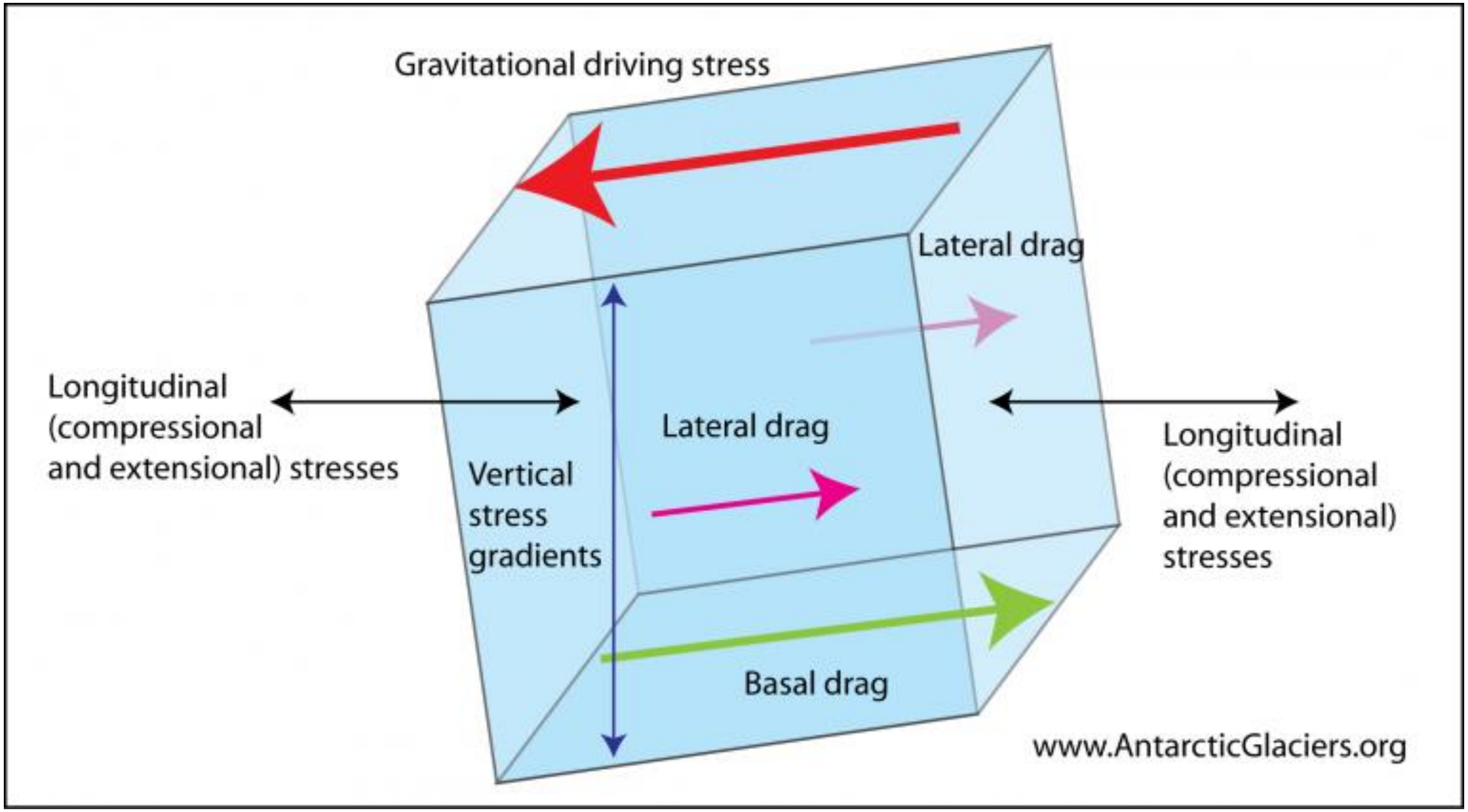
-> Transport zone

-> Ablation zone



General elements on glaciers

-Glacier flow is the result of a number of forces and stresses:



General elements on glaciers

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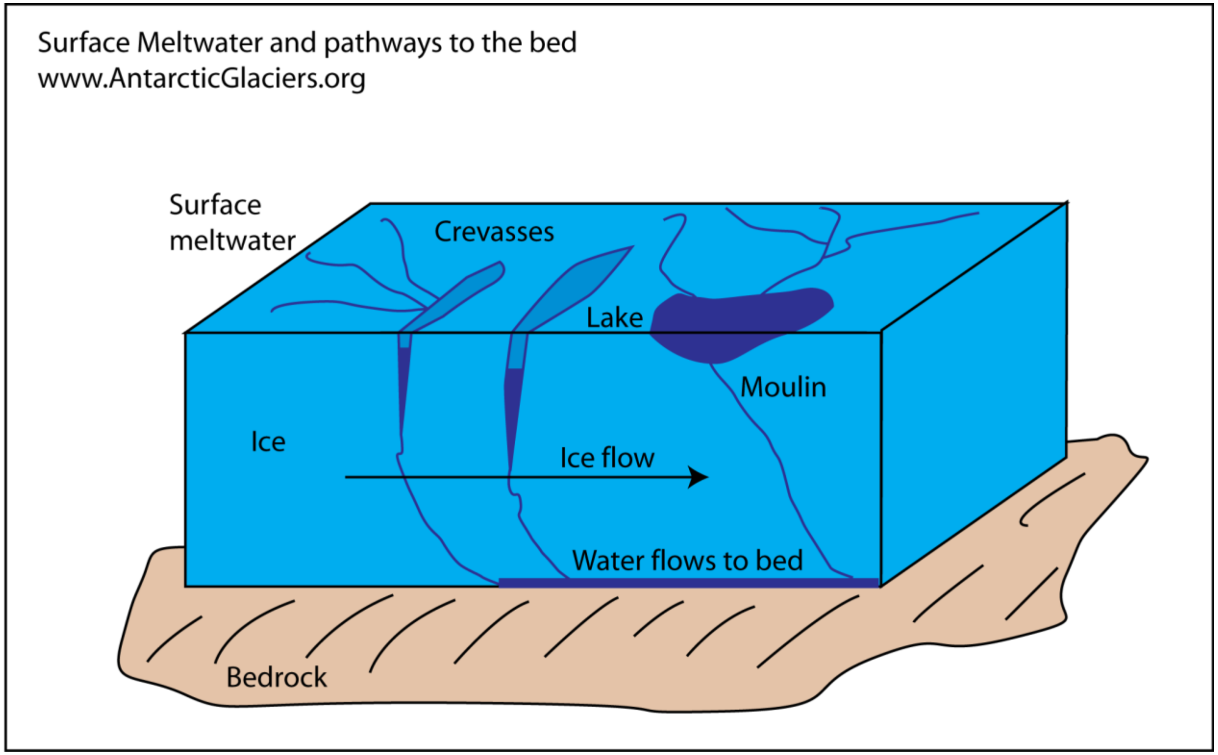
-Hence, sliding can occur by several (possibly simultaneous) ways



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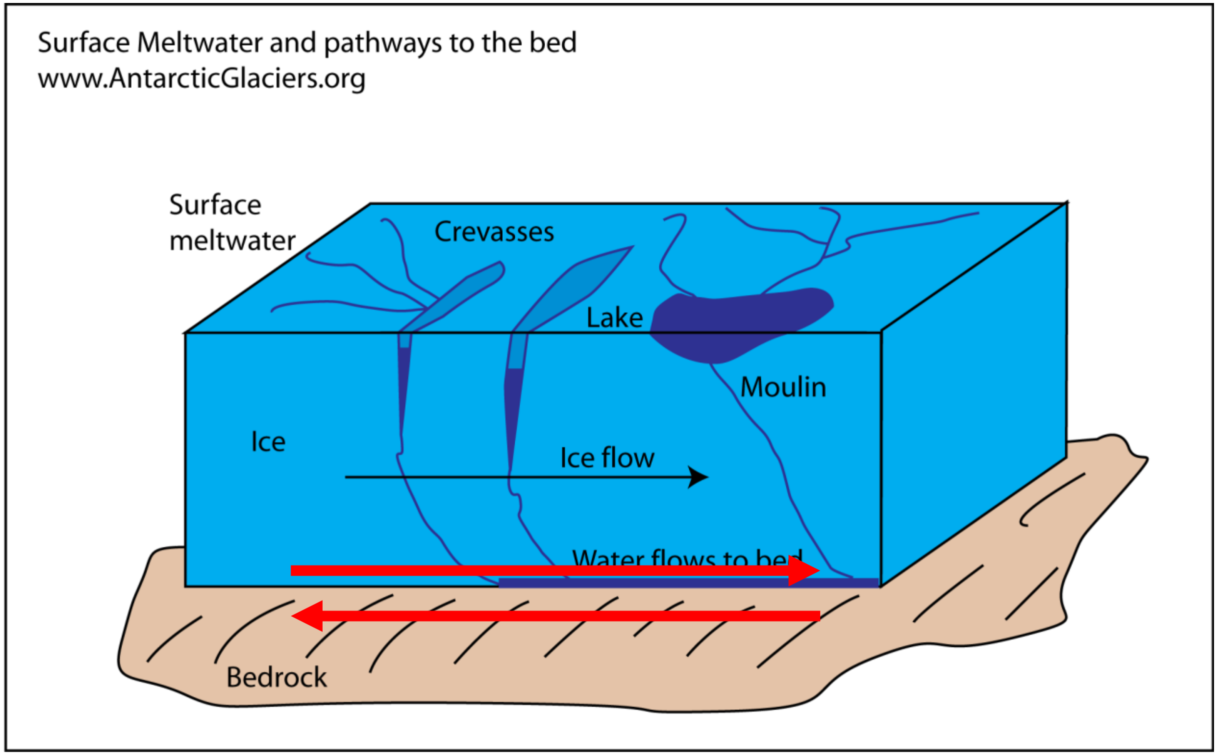
-> Basal sliding (for glaciers in temperate areas)



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https://youtu.be/njTjfJcAsBg?t=21

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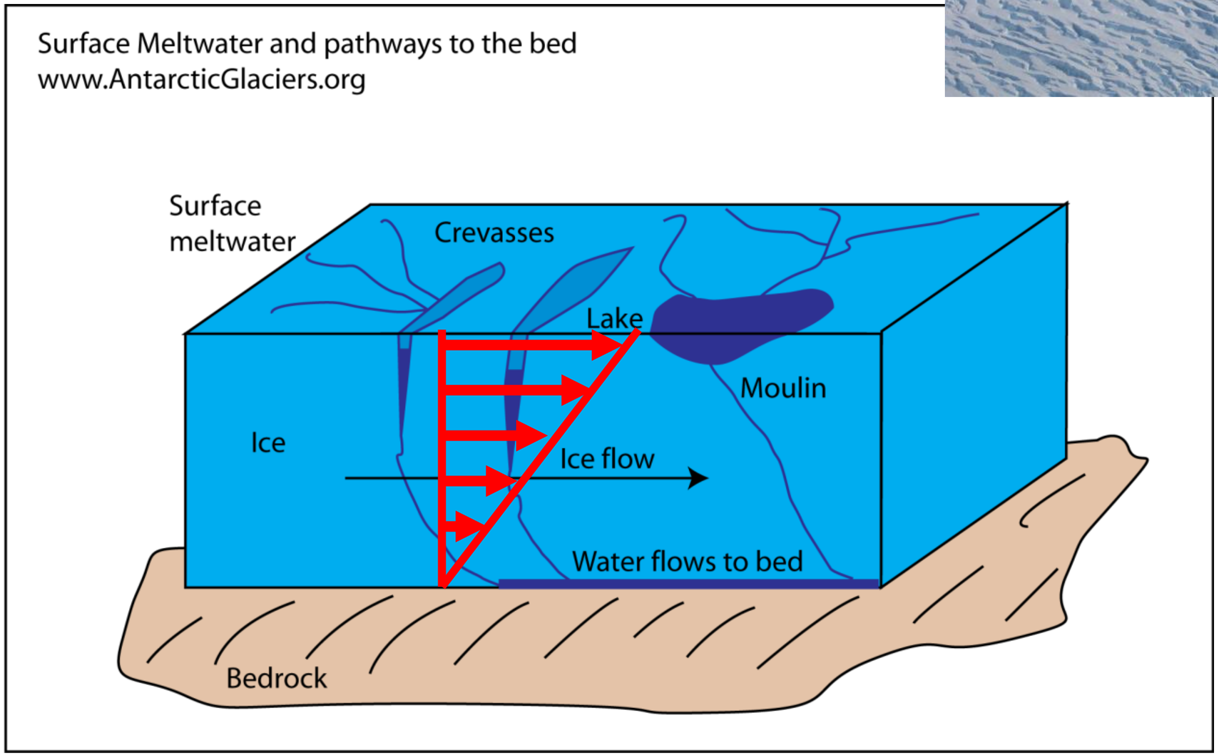
-> Viscoplastic flow of the ice (for glacier in artic regions)



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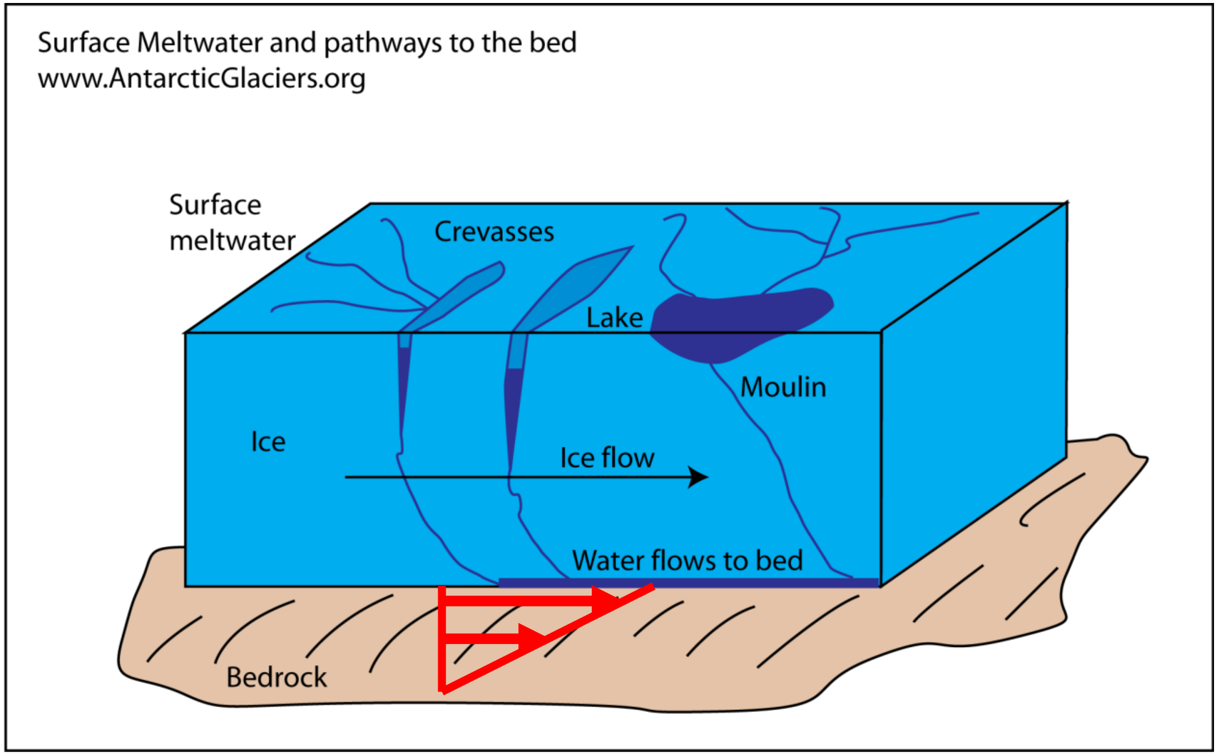
-> Shearing of the underlying weak sediments



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-> Viscoplastic flow of the ice (for glacier in artic regions)

-> Shearing of the underlying weak sediments

-> Shear occurs on the weakest layer

-> Close analogy with the S_iM_j tribological concept!

A spectacular example: the Aletsch glacier

-Largest glacier in the Alps

-Length: 23 km

-Area: 118 km²

-Mass: 27.10^{12} kg of ice

-Max thickness: 900 m

-Velocity: ~0.1 m/day

-3 tributary glaciers

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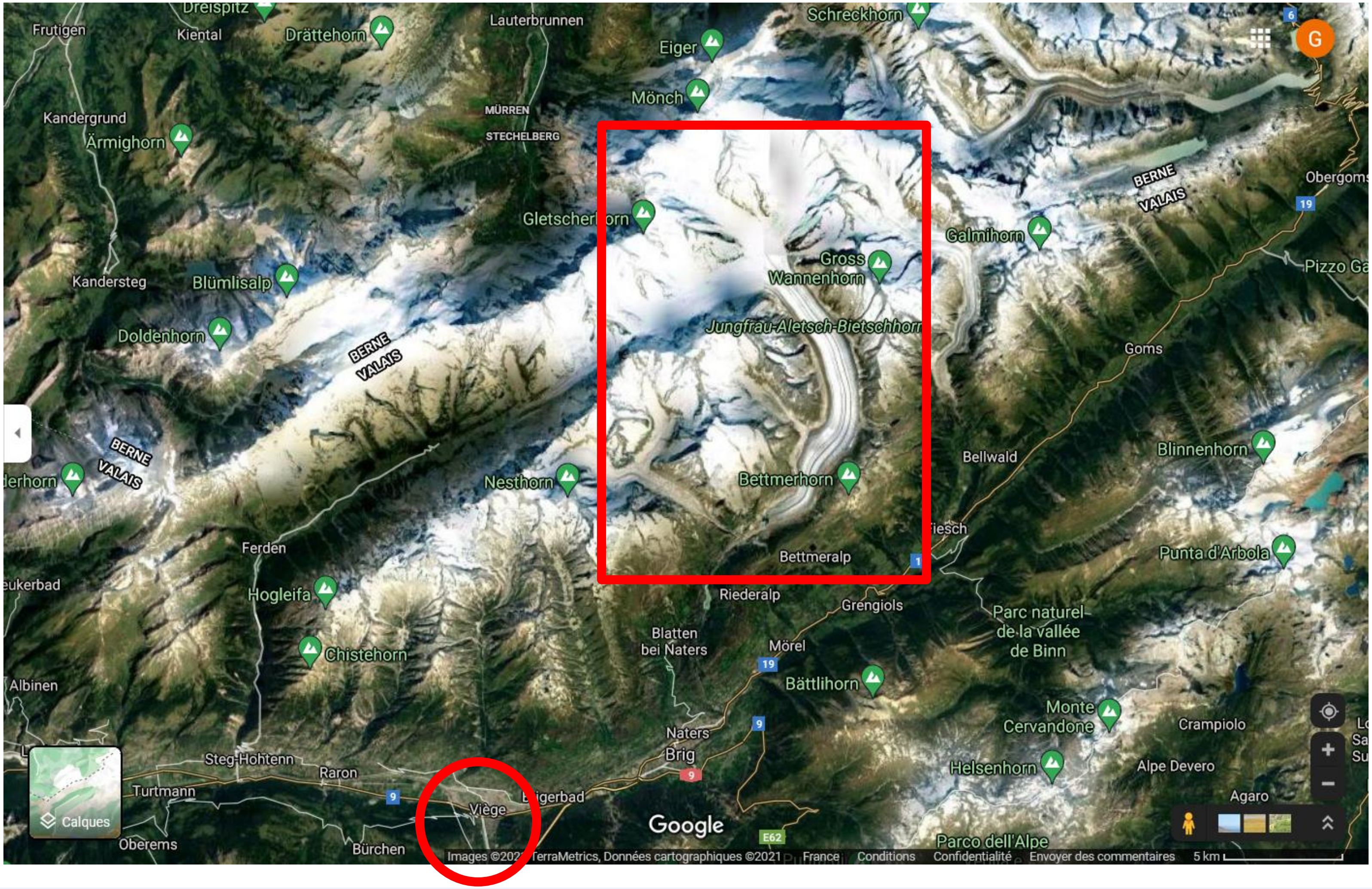
-Not far from here!



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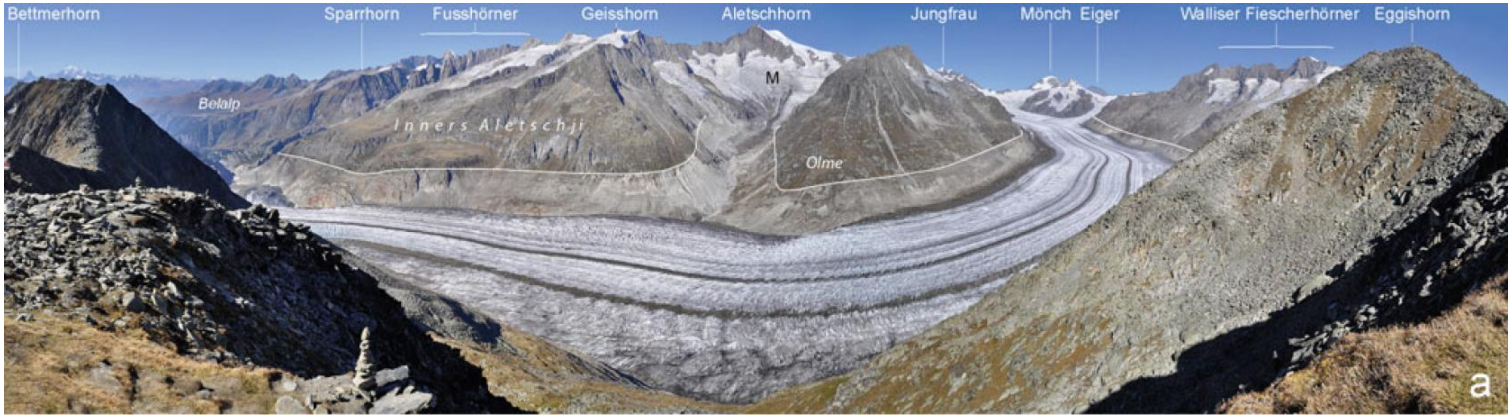

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-Has lost a lot of volume in the last century

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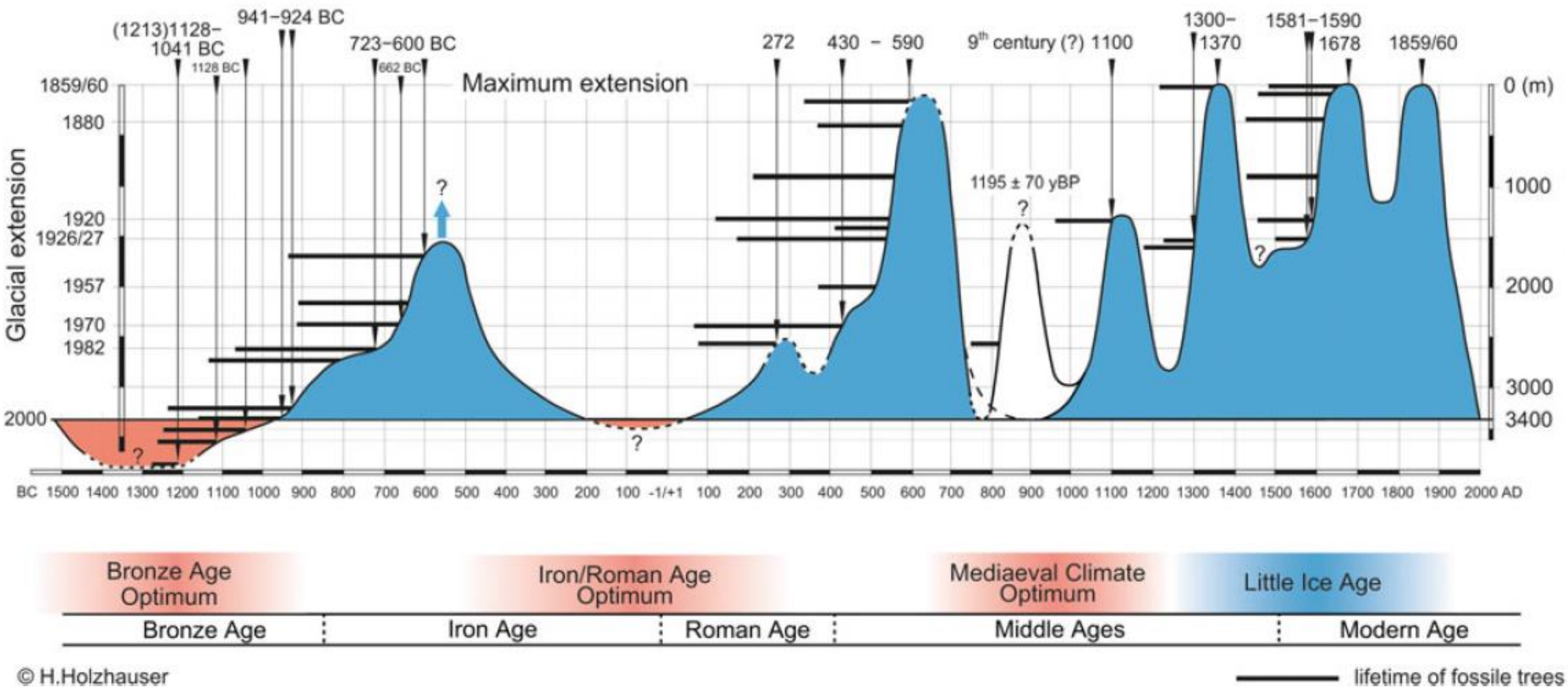
- Has lost a lot of volume in the last century
- Extension now approaches its historical lowest point, and will overcome it soon



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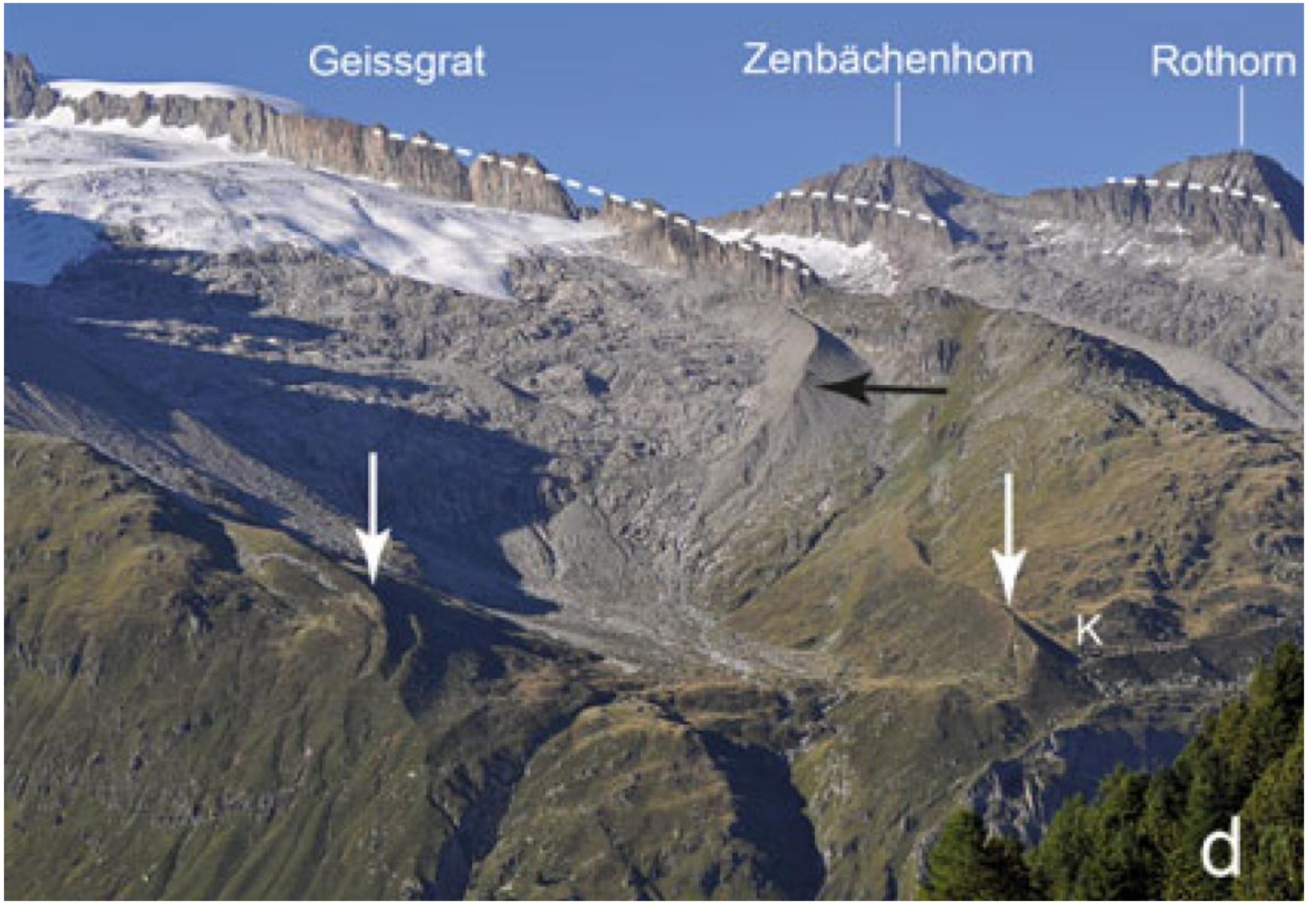

Glacial maximum across geological ages.

A spectacular example: the Aletsch glacier

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-There was a huge glacial lake a century ago, it has now retreated to the much smaller Märjelensee.

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-Projections indicate this retreat will go on, at a velocity which is scenario-dependent.

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-Surface flow patterns were reconstructed from SAR imagery -> seven years of glacier flow!

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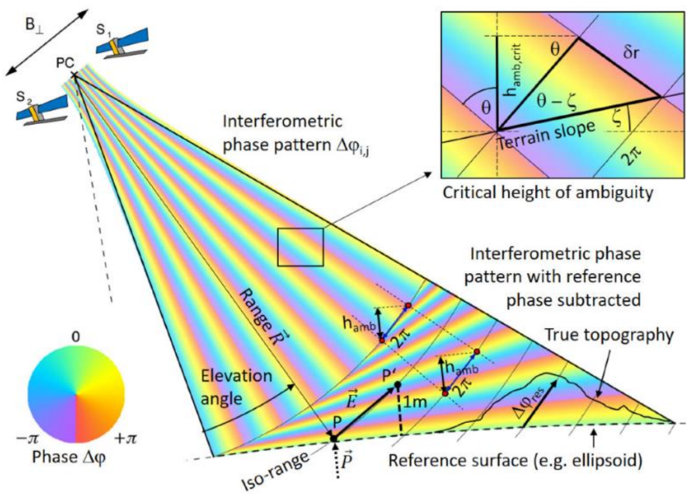
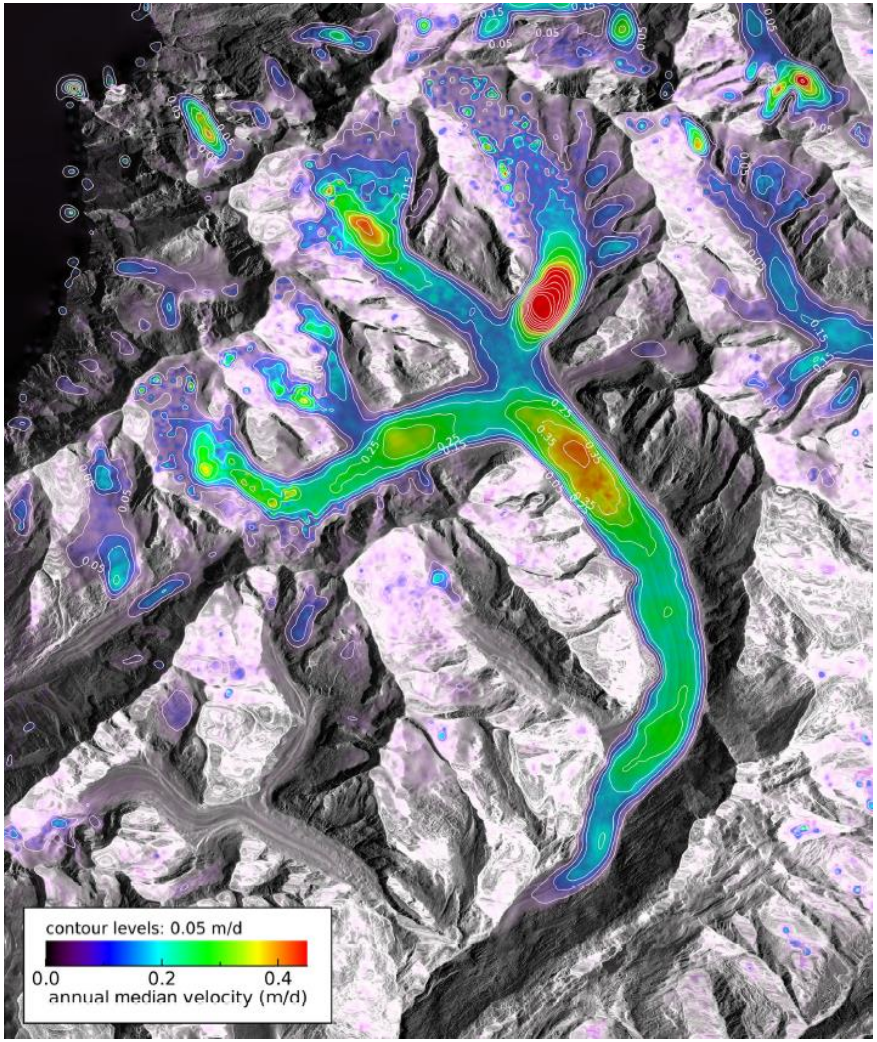
- Surface velocity reconstruction



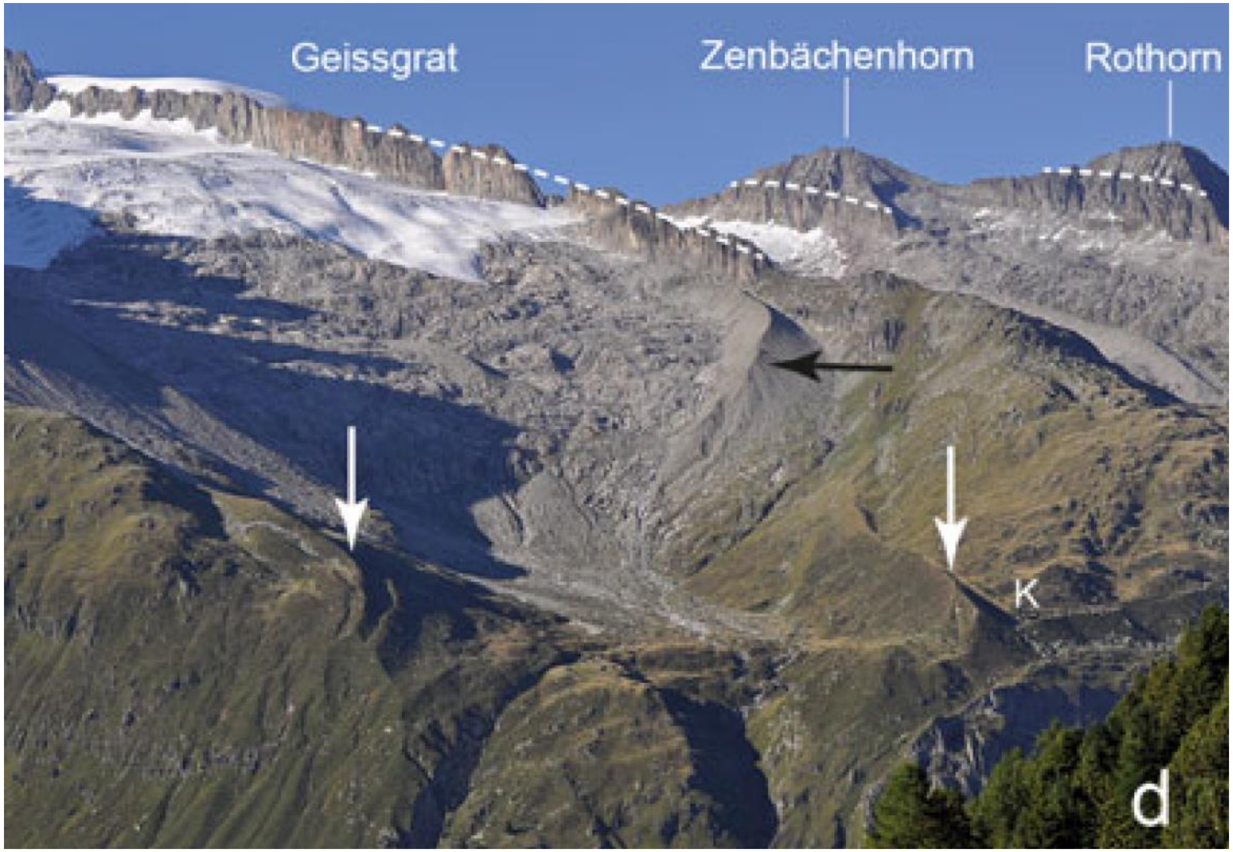


Spotting evidences of glacial sliding

-Moraines : wear material of glacier sliding!

-> Can be observed at the ancient front of a glacier

-> Can also occur as ancient lateral walls of the glacier



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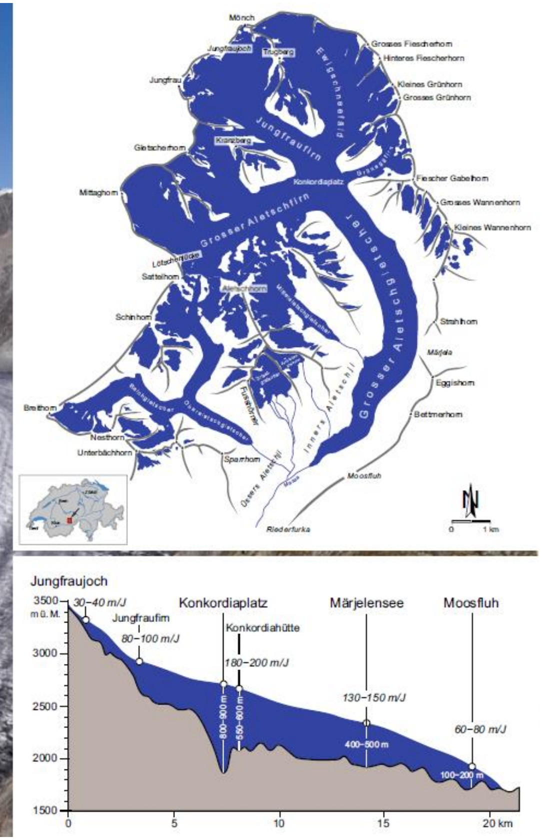

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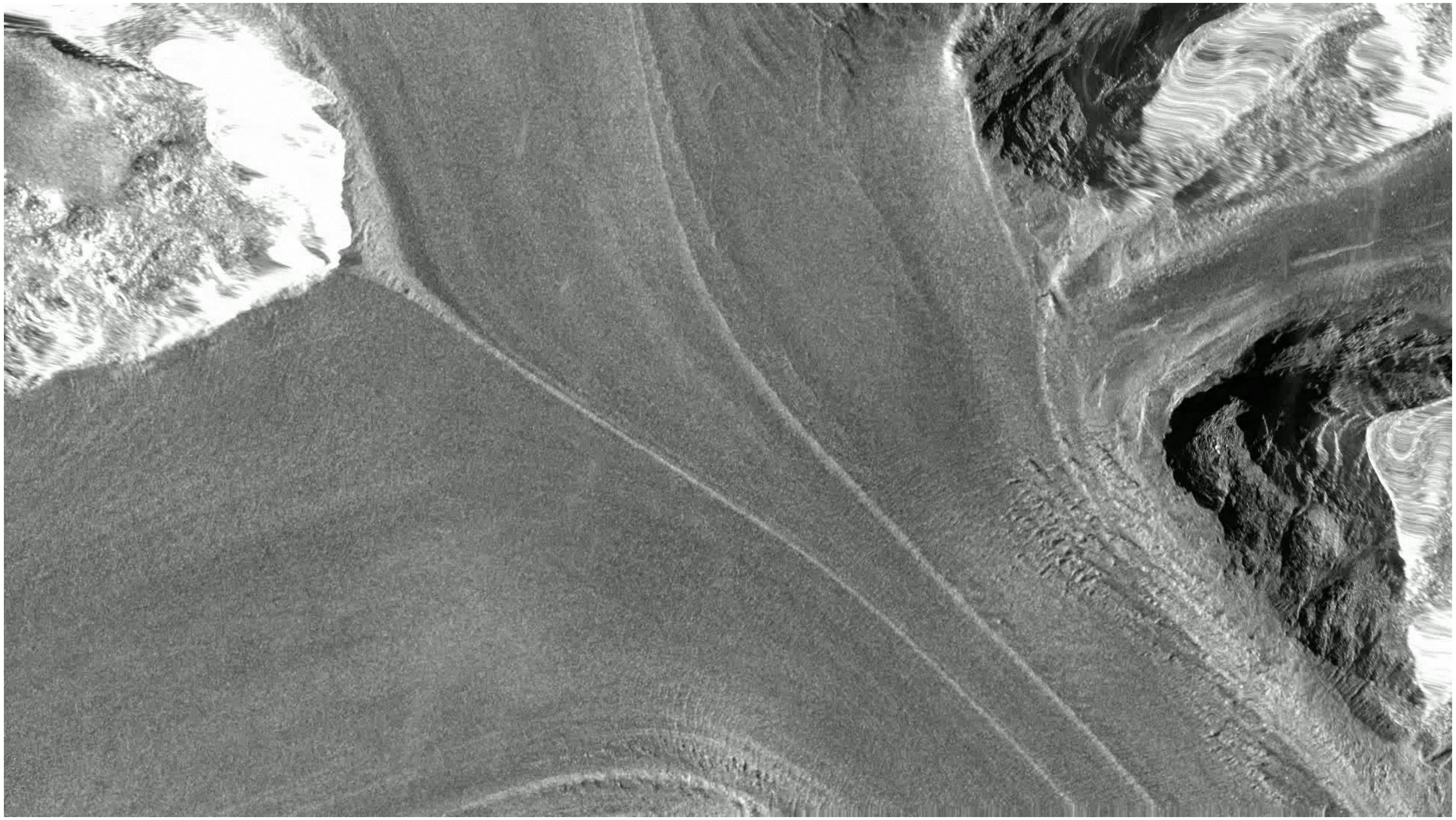
-> Can also occur as ancient lateral walls of the glacier

-> Pushed, but also sheared! Can originate from basal, but also lateral wear.



Spotting evidences of glacial sliding

-Quasi-ductile deformation of pushed rock formations : “Roches moutonnées”

-Reminiscent of severe plastic flows in some tribological contacts

Spotting evidences of glacial sliding

-Wear scars on exposed outcrops (ancient slip surfaces)

Spotting evidences of glacial sliding

-Wear scars on exposed outcrops (ancient slip surfaces)

-Not carved by ice, but by trapped mineral wear debris (3rd body-related wear)

-Patterns usually called “striations”.

Open your eyes, and good luck!

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