HISTORY MATCHING
&
ROCK MECHANICS

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Reservoir Mechanics 20 years anniversary 30.08.02

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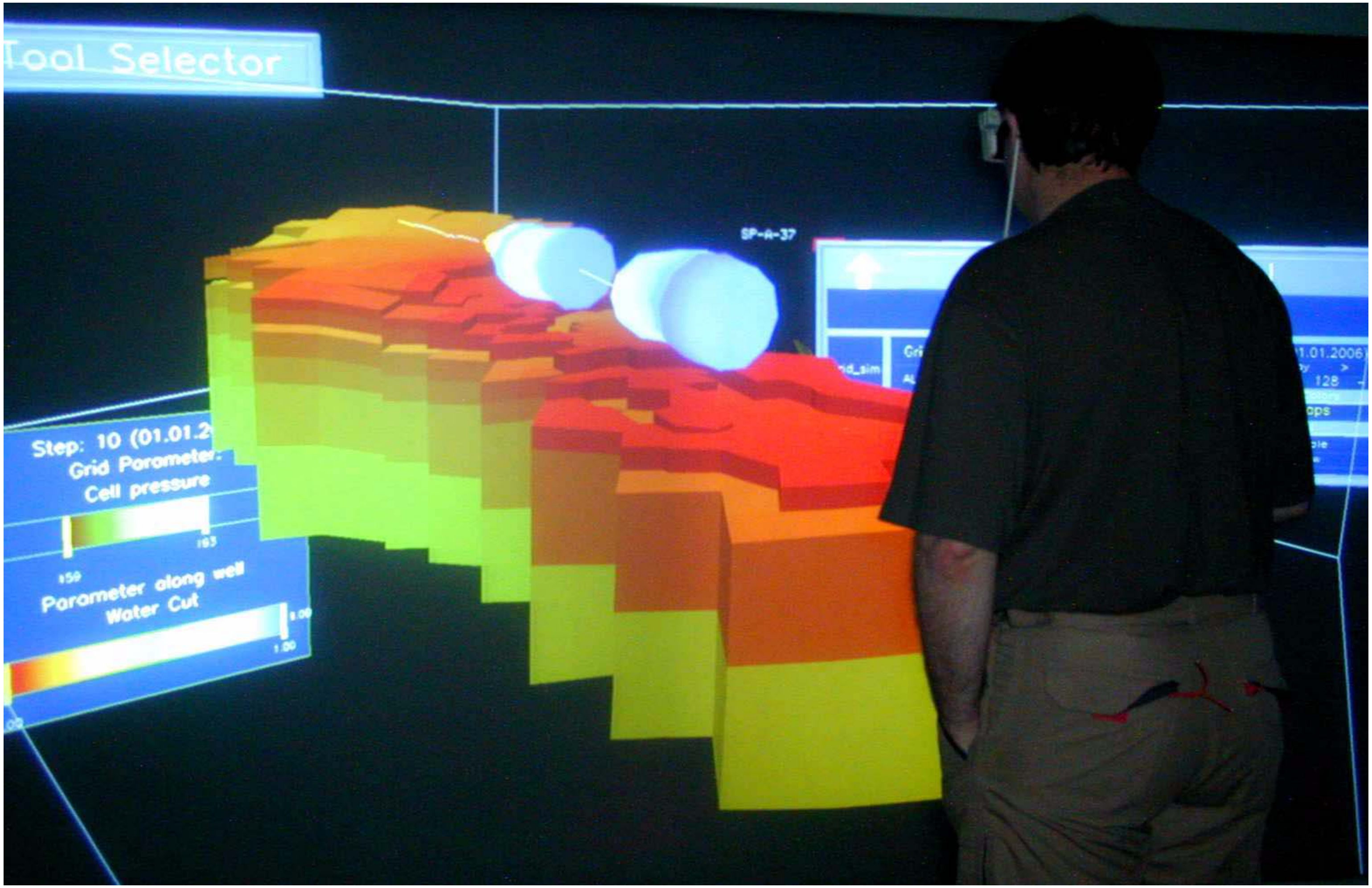
A Simulation Model in Virtual Reality



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Real History Matching

Original photography

Official photography after
Trotskij had fallen into disgrace

Now you see him -- now you don't

What is History Matching?

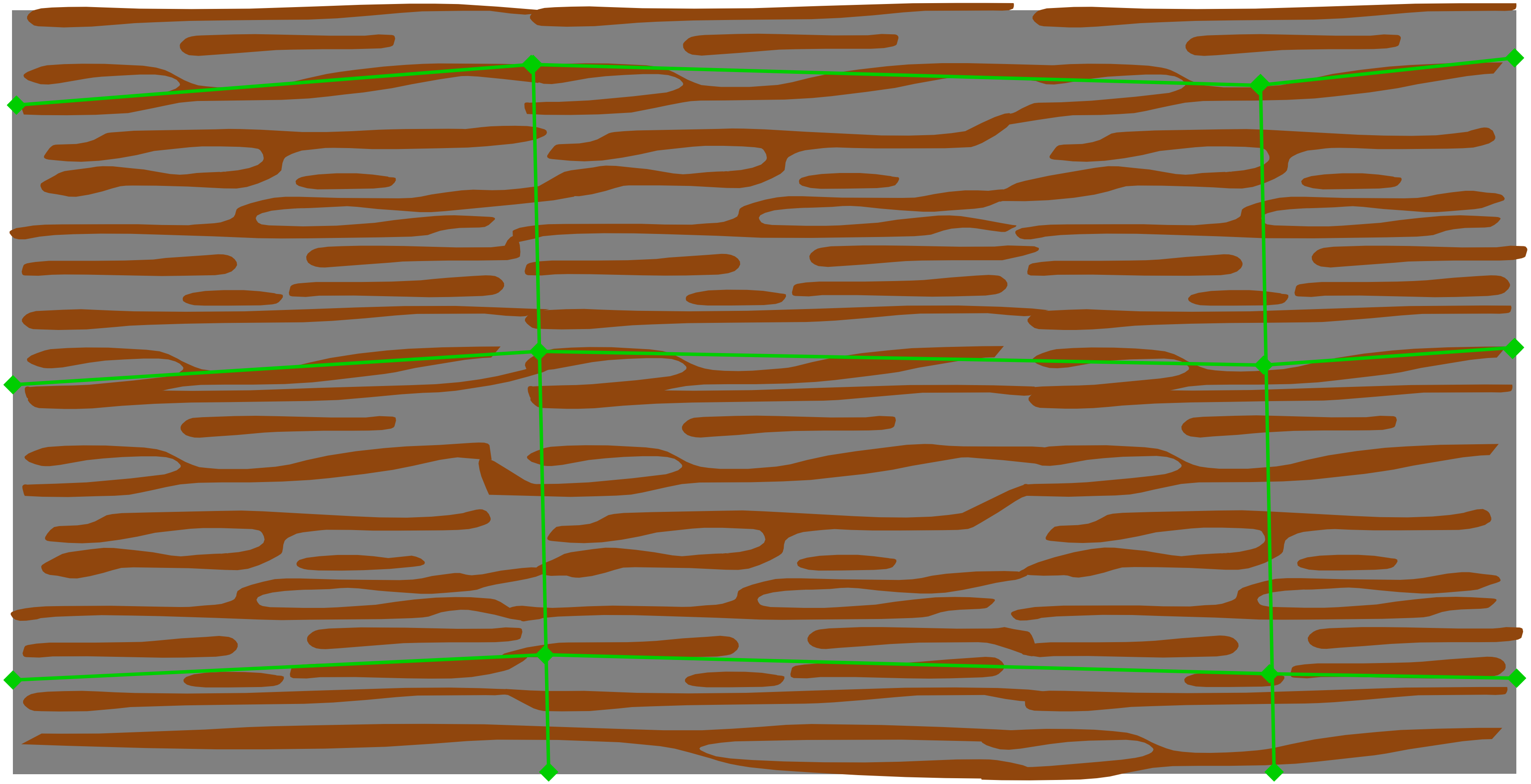
- ***Standard procedure:***
  - ***From a system of equations $L(\underline{u}(\underline{x}), \underline{a}, \underline{x}) = \underline{0}$ with I.C. and B.C. find the solution $\underline{u}(\underline{x})$, with known parameters $\underline{a}$.***
- ***History matching:***
  - ***From a system of equations $L(\underline{u}(\underline{x}), \underline{a}, \underline{x}) = \underline{0}$ with I.C. and the solution $\underline{u}(\underline{x})$ known, determine the boundary conditions and parameter set $\underline{a}$.***
    - ***Normally some of the B.C.'s and (part of) $\underline{a}$ will be known.***

History Matching in Practice

- *$\underline{u(x)}$ will not be known as a continuous function of a continuous space/time variable, but only at a few points in space at a few times. Mathematically, the solution is unknown almost everywhere.*
  - *The achieved B.C. "solution" cannot be unique.*
- *In addition the known (sparse) solution $u_i(x_i)$ is not always reliable.*
  (standard uncertainty, allocation errors, coarse errors).
- *The observed quantity may reflect a realisation of the solution which is not possible to model, and therefore would be wrong to honour.*
- *Our task is to critically utilize the provided historical data in the best possible manner, such that the parameters we determine by the H.M. process are the most likely ones from a physical point of view. (Difficult, difficult,....)*

Heterogeneity: Sandstone Outcrop

Idealised Heterogeneous X-Section



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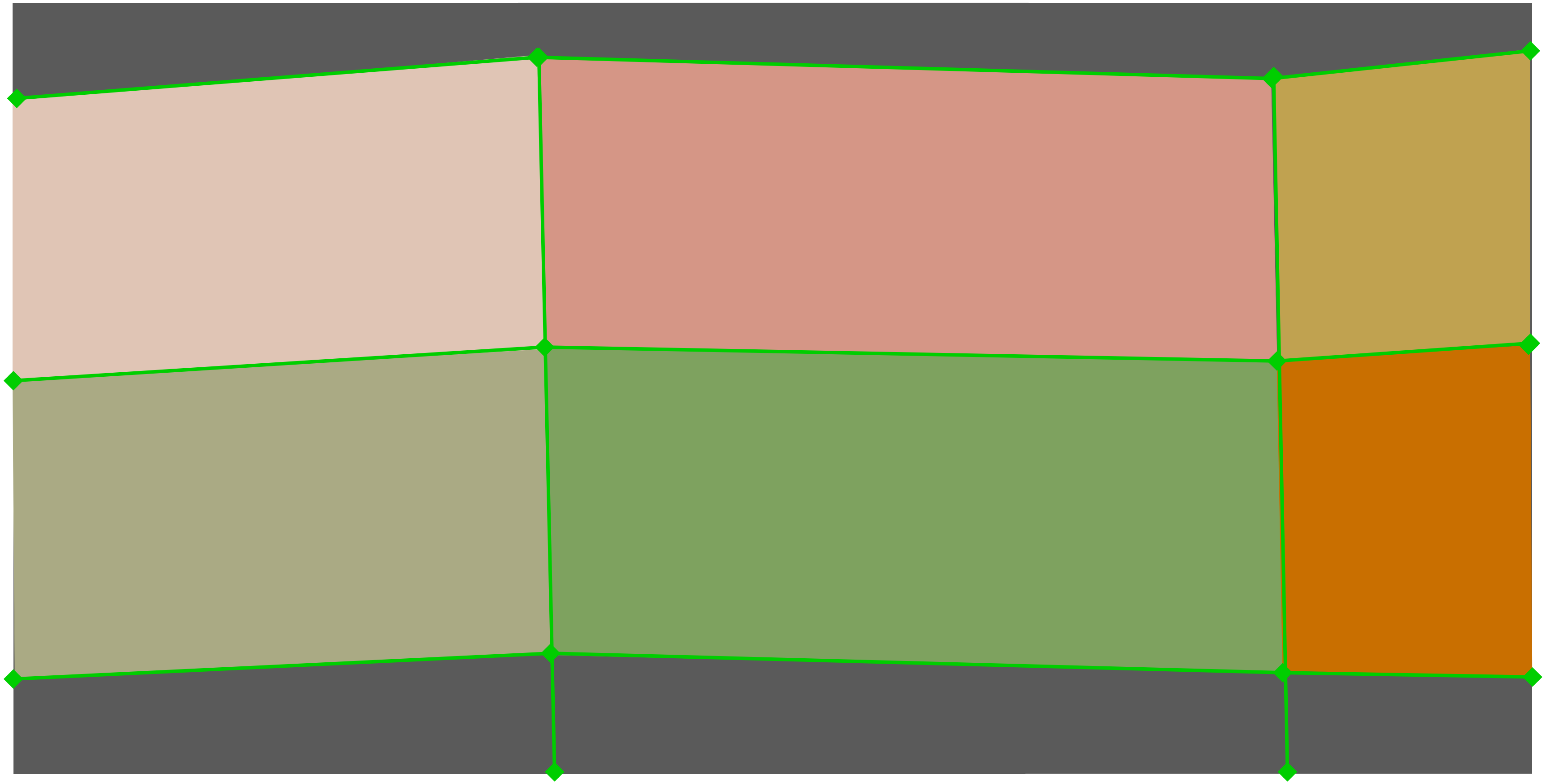
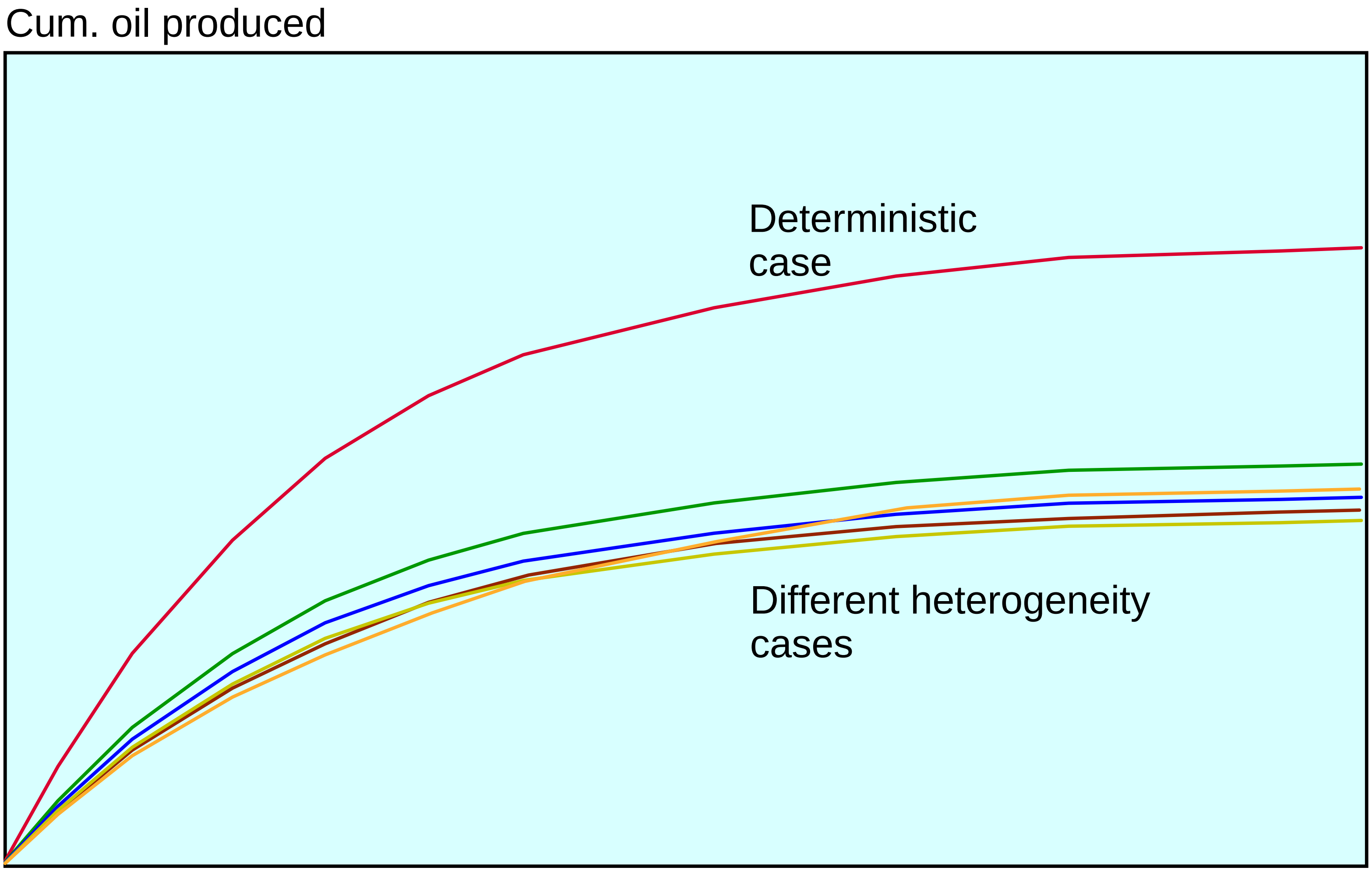
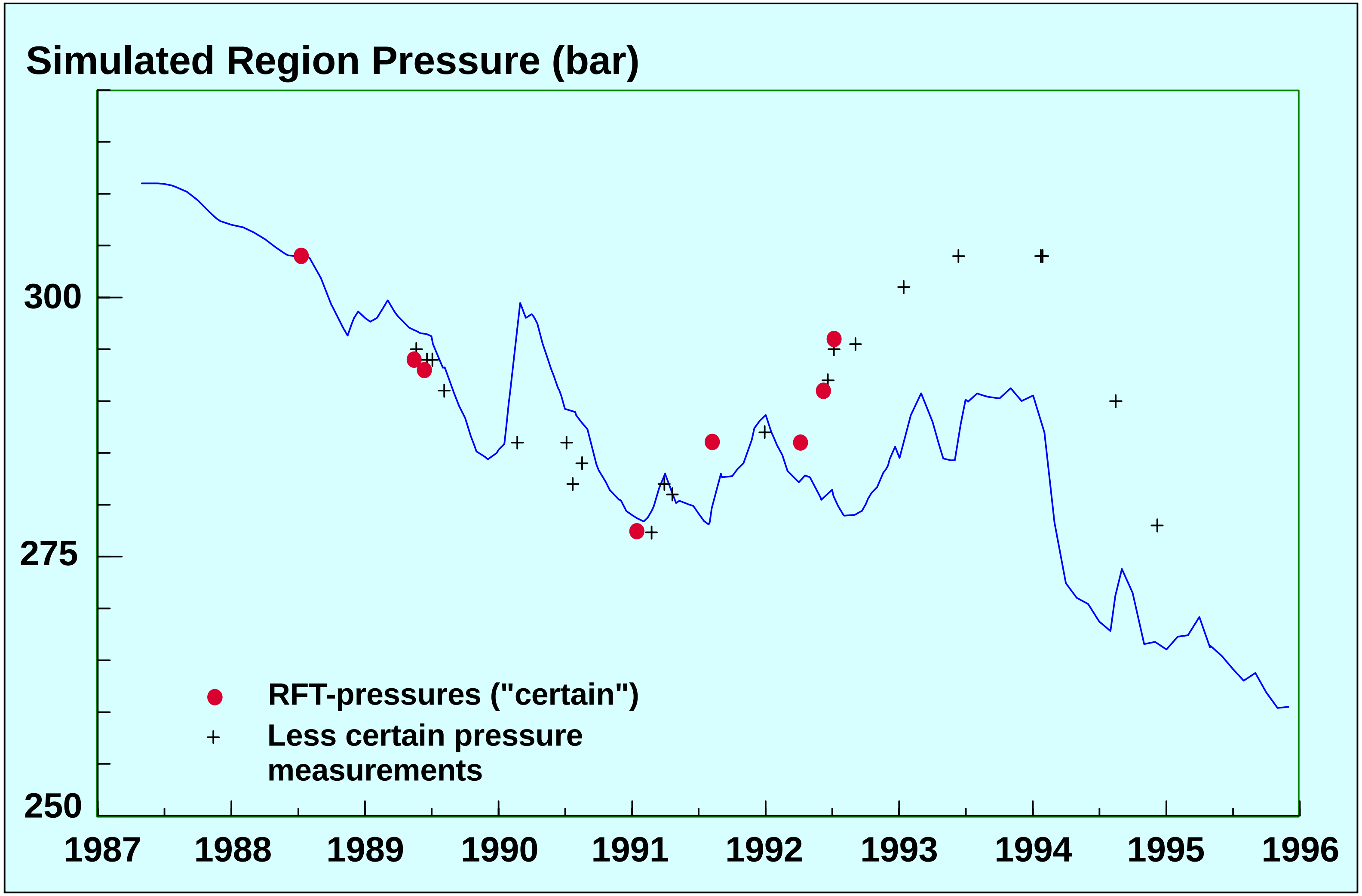
After Upscaling to a Simulation Grid



Heterogeneity Modelling (generic example Field A)



Field A History Matching:
Region Pressure -- Best result after > 200 runs



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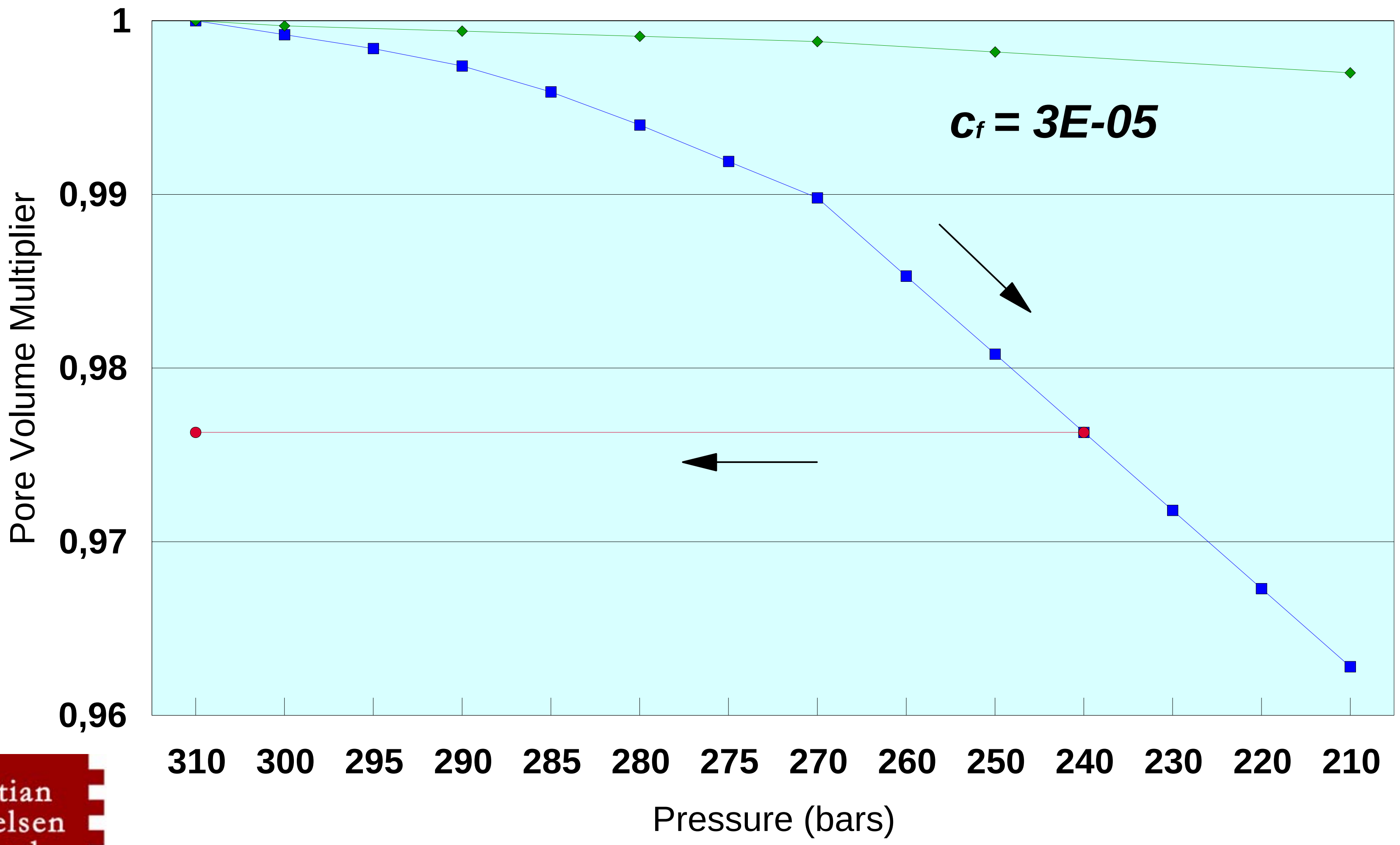
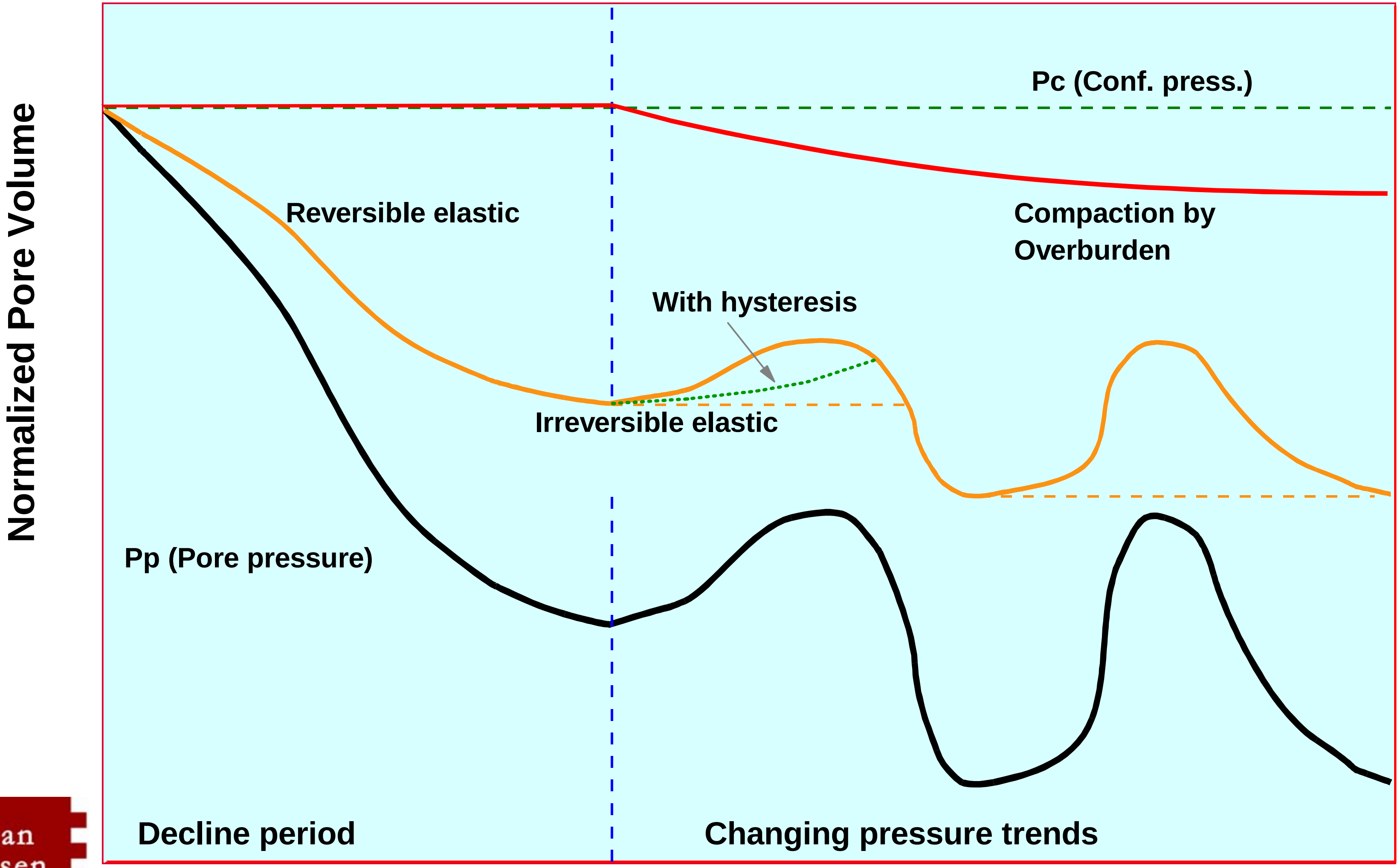
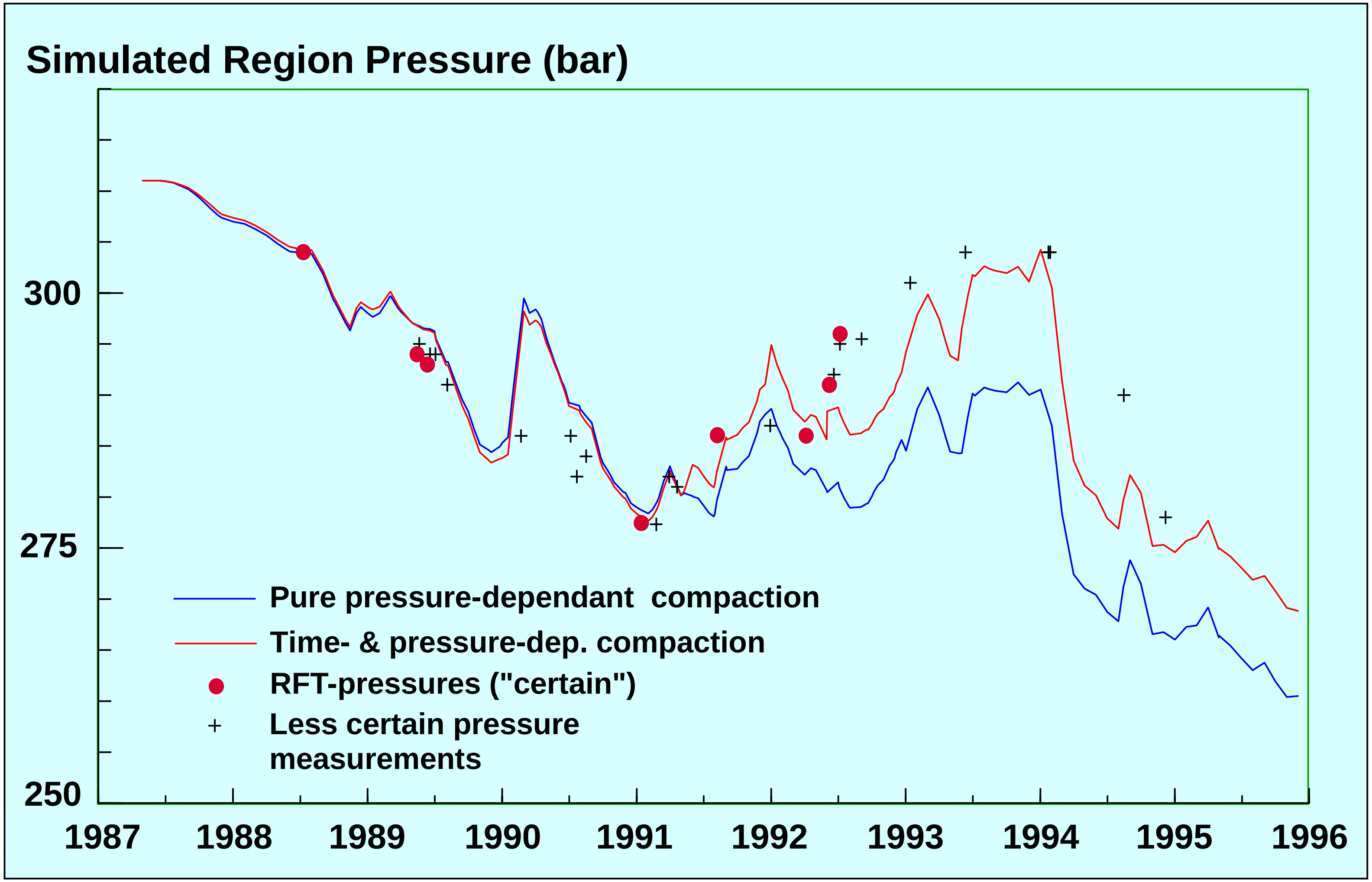
Example rock compaction curves
(ROCK constant and Irreversible ROCKTAB)



Classification of Compaction



Time-dependent compaction (creep) -- 1 cm reservoir compaction pr. year



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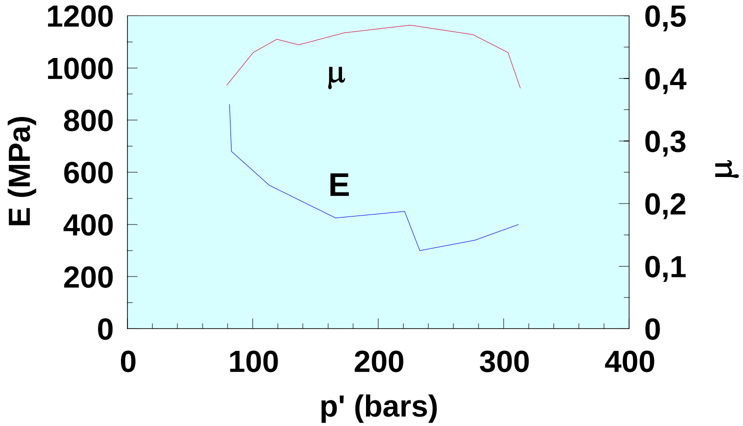
The Influence of Rock Mechanics

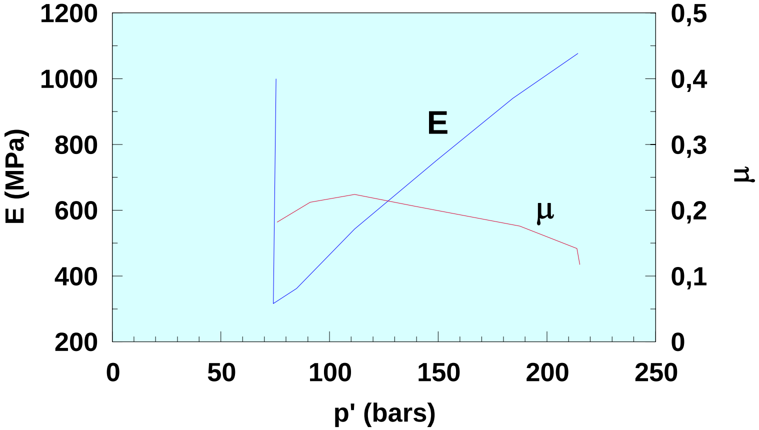
- By tweaking compaction curves on a per-region basis, pore volume change can be modelled to honour history
- A better approach would be to compute the changes from the stress-strain relations
- We should expect that compaction also influences permeability, including permeability isotropy
- What if the soil doesn't behave like a stable soil / rock at all?
  - Are Darcy's law and the flow equations still valid?

Elastic moduli

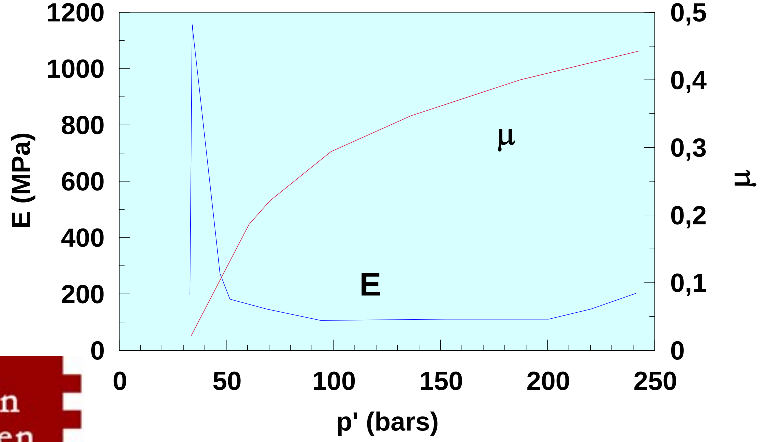
Field A -- Weak Sandstone



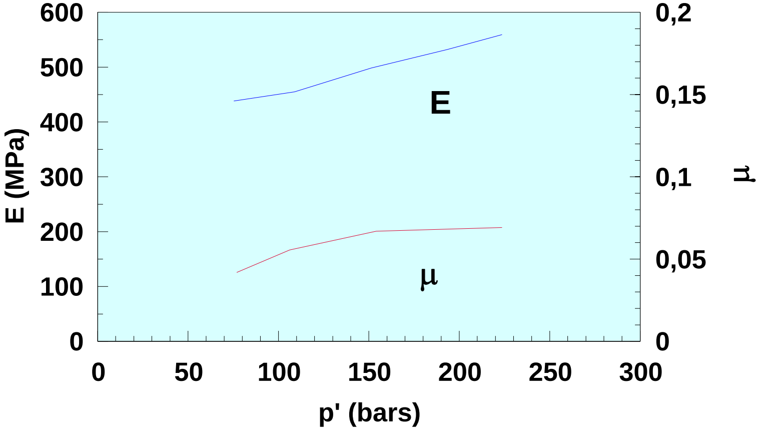
Field B -- Weak Sandstone



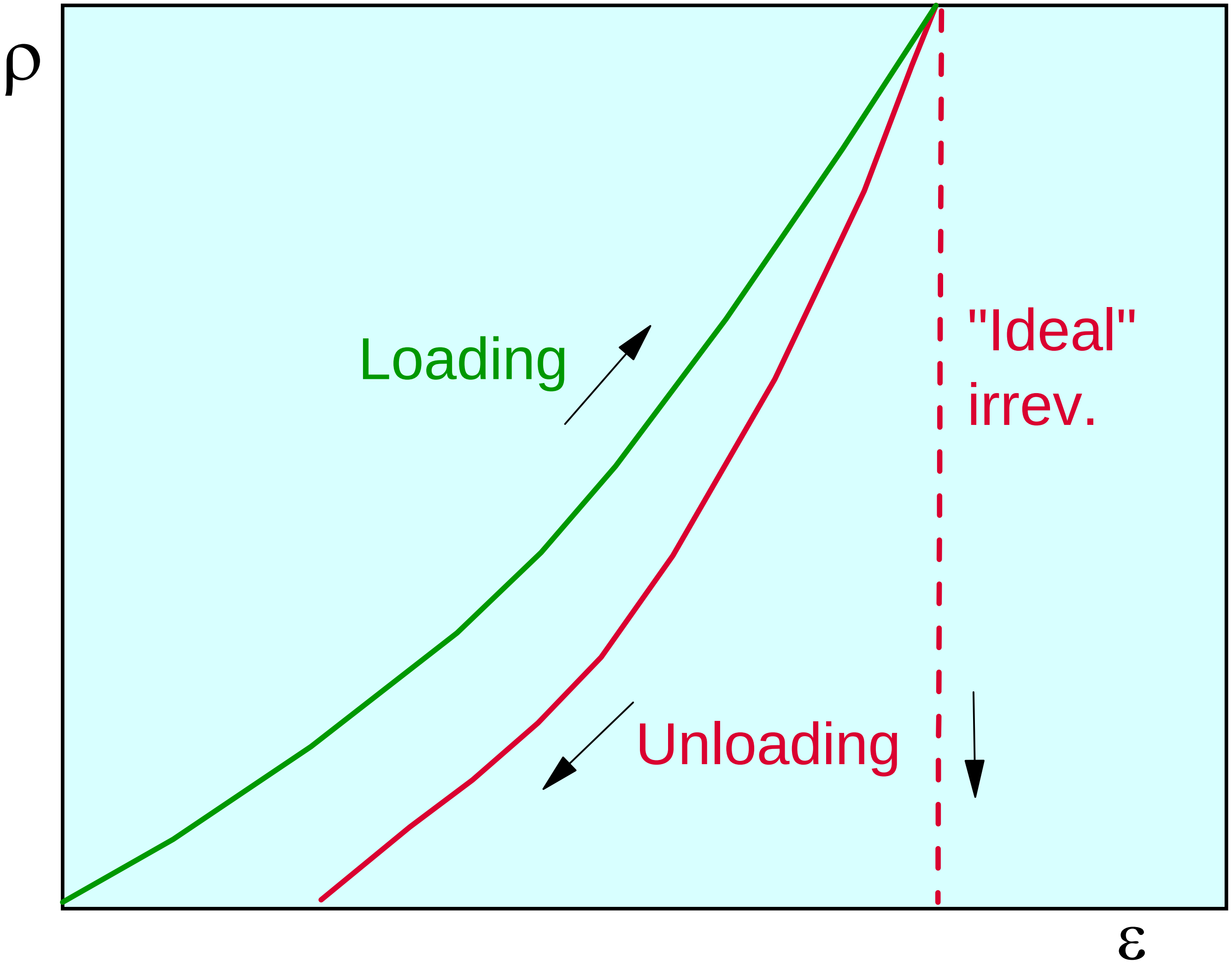
Field C -- Unconsolidated Sand



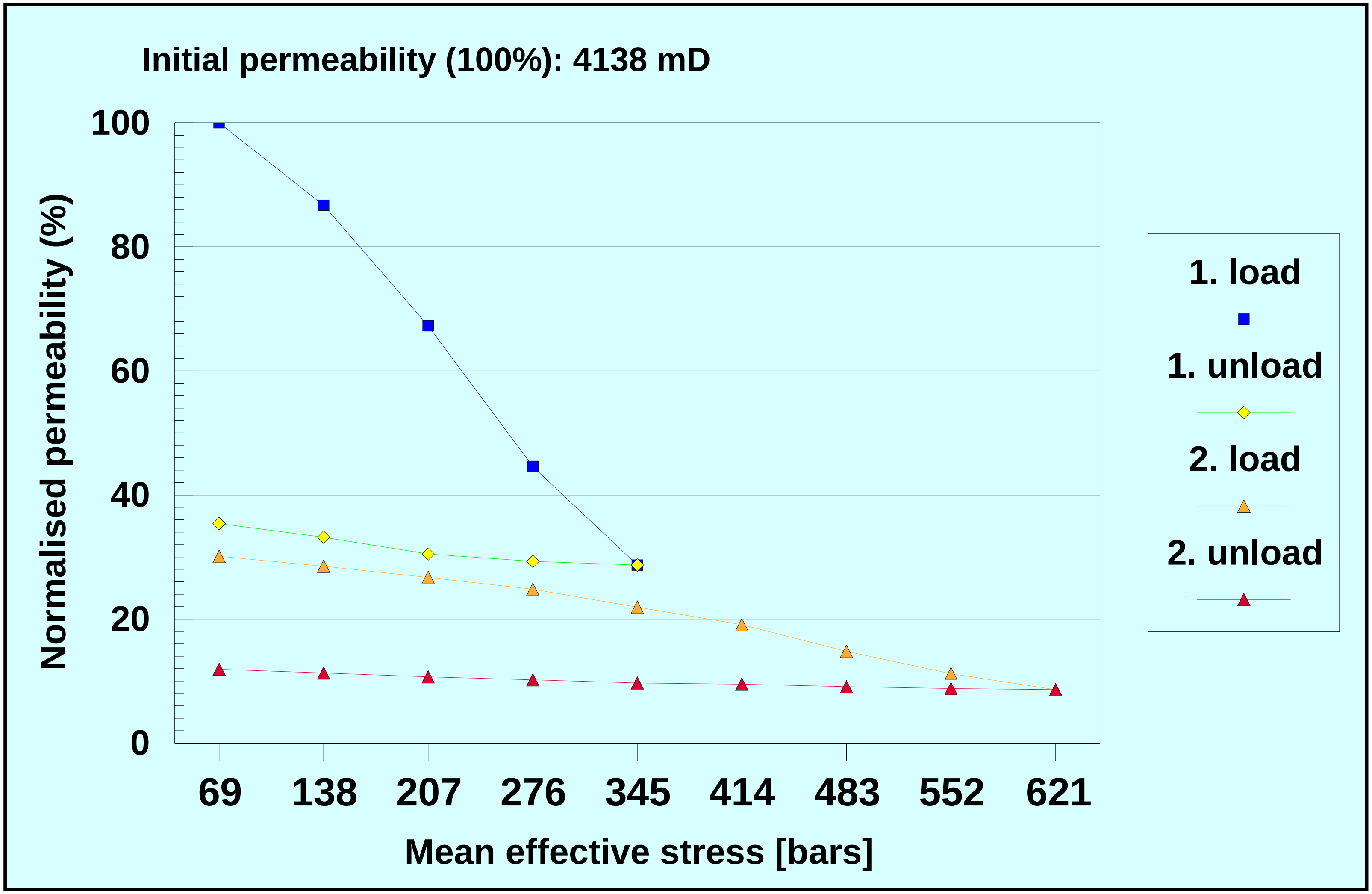
Field B -- Unconsolidated Sand



Elasticity with permanent deformation ("Irreversible")



Permeability vs stress
Unconsolidated Sand Field A



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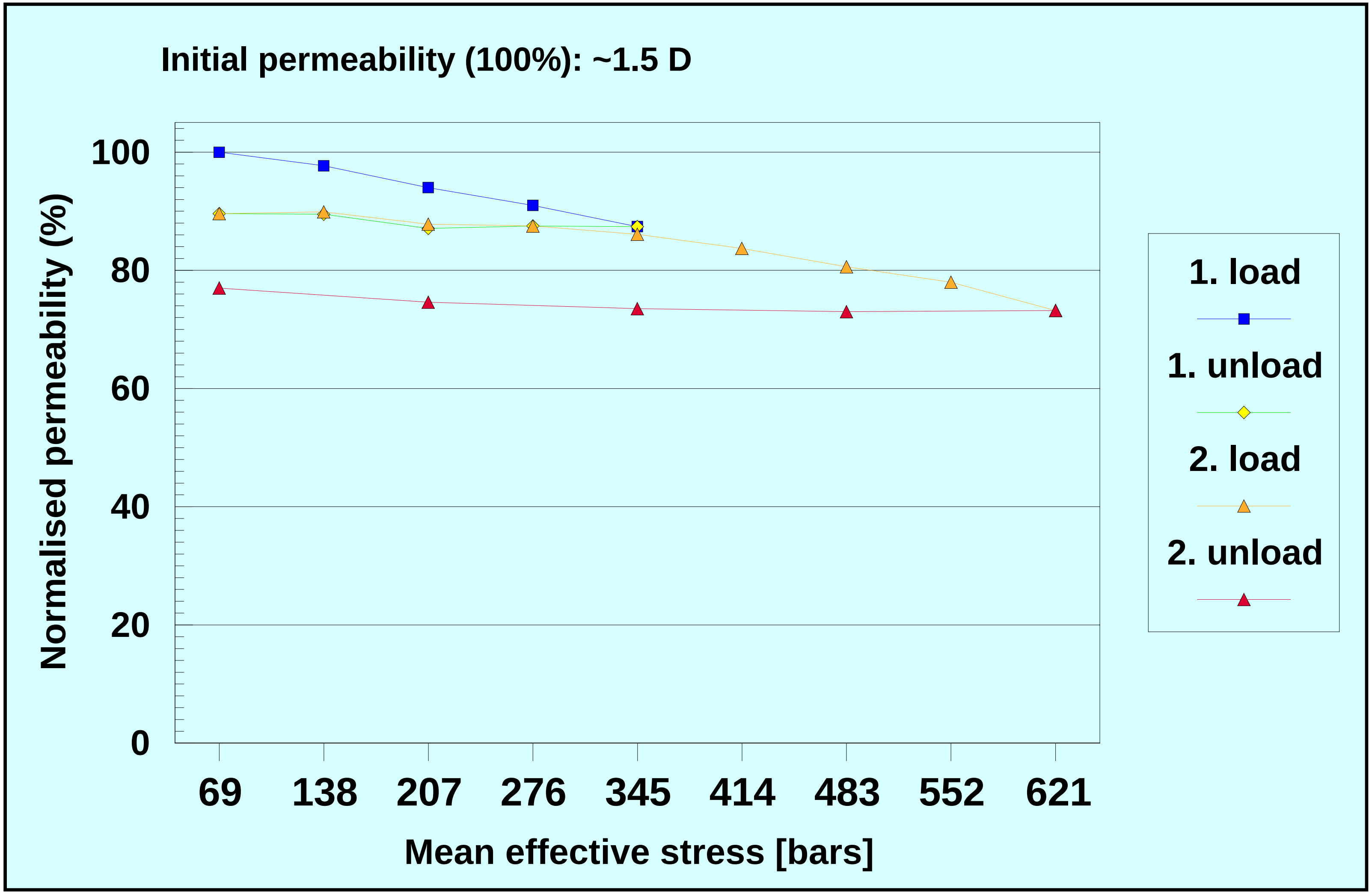
Permeability vs stress
Unconsolidated Sand Field B



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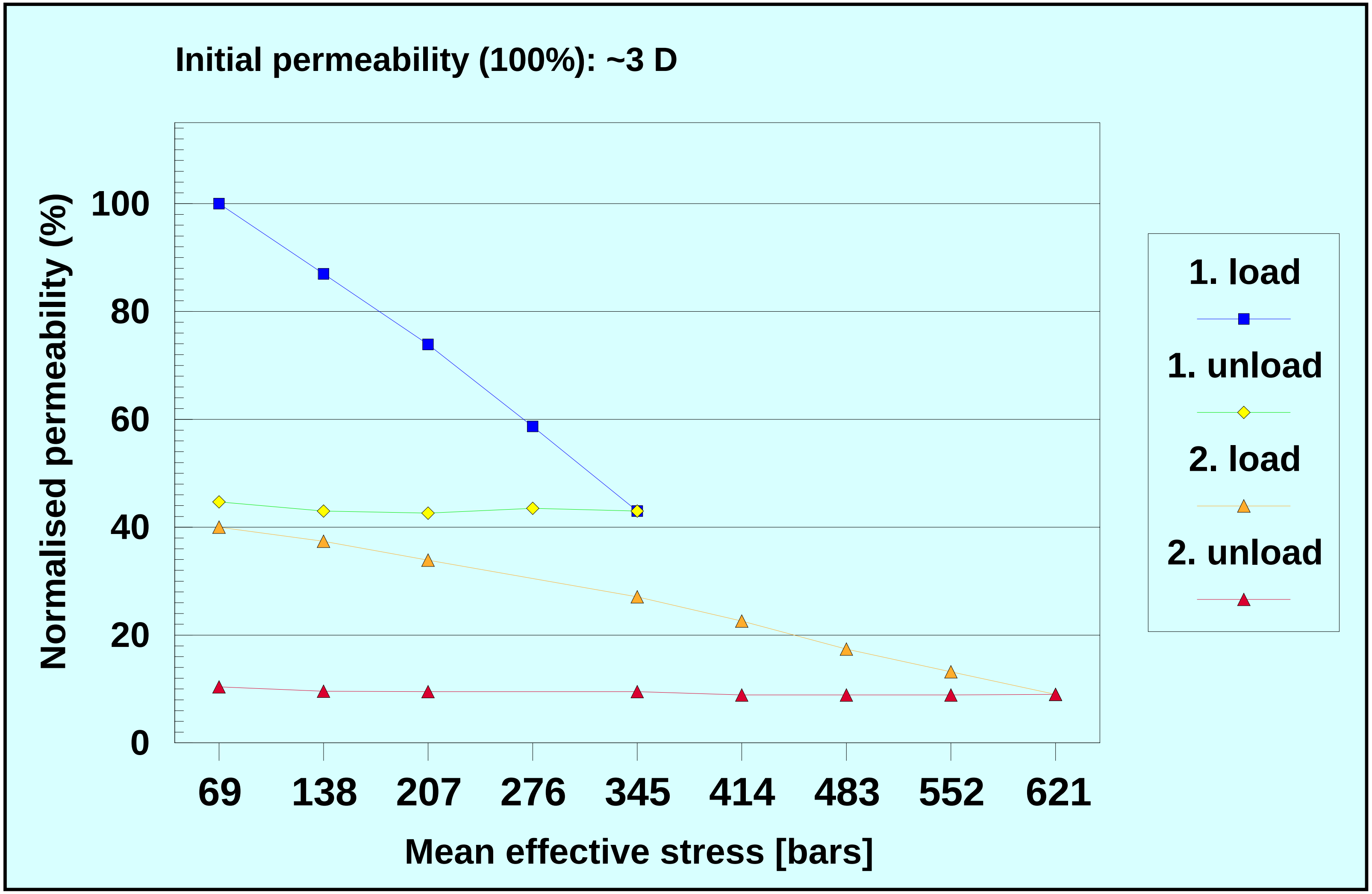
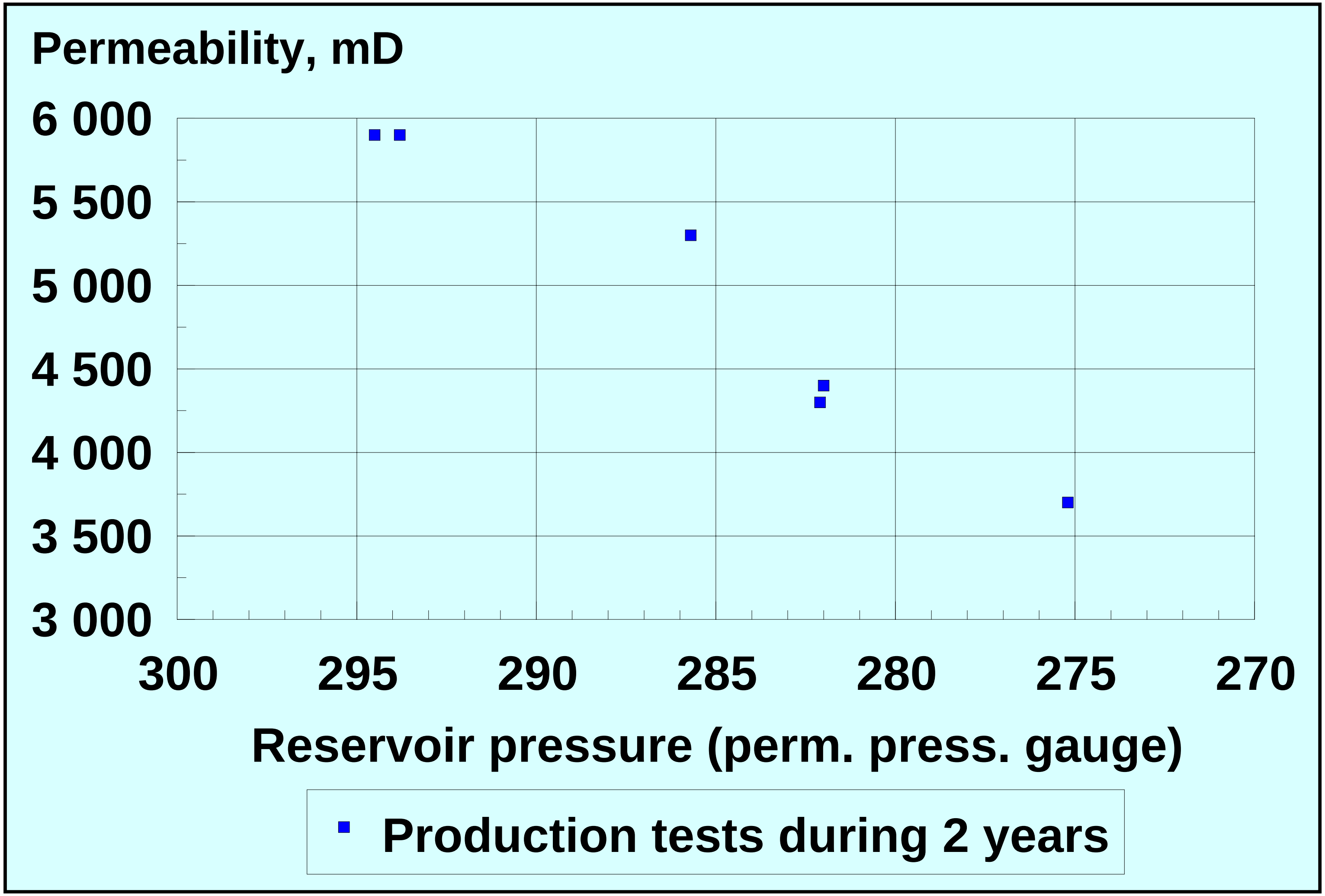
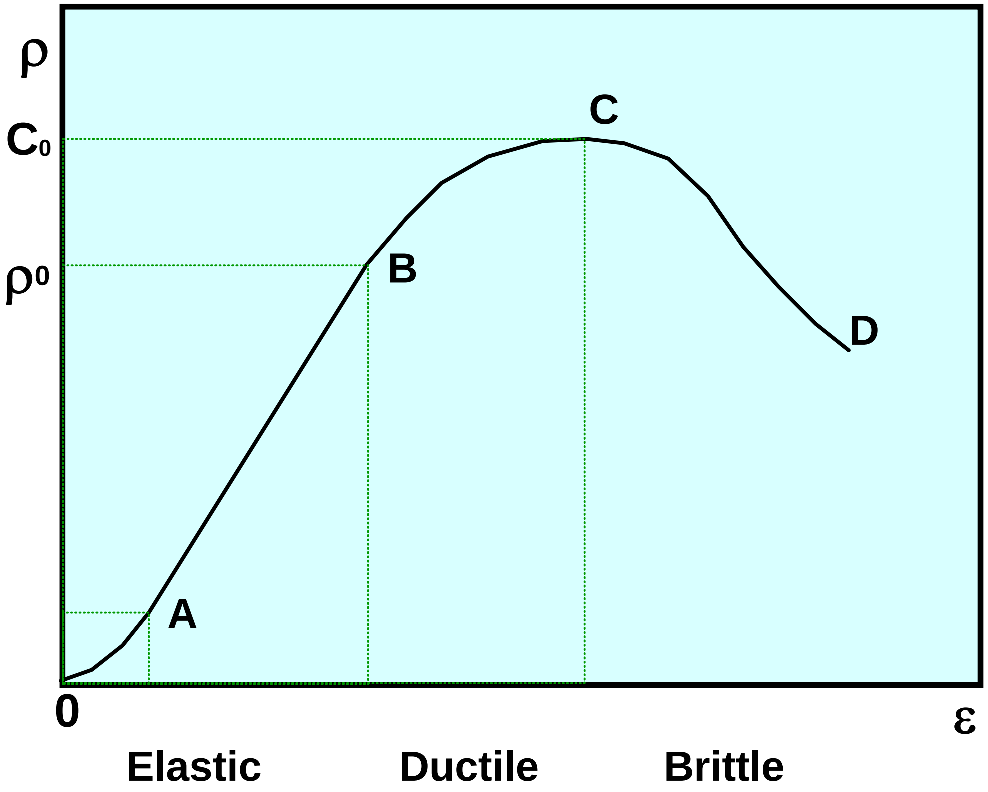
Permeability vs stress
Unconsolidated Sand Field C



Permeabilities from transient test analysis
Field A



Soil strength



ρ_0: Yield point (transition elastic ♎ductile)

(typically B ●2/3 C)

C_0: Uniaxial compressive strength

OA: Increasing -- slightly convex

AB: Increasing -- linear

OAB: Elastic (appr. linear)

BC: Increasing -- concave

Ductile: ***Can endure permanent deformation without losing ability to withstand load.***

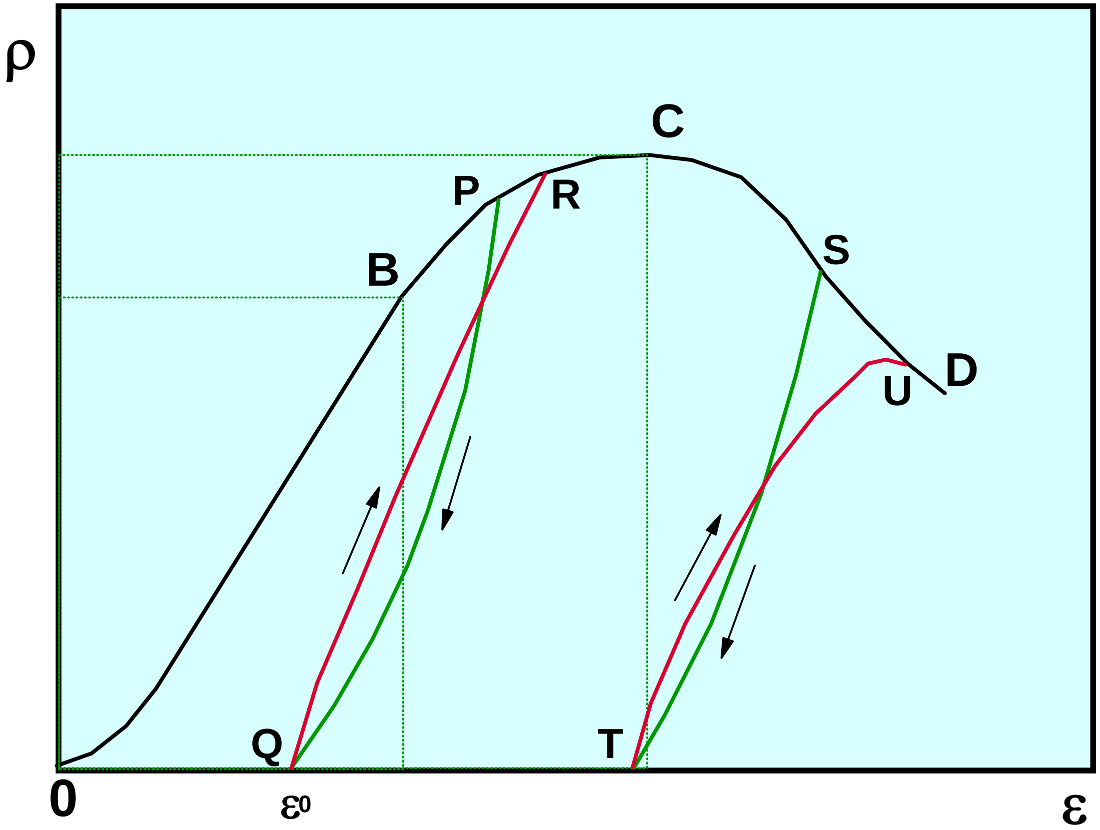
CD: Decreasing

Brittle: ***Ability to withstand loading decreases with increasing deformation.***

"Brittleness": Largest slope angle on CD.

(In theory a continuous process through CD. In practice sudden failure occurs at some point on CD: Total loss of cohesion across a plane.)

Soil strength:
Hysteresis and deformation



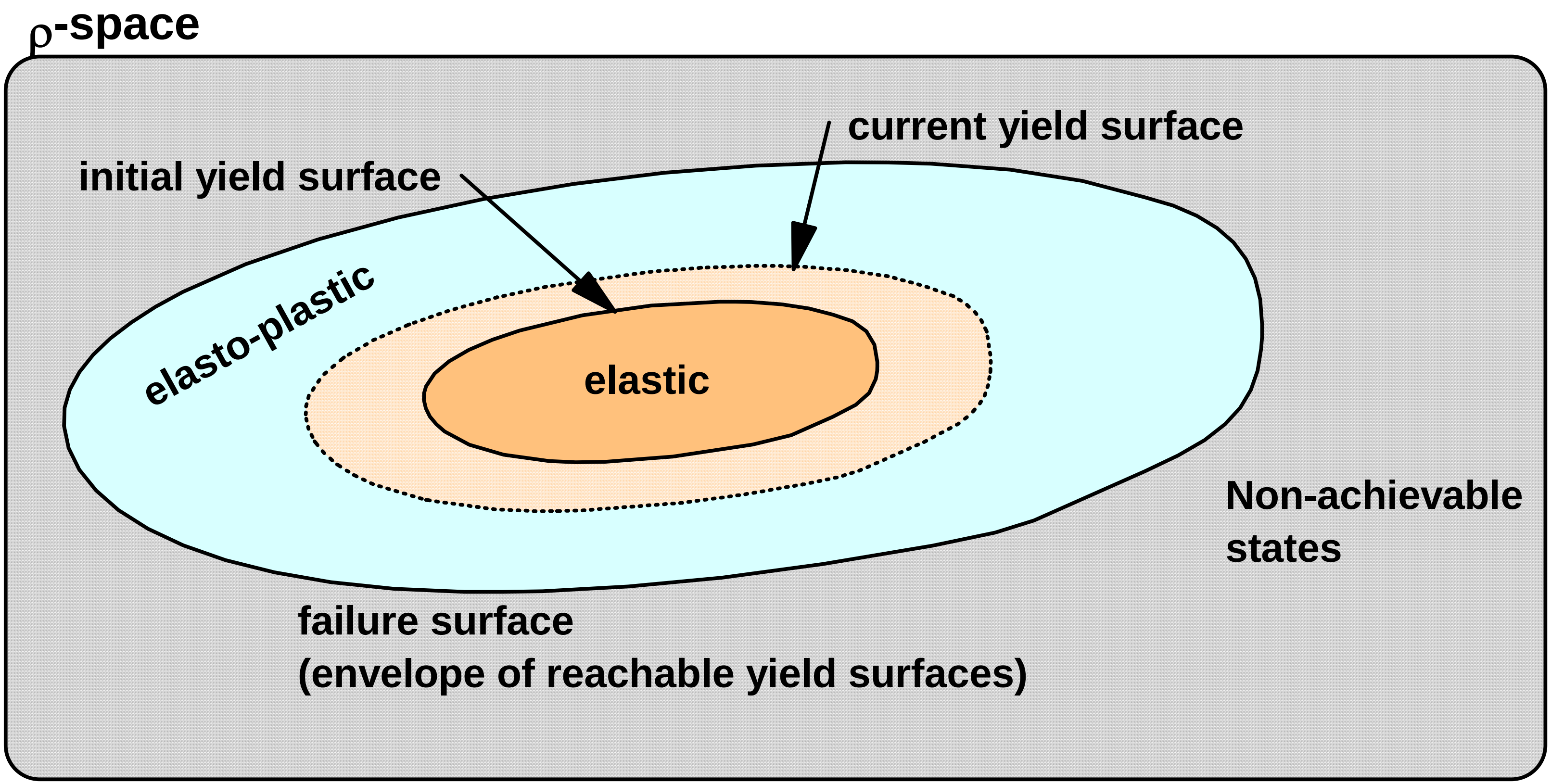
OB: Perfect elasticity
(No irreversible behaviour)

BC: Irreversible changes occur
Successive loading / unloading by different curves. E.g. PQ gives a permanently set deformation ε_0.
QR ≠ PQ, but R still on BC.

CD: Unloading curve ST often results in large permanent deformation. The following load sequence TU meets CD on a lower stress level than S.

Characteristic for brittle matr's, but normally hidden by failure near point C.

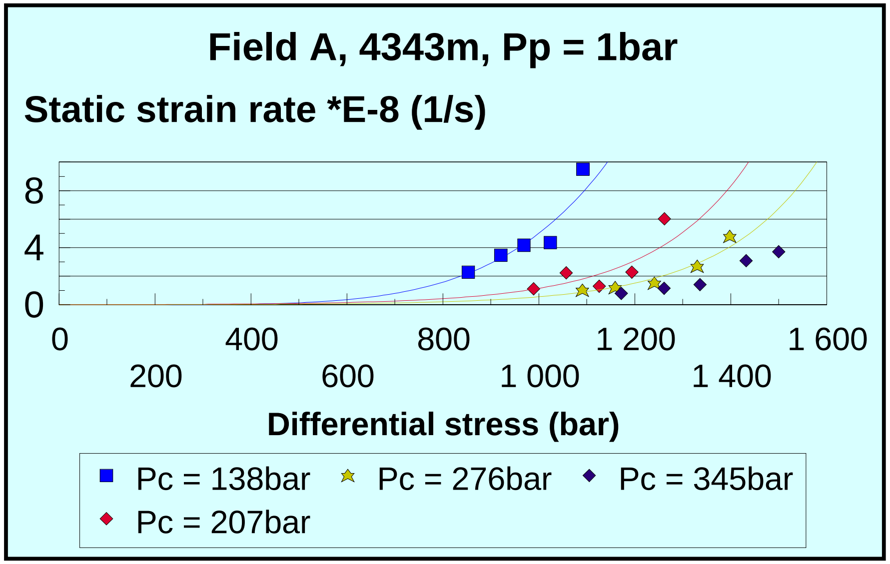
Elasto-plasticity and failure



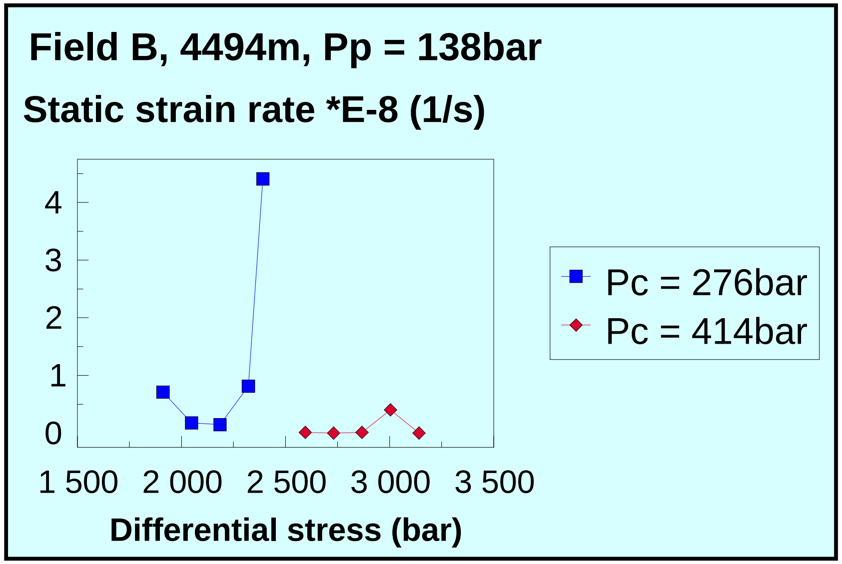
Yield criterion: Specified surface in ρ-space where failure occurs. In elasto-plasticity the yield surface can change with time, as the material hardens.

Ideal plasticity: ***Initial yield surface = failure surface***.

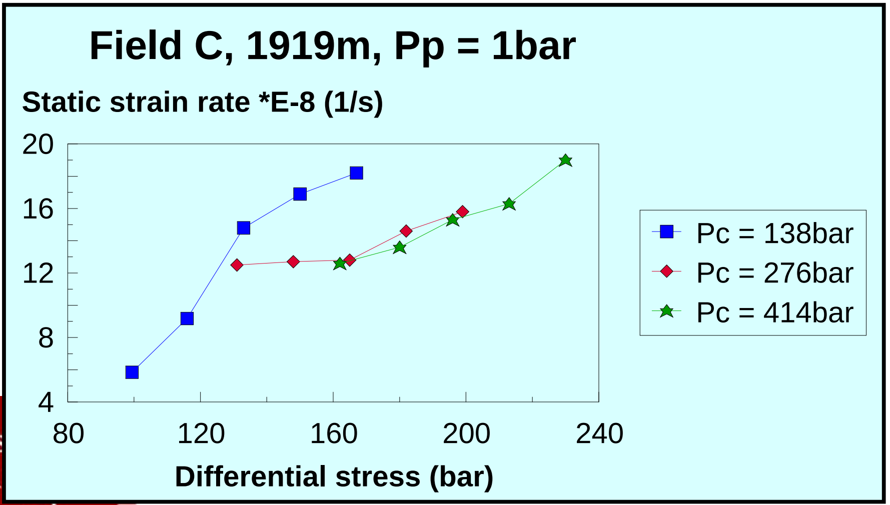
Sand / soil strength (Creep)
Elasticity -> Plasticity -> Failure



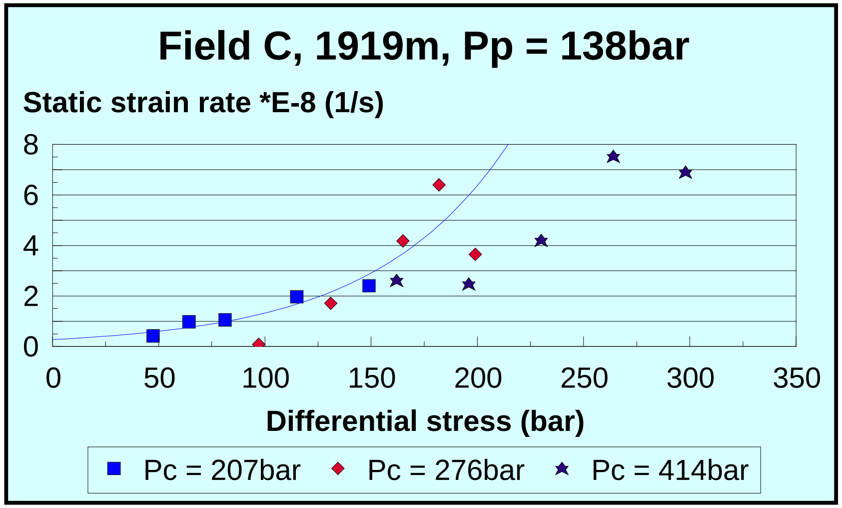
Field A, 4343m, Pp = 1bar



Field B, 4494m, Pp = 138bar

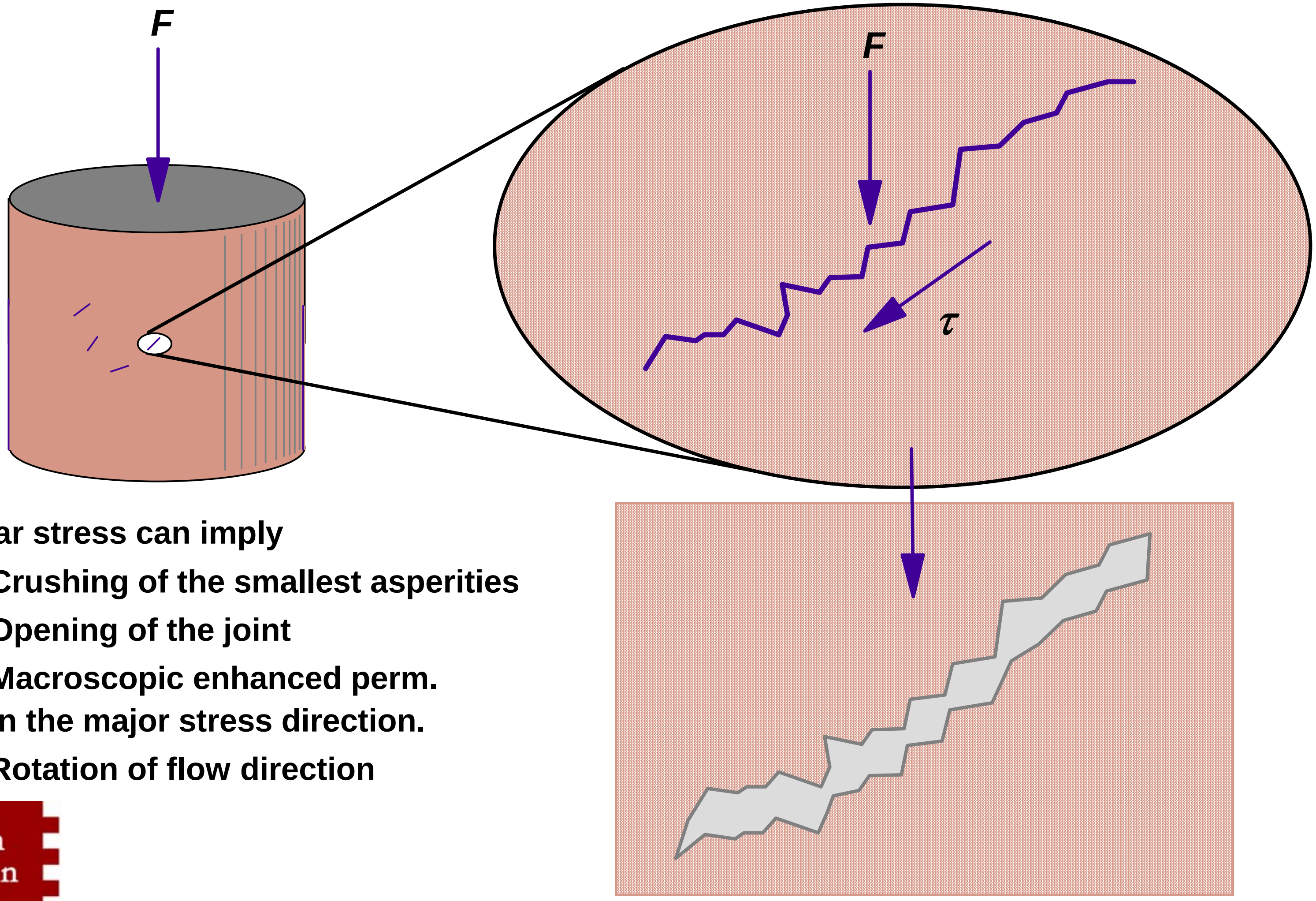


Field C, 1919m, Pp = 1bar



Field C, 1919m, Pp = 138bar

Fluid flow in microfractures (joints) generated by impurities

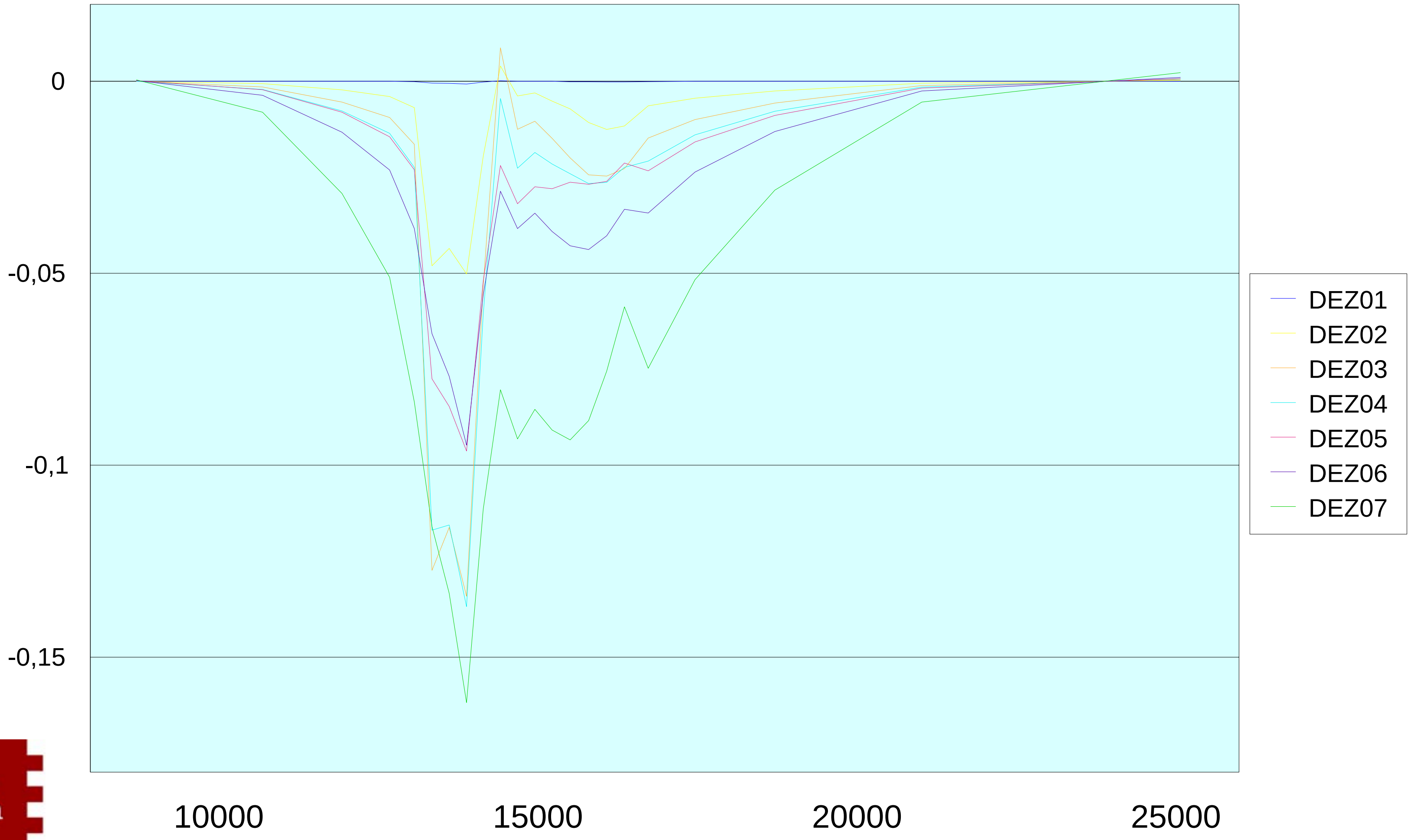


Shear stress can imply

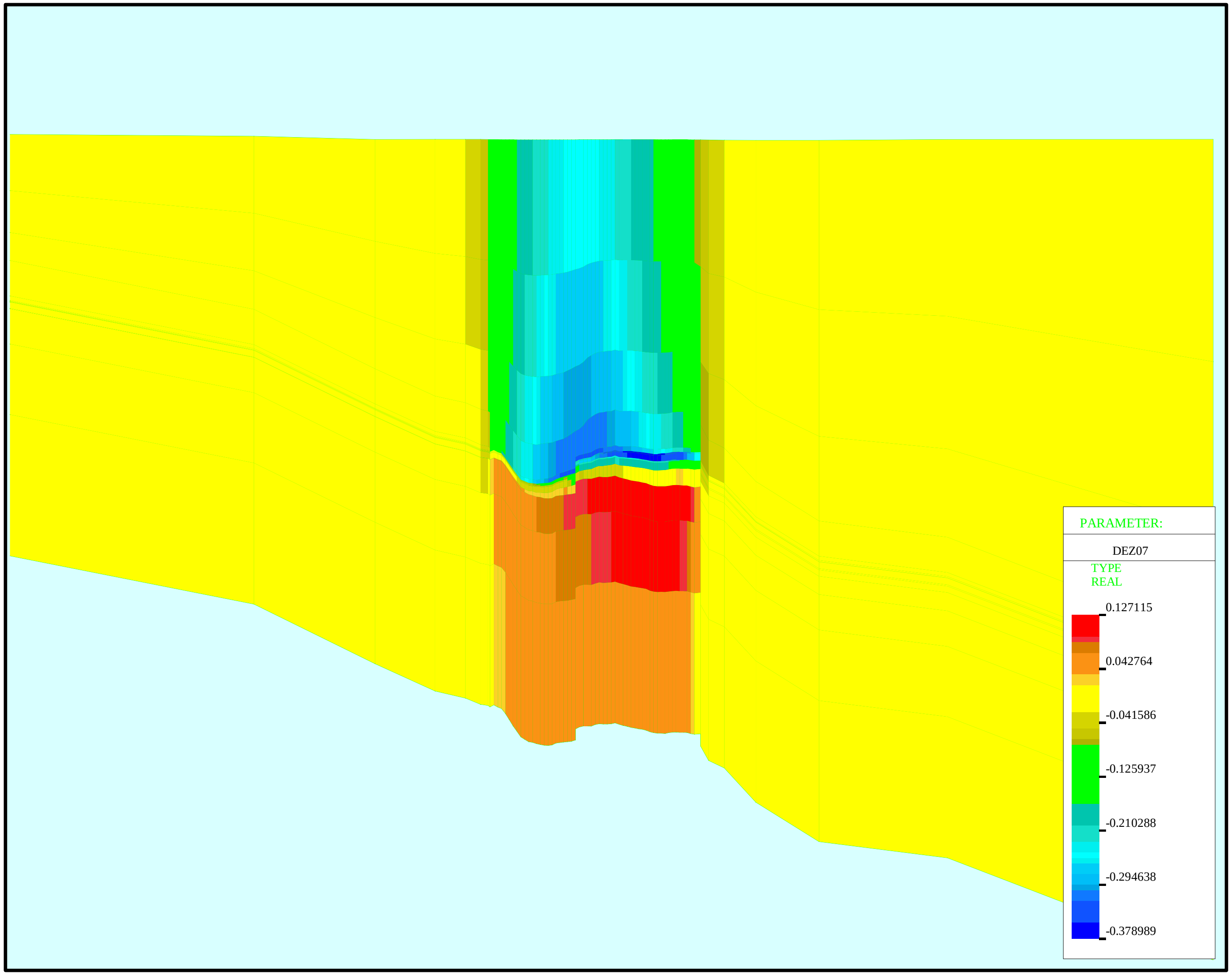
- Crushing of the smallest asperities
- Opening of the joint
- Macroscopic enhanced perm.
  in the major stress direction.

➡ Rotation of flow direction

Field A, Vertical elastic displacement vs. time at top reservoir level



Field A, Vertical Elastic Displacement
N-S section, Time 1517 days (4 yrs 2 mnths)



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Conclusion

Although Newton's laws of motion are perfectly adequate for everyday physics,

no-one would even consider using them at the Planck scale, or at galaxy scale