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Hydrofracking and Hydroshearing: Naturally Fractured Rock Mass Stimulation for EGS

2019 ARMA-CUPB

Geothermal International Conference

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High-Grade Geothermal Energy

Hudson Ranch, Imperial valley, CA, USA

The Four Geothermal Pillars

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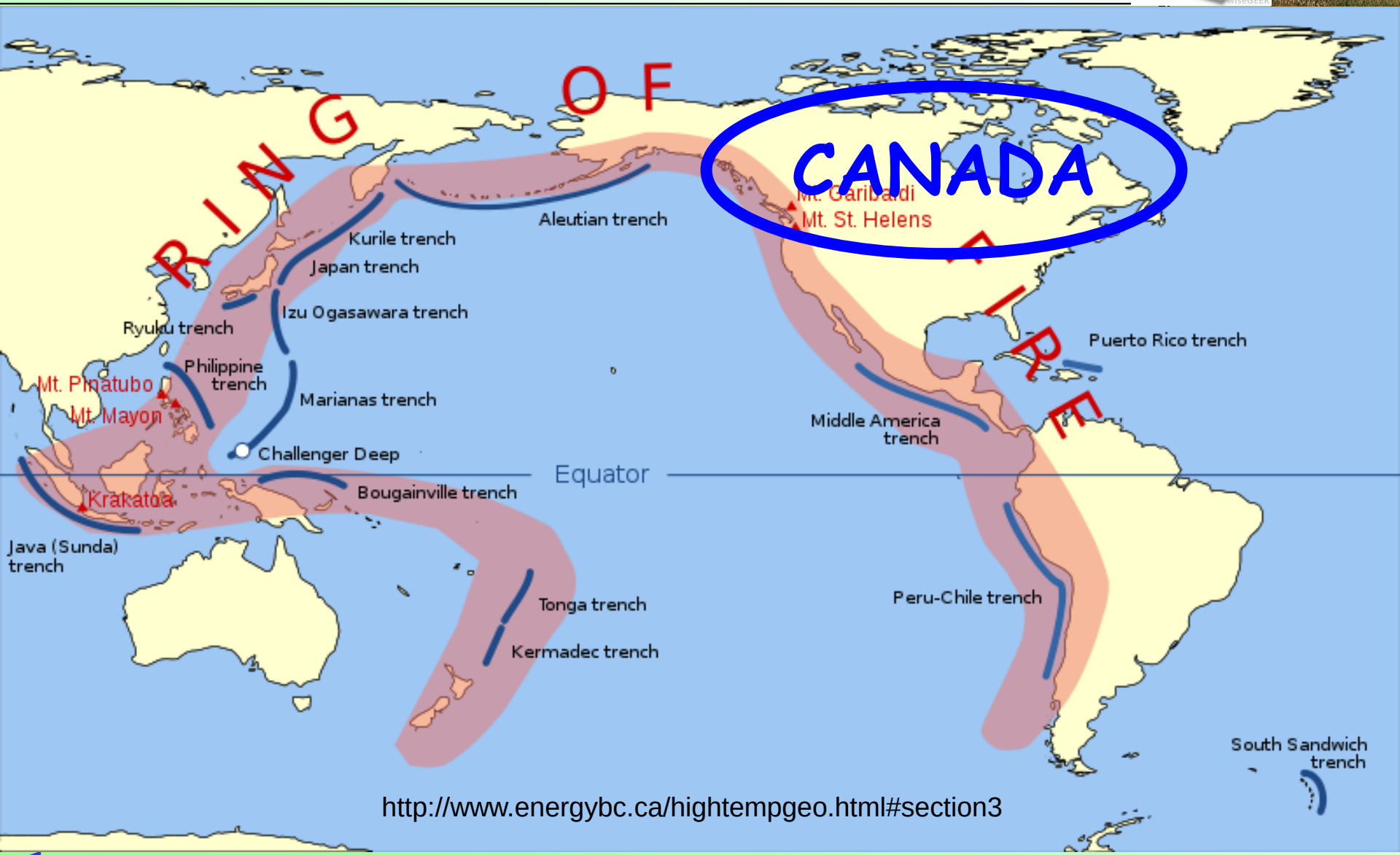
- **High-grade** (steam), power generation
  - ⇨ Dry and wet steam, direct generation of power
- SedHeat for energy in **warm pore fluids**
  - ⇨ 50-140°C liquids, power + heat
- **Hot (warm) dry rock** geothermal – EGS
  - ⇨ 50-300°C low permeability rocks, power and heat
- Heat pump geothermal (GSHP – **storage**)
  - ⇨ Transfer of heat to and from a georepository for cyclic, even seasonal heat storage, perhaps power

High-Grade Geothermal Siting



http://www.energybc.ca/hightempgeo.html#section3

Heating, Cooling, and the Earth…

Political Map of the World, November 2011

Heat is vital (existential)

Seasonal heating & cooling

Polar and subpolar zone
Temperate zone
Subtropical zone
Tropical zone

Cooling is desirable

Seasonal heating & cooling

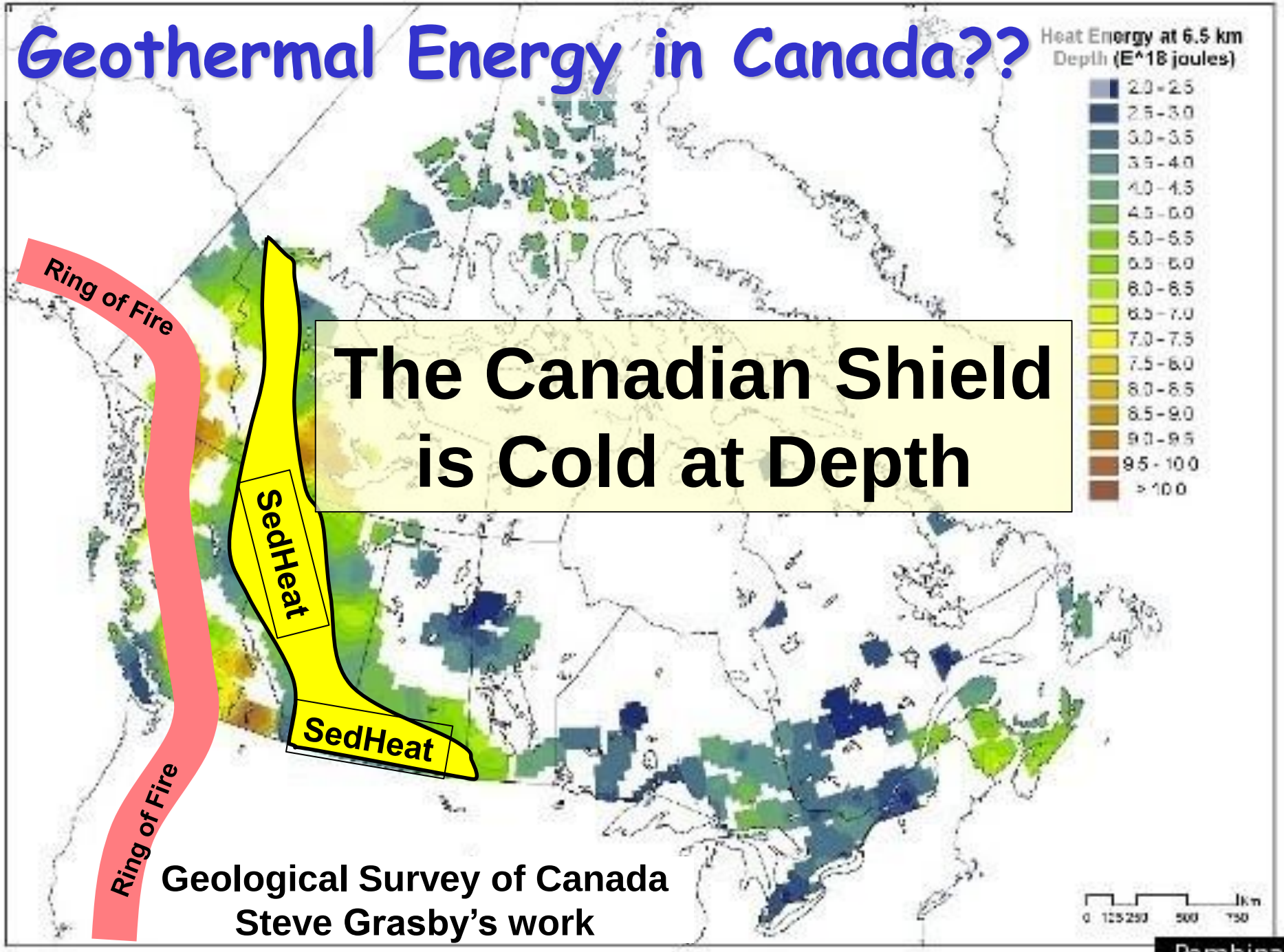
And everyone wants a bit of power…

Generally…

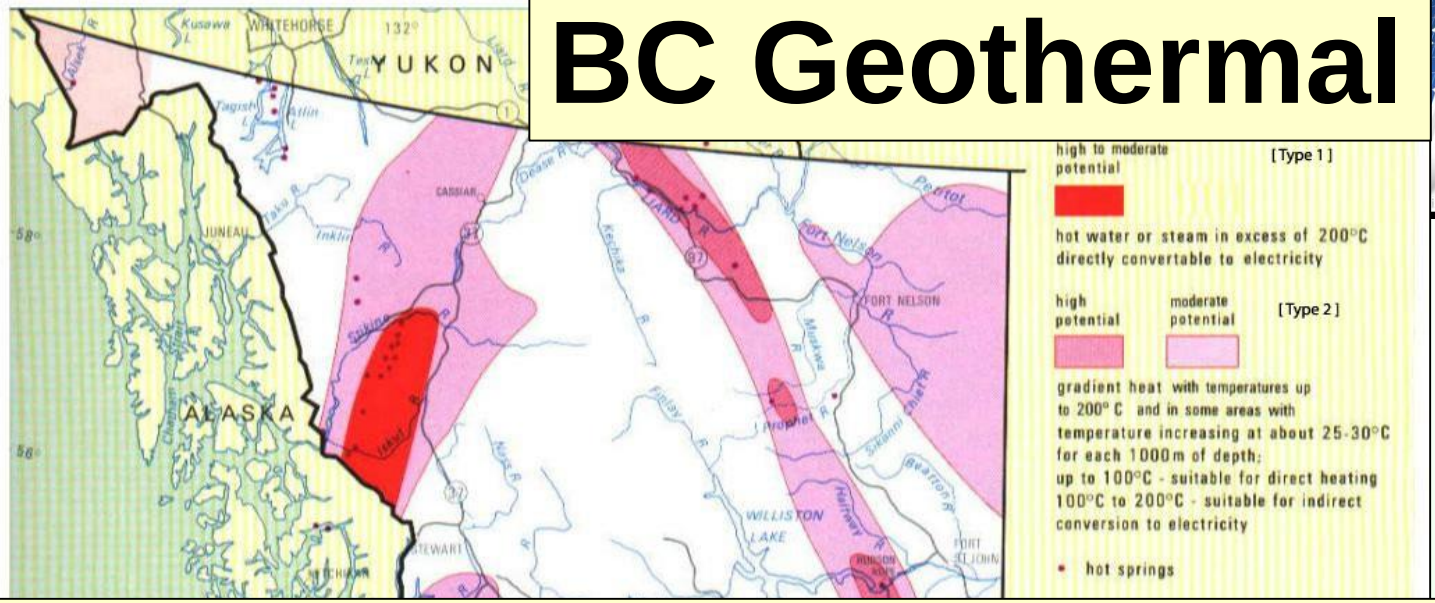
- 600 million people need heat (mainly)
- 3 billion people need cooling (mainly)
- 3 billion people desire both, seasonally
- Everyone wants some power

The geothermal focus has been power: heat provision secondary, cooling largely ignored

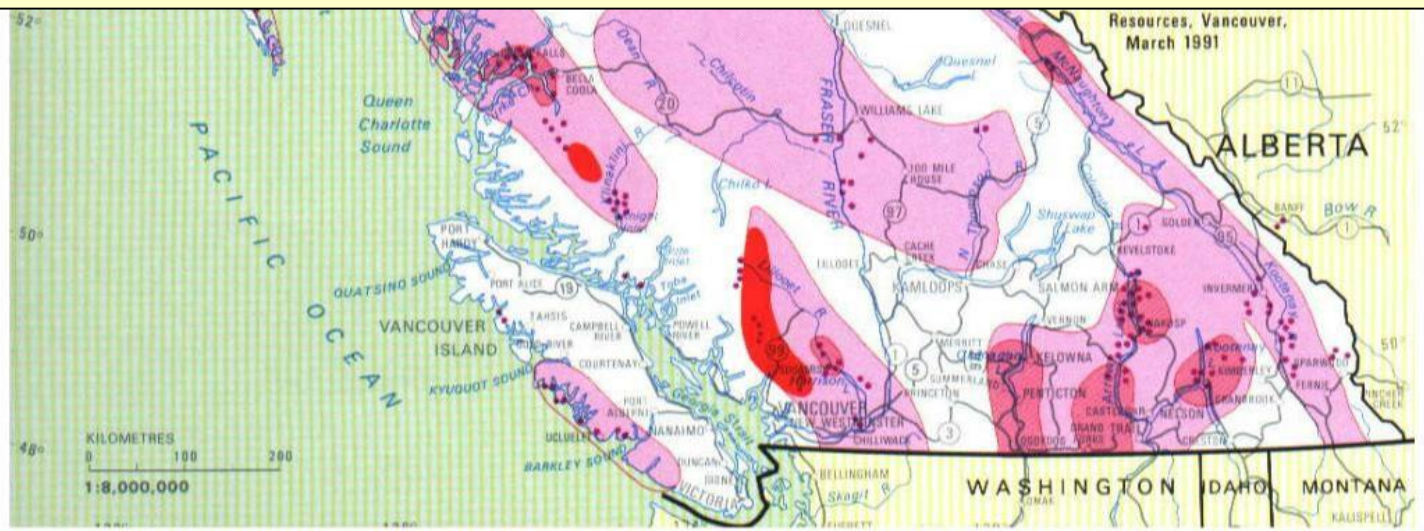
Geothermal Energy in Canada??



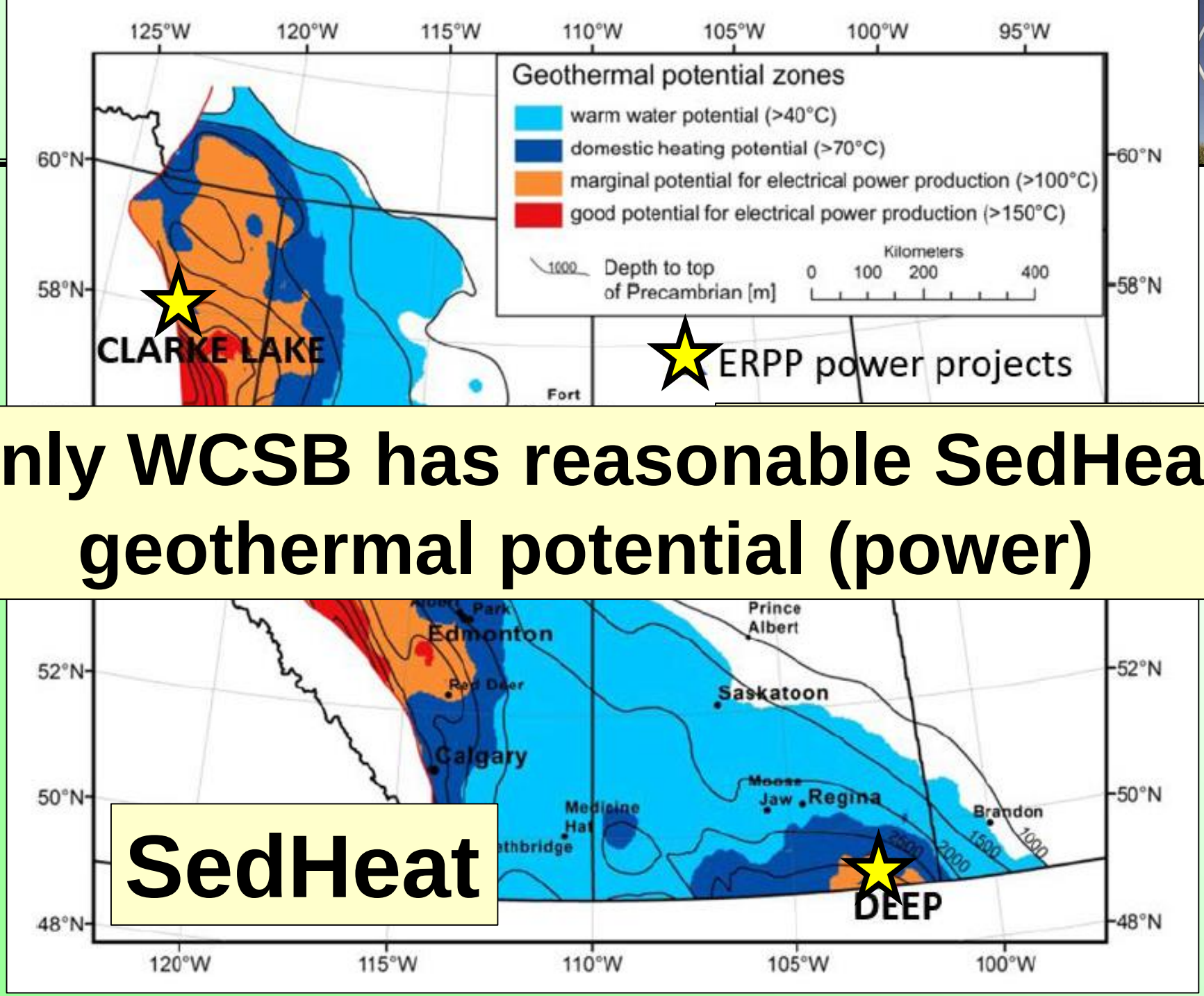
BC Geothermal



Only BC & Yukon have high-grade geothermal potential (power)



ARMA-CUP – HF and HS for EGS

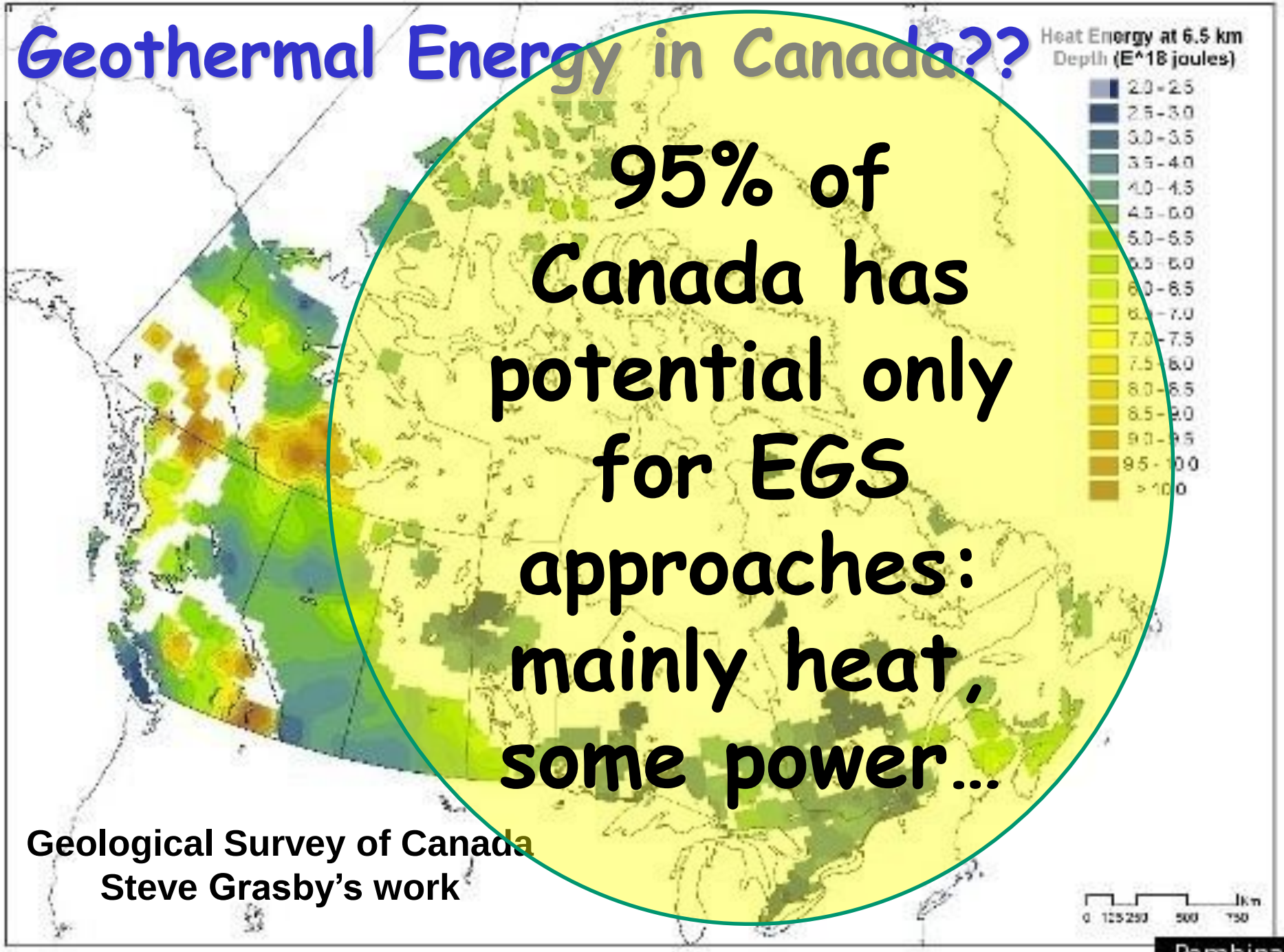


Only WCSB has reasonable SedHeat geothermal potential (power)

SedHeat

ARMA-CUP – HF and HS for

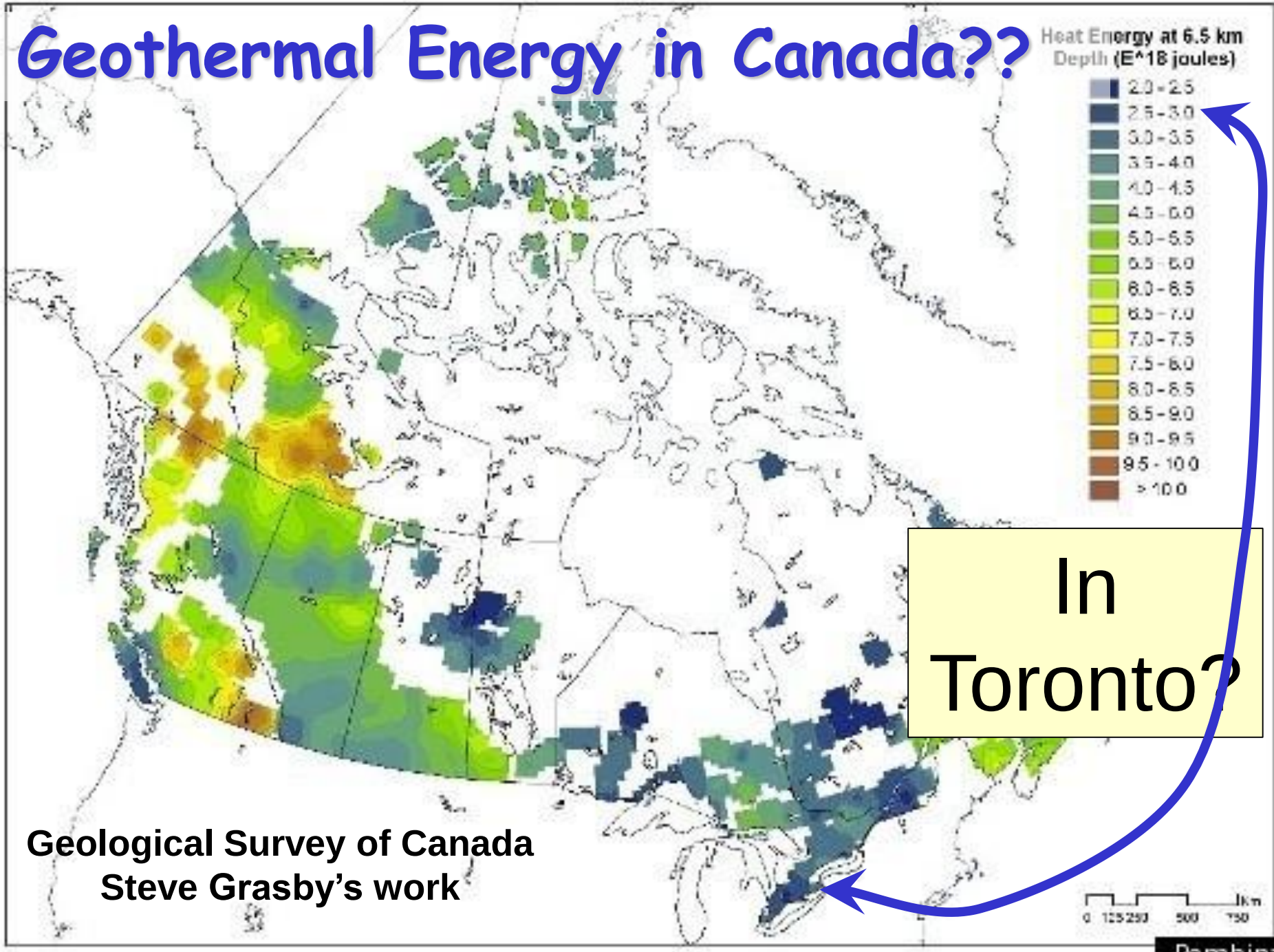
Geothermal Energy in Canada??



95% of Canada has potential only for EGS approaches: mainly heat, some power…

Geological Survey of Canada
Steve Grasby's work

Geothermal Energy in Canada??



Geothermal Methods…

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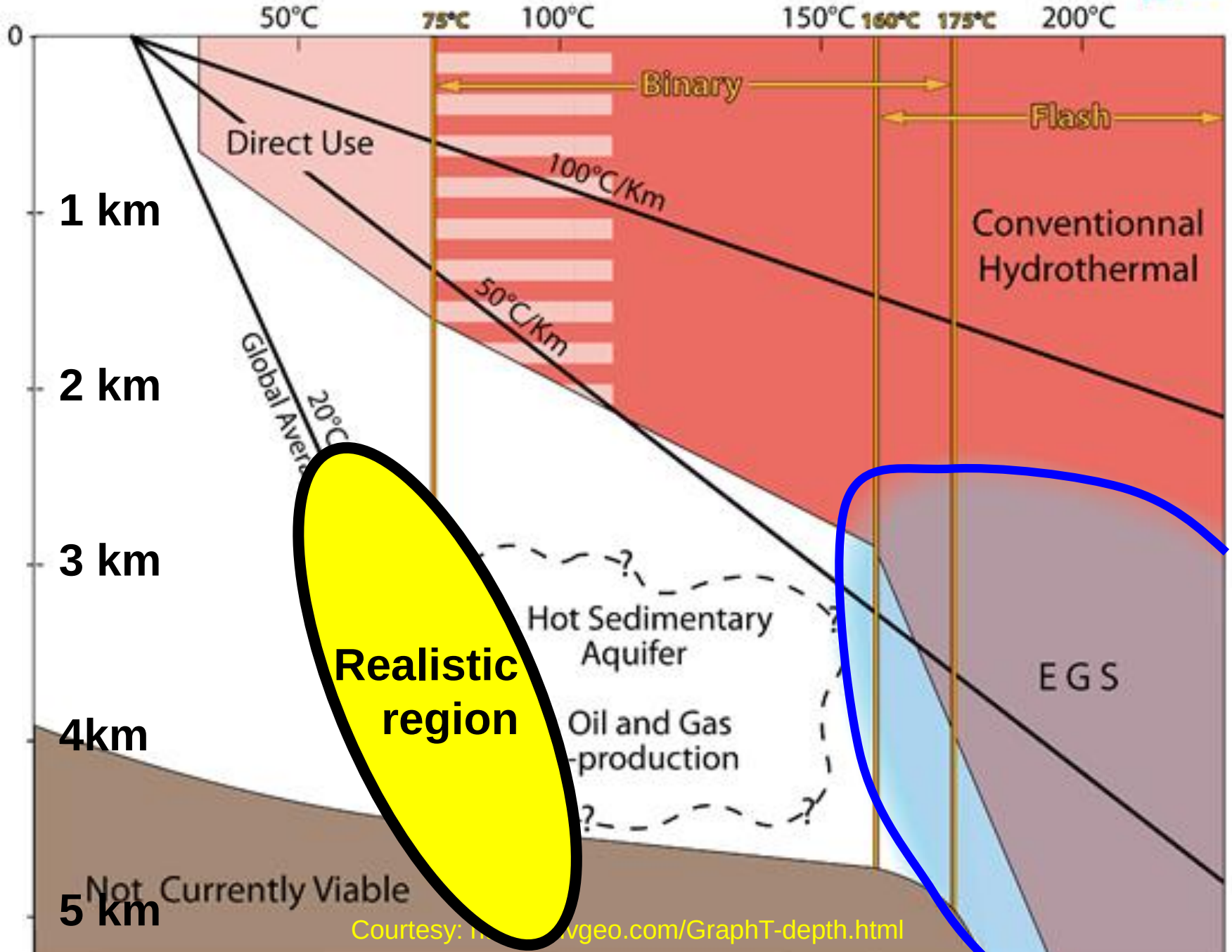
- Deep, High-T Geothermal or SedHeat?
- Not in 95% of Canada!
- Shallow local geothermal with heat pumps is used - energy storage
- EGS – Enhanced Geothermal Systems
  - ⇨ "Intermediate-grade" thermal energy
  - ⇨ "Heat mining" at depths of > 4 km (T > 70°C)
  - ⇨ Large volumes of rock, but little water…
- EGS possibilities?
- Rock mass stimulation?

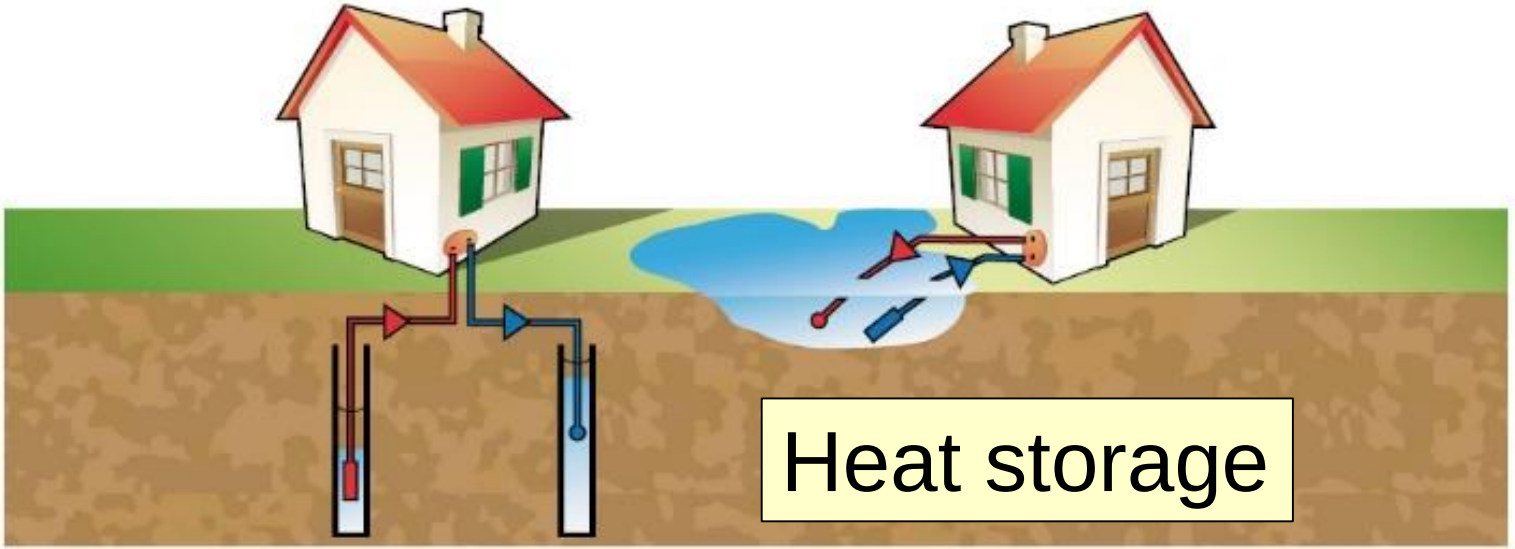
ZxT for Geothermal Resources



Courtesy: [illegible]vgeo.com/GraphT-depth.html

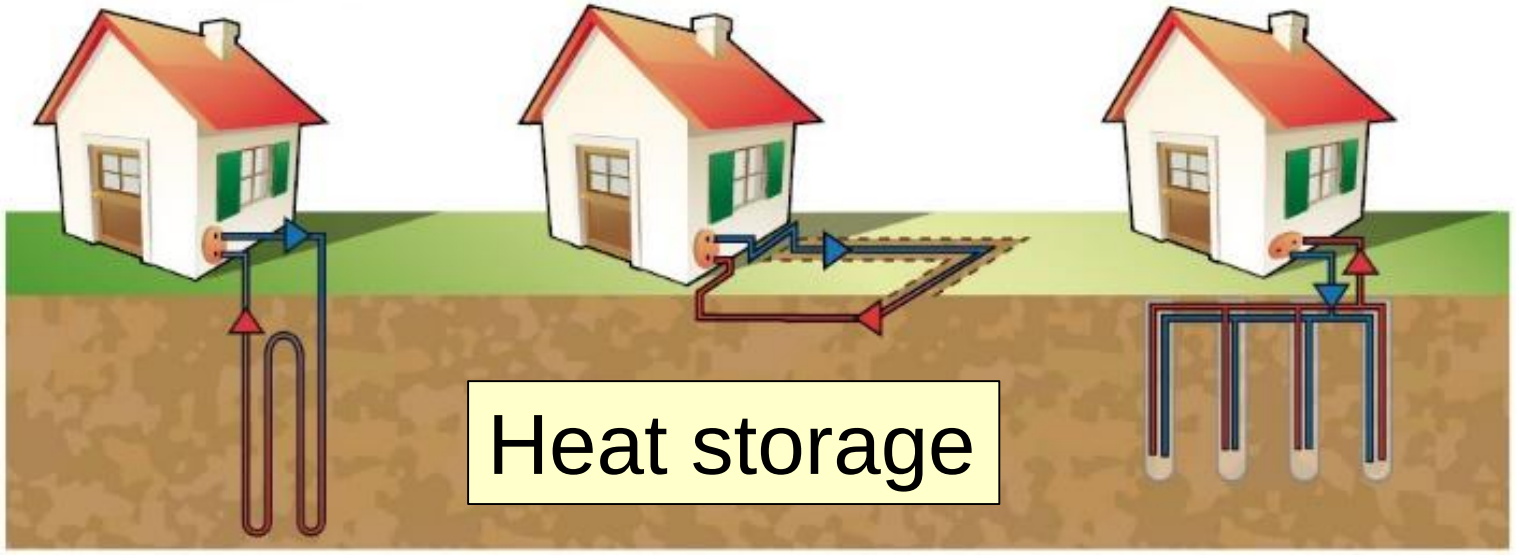
http://iter-geo.eu/shallow-geothermal-systems-how-extract-inject-heat-into-ground/

open loop system



2 wells *water body*

closed loop system



vertical *horizontal* *geothermal piles*

GSHP T-Balance

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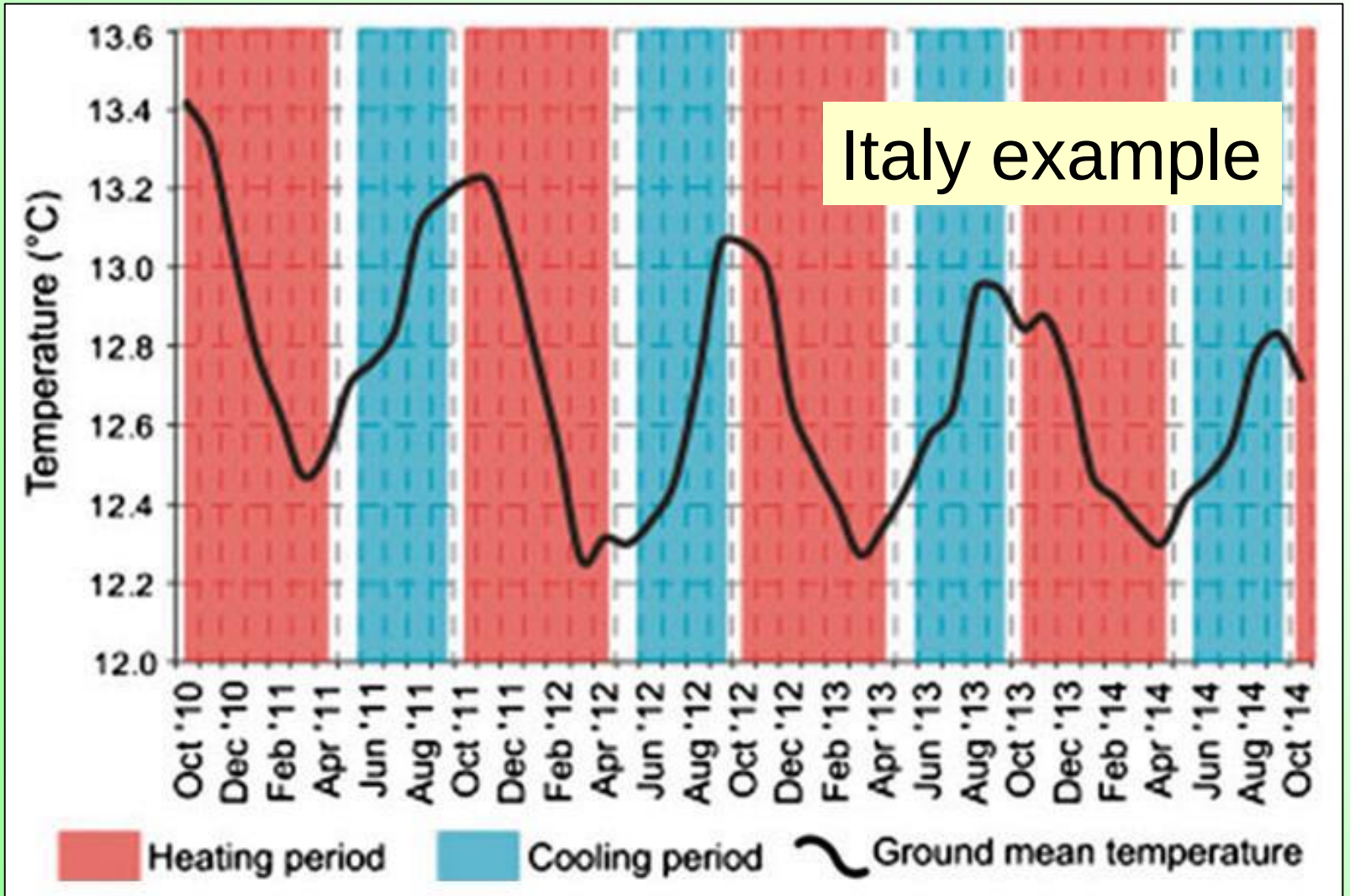
- Heating dominates in the north



So Here is the Problem…

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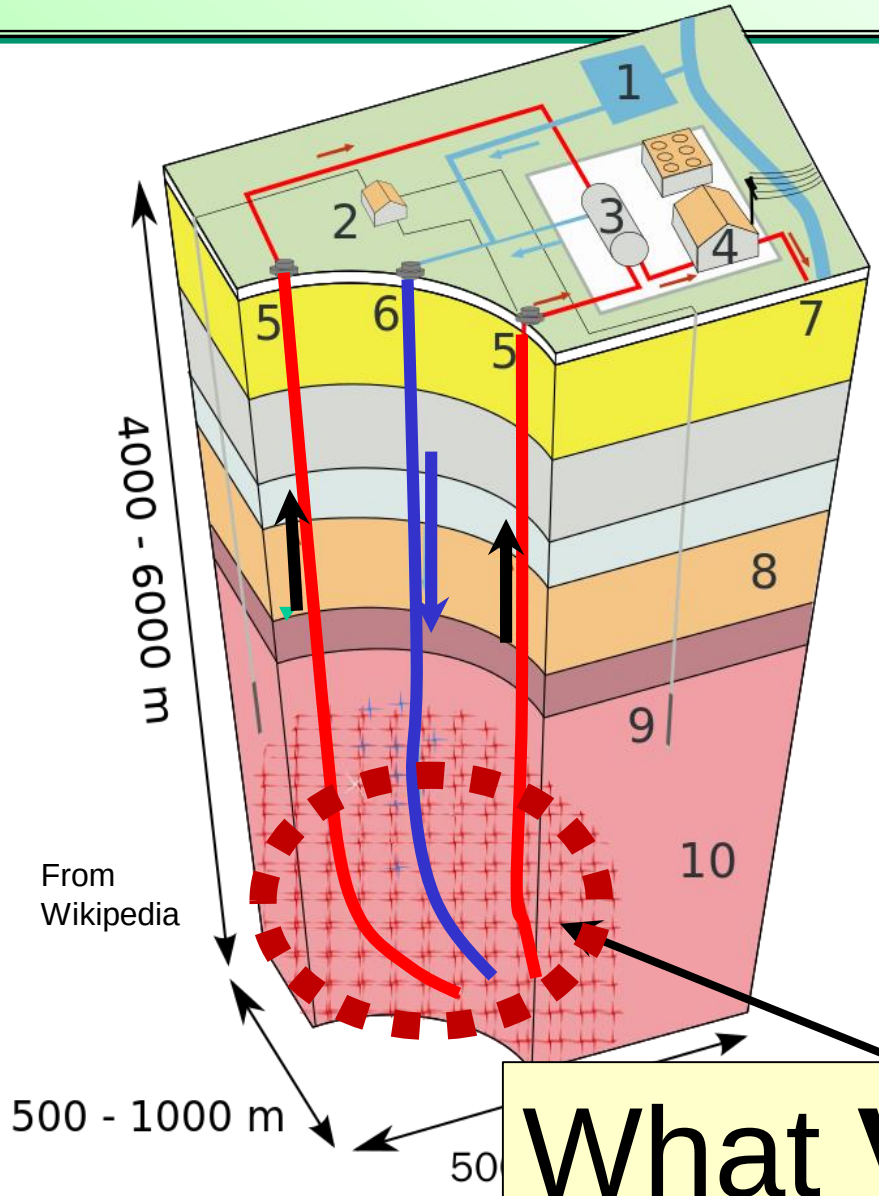
- Conventional co-generation – **power + heat** – needs T > 75°C
- And we need to drill at least 3-4 km deep
- Shallow geothermal (GSHP) alone does not work in extreme climates as the ground heats or cools too much over time
- It seems that shallow geothermal and EGS coupled may help address issues…
- But heat (or cool) storage will be necessary in extreme climates – hence **Q**

The EGS Concept…



From Wikipedia

1 Water lagoon
2 Pump house
3 Heat exchanger
4 Turbine hall
5 Production well
6 Injection well
7 Hot H_2O to district heating
8 Porous sediments
9 Observation well
10 Crystalline bedrock

What **V, Q** are needed?

EGS and SedHeat Geothermal

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- EGS from hot, dry rock
  - ⇨ Little to **no intrinsic permeability**
  - ⇨ Heat exchange to a working (circulating) fluid is needed (convection is too slow)
  - ⇨ Rock mass **permeability must be increased**
  - ⇨ At least two wellbores are needed
- SedHeat from hot sedimentary fluids
  - ⇨ Reservoir fluid must be hot enough
  - ⇨ …and **rock permeable enough**
  - ⇨ Can be integrated with O&G operations
  - ⇨ Single deep well may suffice, with shallow disposal

Q - Heat Flux

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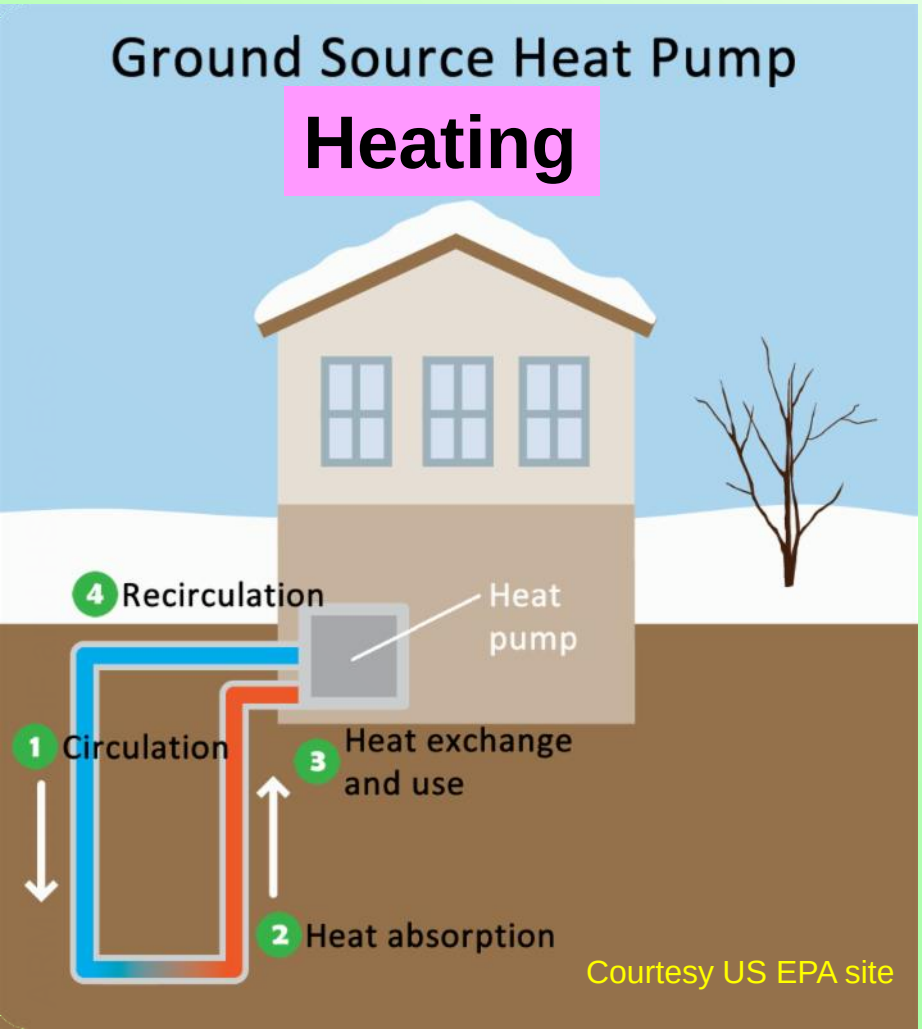
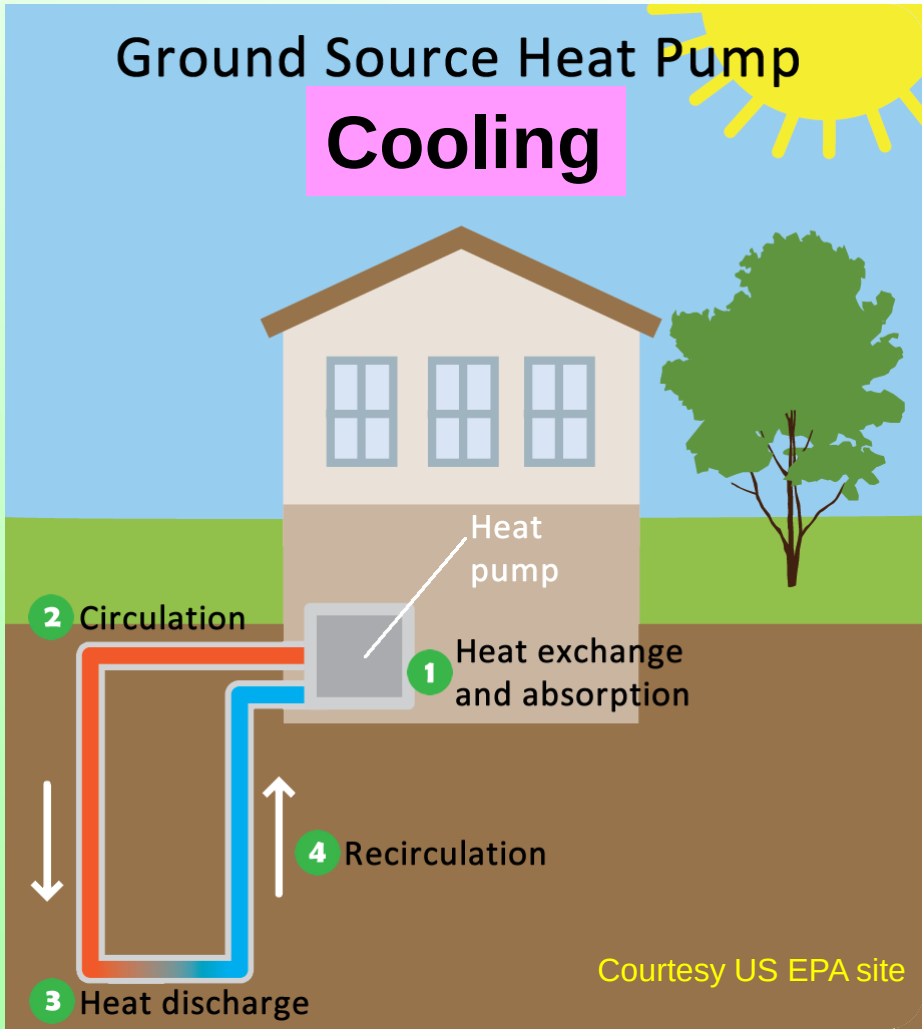
- Q - heat flux controls commerciality





Heat Flux by Pure Conduction

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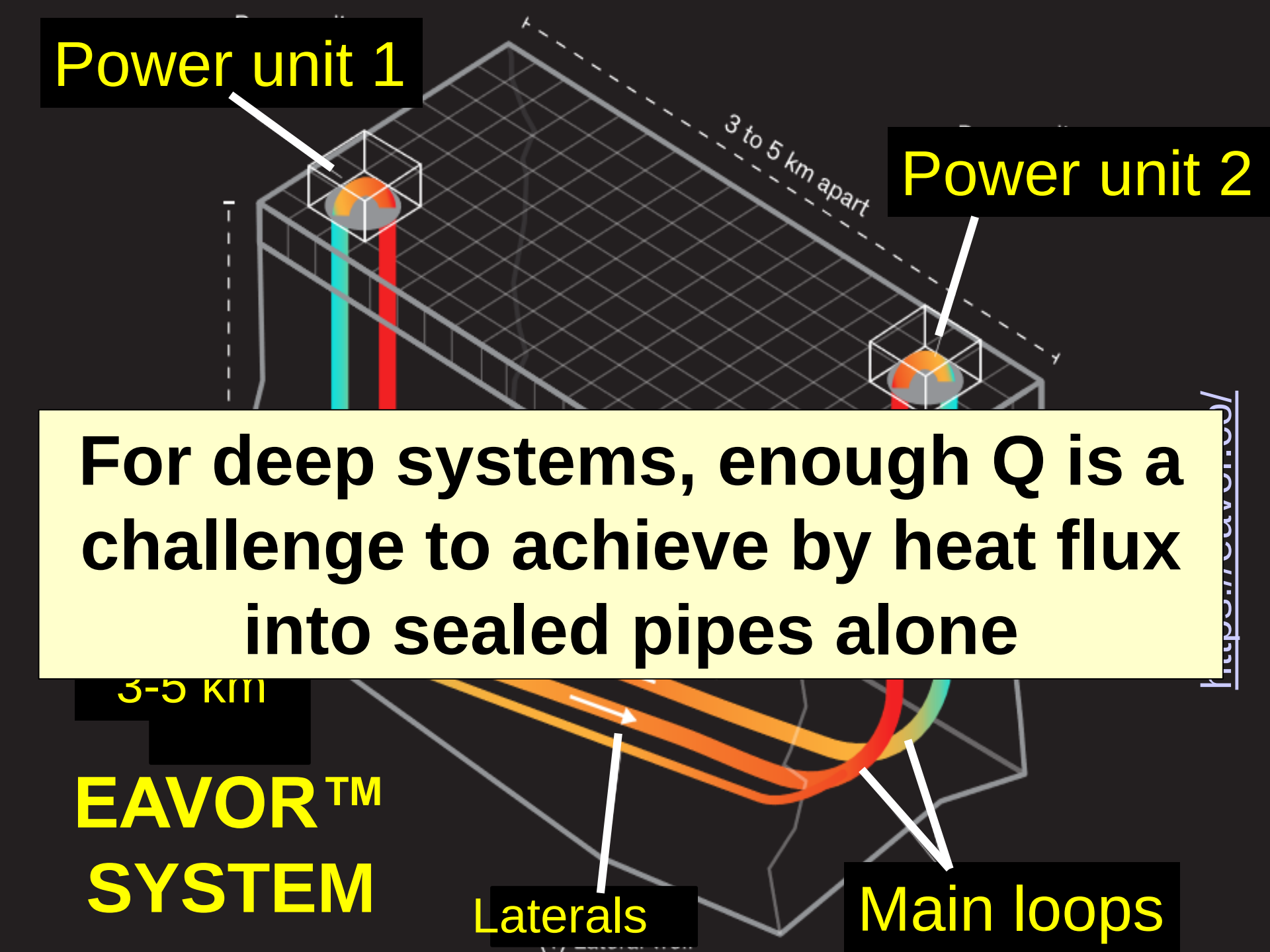
- Closed pipe system
- Heat transfer fluid circulated in pipes
- Fluid heated through conductive heat flux from the rock mass to the pipe
- Classic diffusion problem…
- Heat flux depends on T-gradient
- …but this drops quickly! So…
- …pipes must be very long for a long life.
- Can this be commercial for EGS?



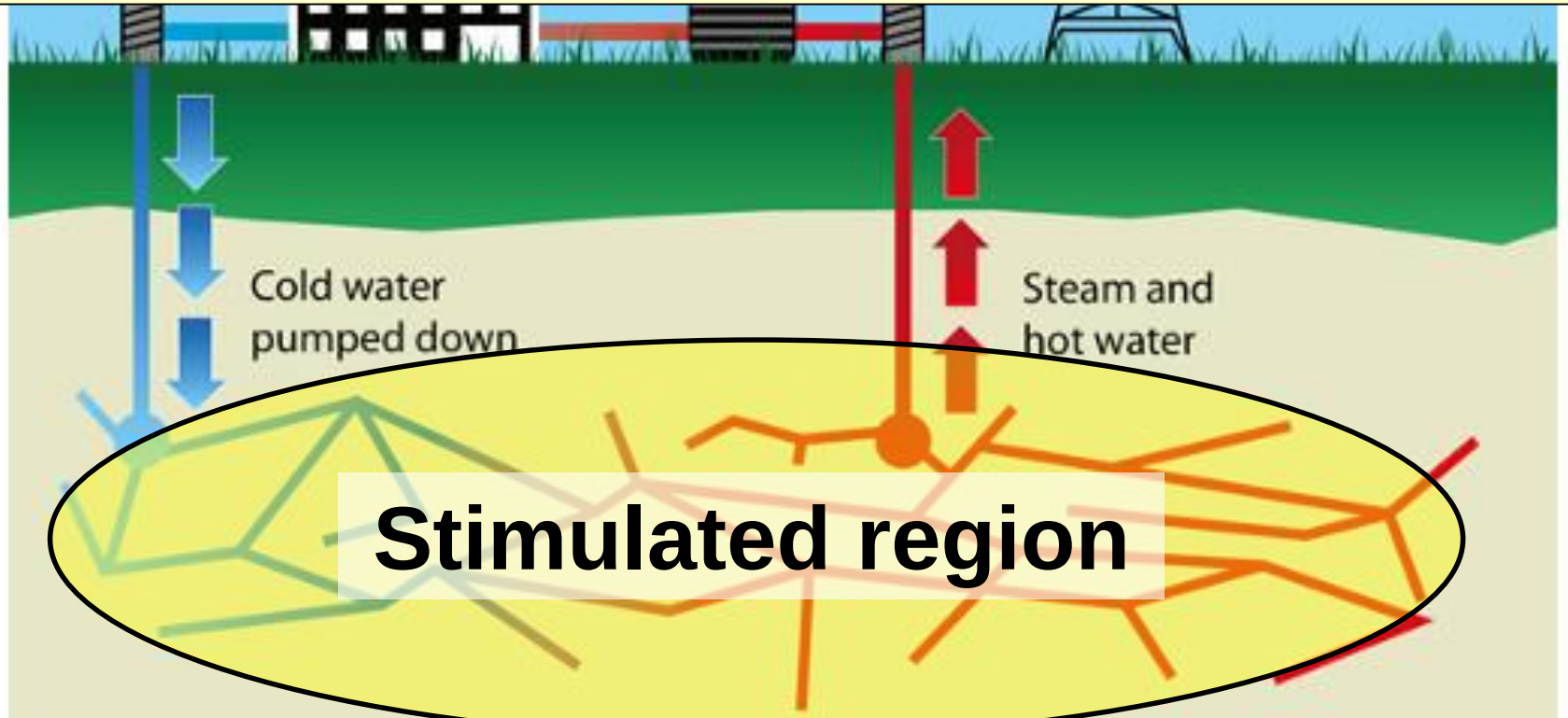
For deep systems, enough Q is a challenge to achieve by heat flux into sealed pipes alone

Some Interim Conclusions…

Purely **conductive Q** to and from a deep rock mass remains a possibility… (e.g. https://eavor.co/ technology)

…but EGS and many SedHeat cases require **stimulation** and **fluid flow** in the rock mass to achieve commercial levels of **Q**

Stimulation and fluid flow through the rock mass needed for EGS...



http://ieet.org/index.php/IEET/mor

What Controls Q over Years?

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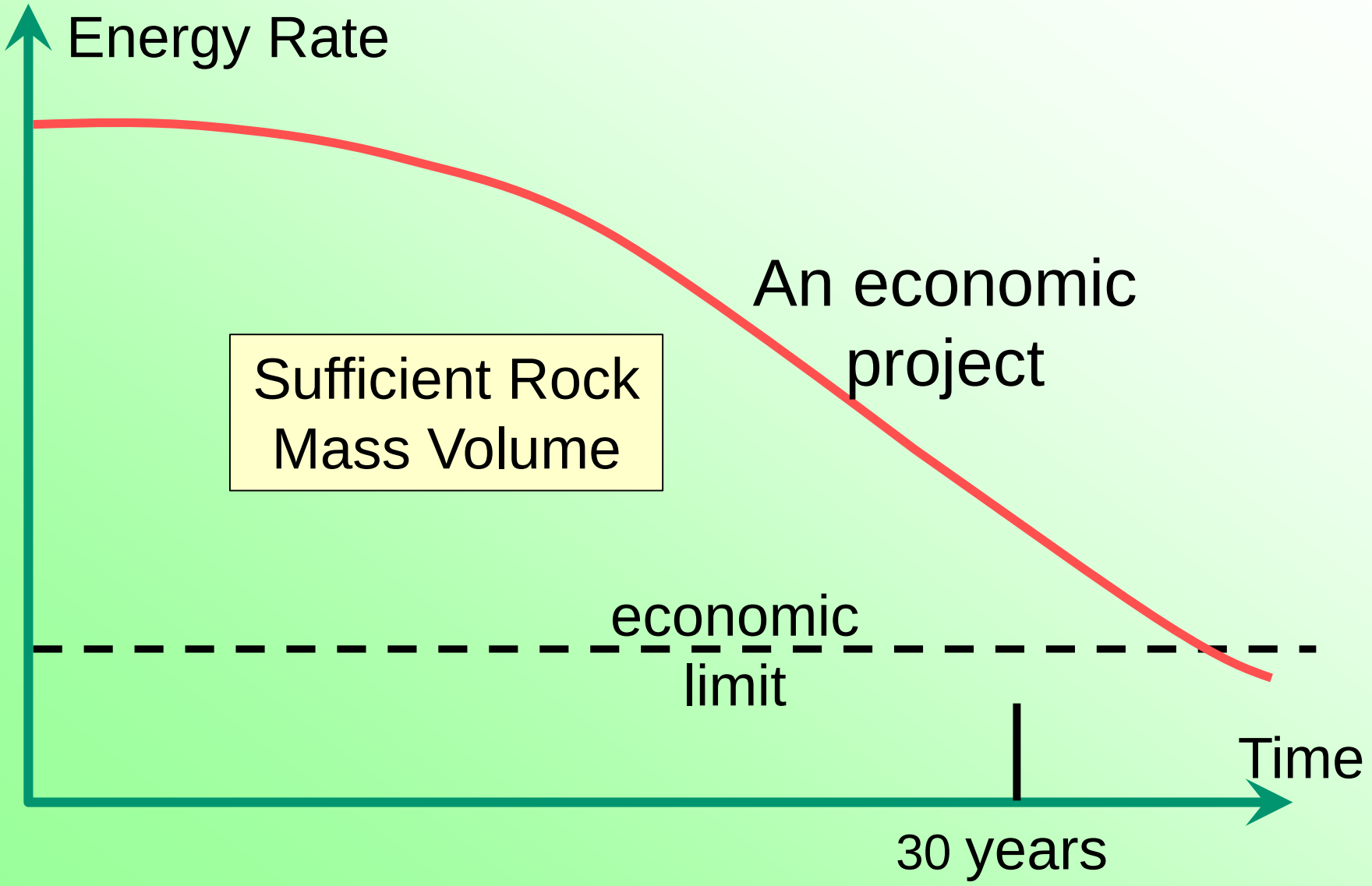
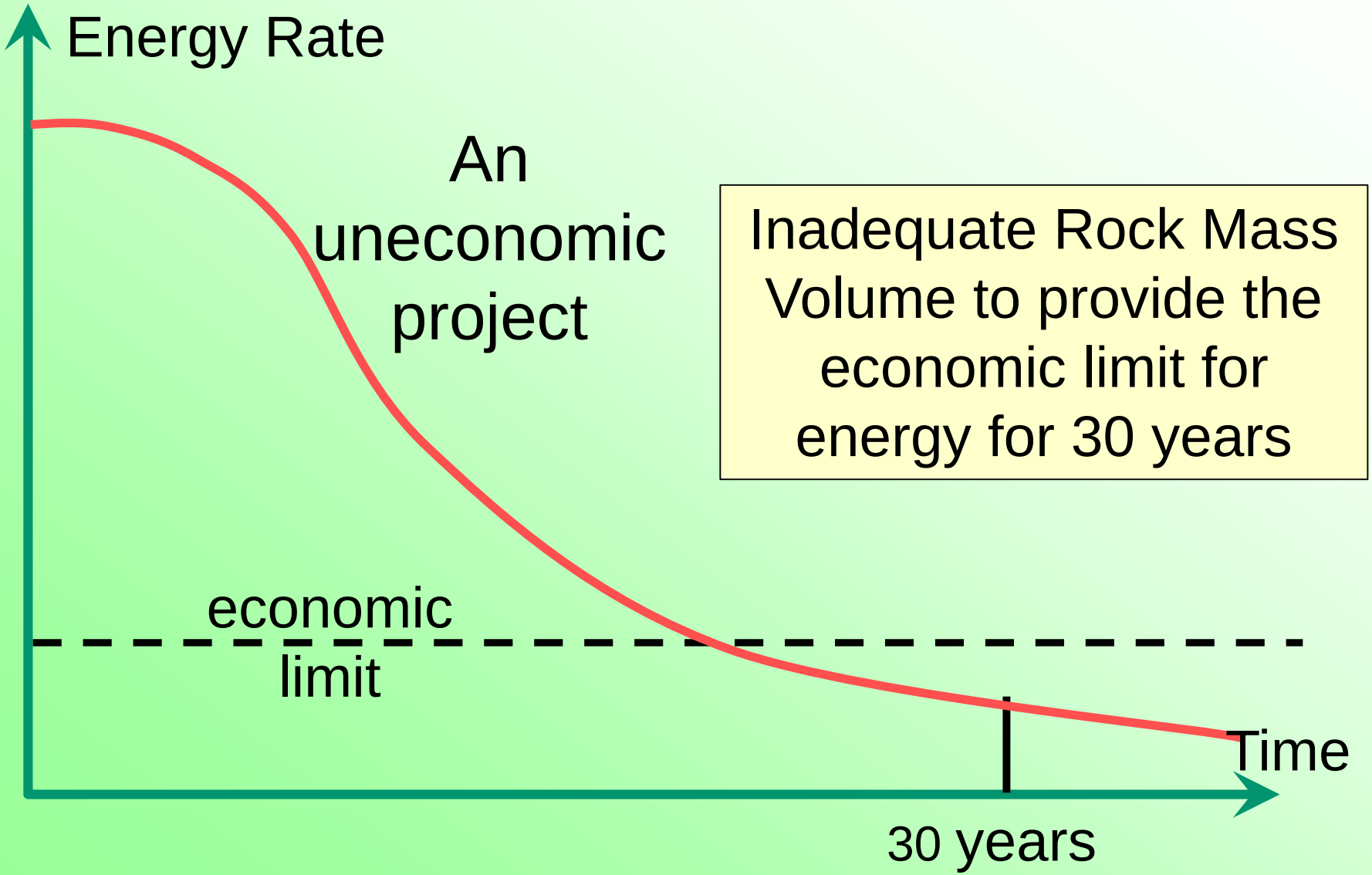
- Accessible **Rock Volume**
- **Flow Rate** of the fluid
- Pathway **Spacing and Aperture (Area)**
- **ΔT** between fluid and rock mass
- **Changes in Pathway Aperture** with time (thermoelastic stress-strain response)

Problem: cooling increases pathway aperture, such that one pathway becomes dominant with time…

Q. Time and Economics



Q. Time and Economics



Our EGS Challenges…

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- Predict reliably
  - ⇨ Can you model 30 years of **Q** behavior with P90?
- Drill cheaply
  - ⇨ Good news: new technology is lowering costs
- Stimulate effectively
  - ⇨ Can you stimulate for 30 years of **Q**?
  - ⇨ …with P90?

Unless you have a 90% success probability, the project will not begin

7 km Deep Drilling Rig…

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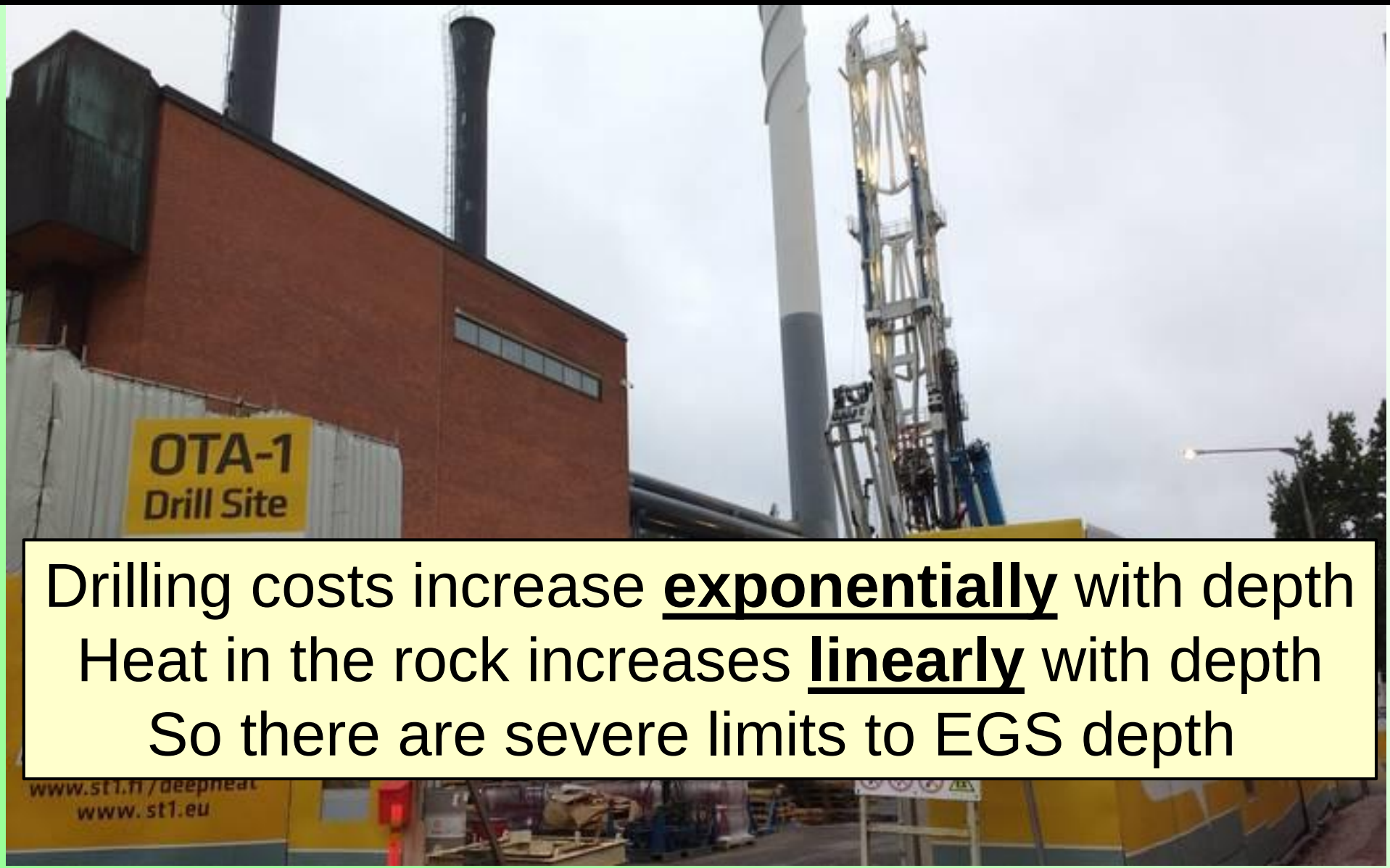
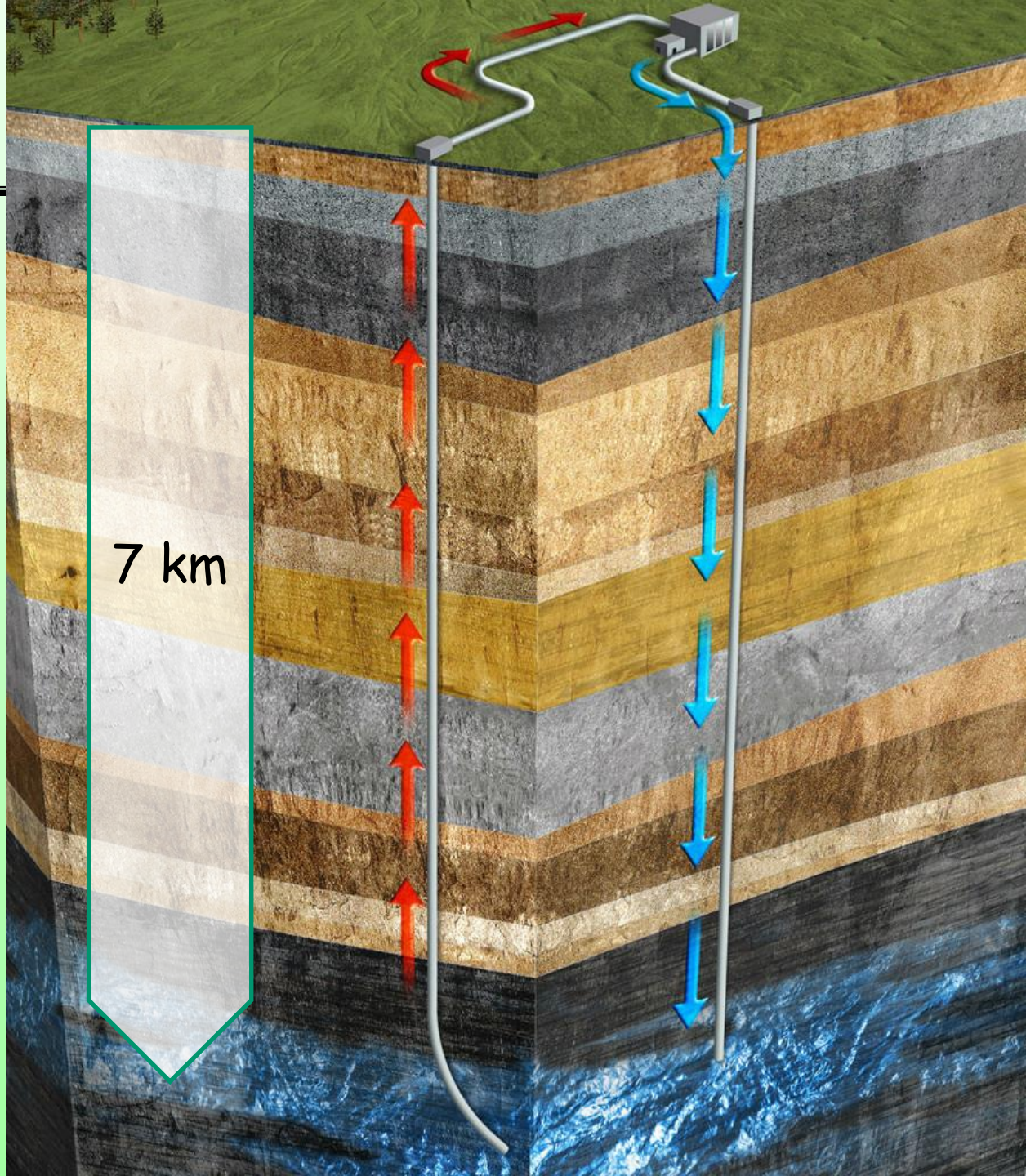


Drilling costs increase **exponentially** with depth
Heat in the rock increases **linearly** with depth
So there are severe limits to EGS depth

7 km deep 40 MW granite

Finland

OTA-1 drill site concept



Strada Energy

- Geothermal drilling
- Claims up to 25 m/hr in granite at 1 km depth, air hammer
- Double drill pipe, reverse circulation
- Espoo project – 7 km deep, 2 wells
- 40 MW **heating**


First well
completed
this year

Drilling Costs

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- The primary cost factor in EGS
- With air and water hammer drilling, technology advances means that $dz/dt]_{ave} \rightarrow$ 4-5 m/hr might be possible
- This means that a 4 km hole would take 50 days (including surface casing, logging, running deep casing…)
- …other methods (rotary, plasma…)?
- …and with modern rigs, there is more and more automation – so… **STAY TUNED**

Realistic Stimulation Options?

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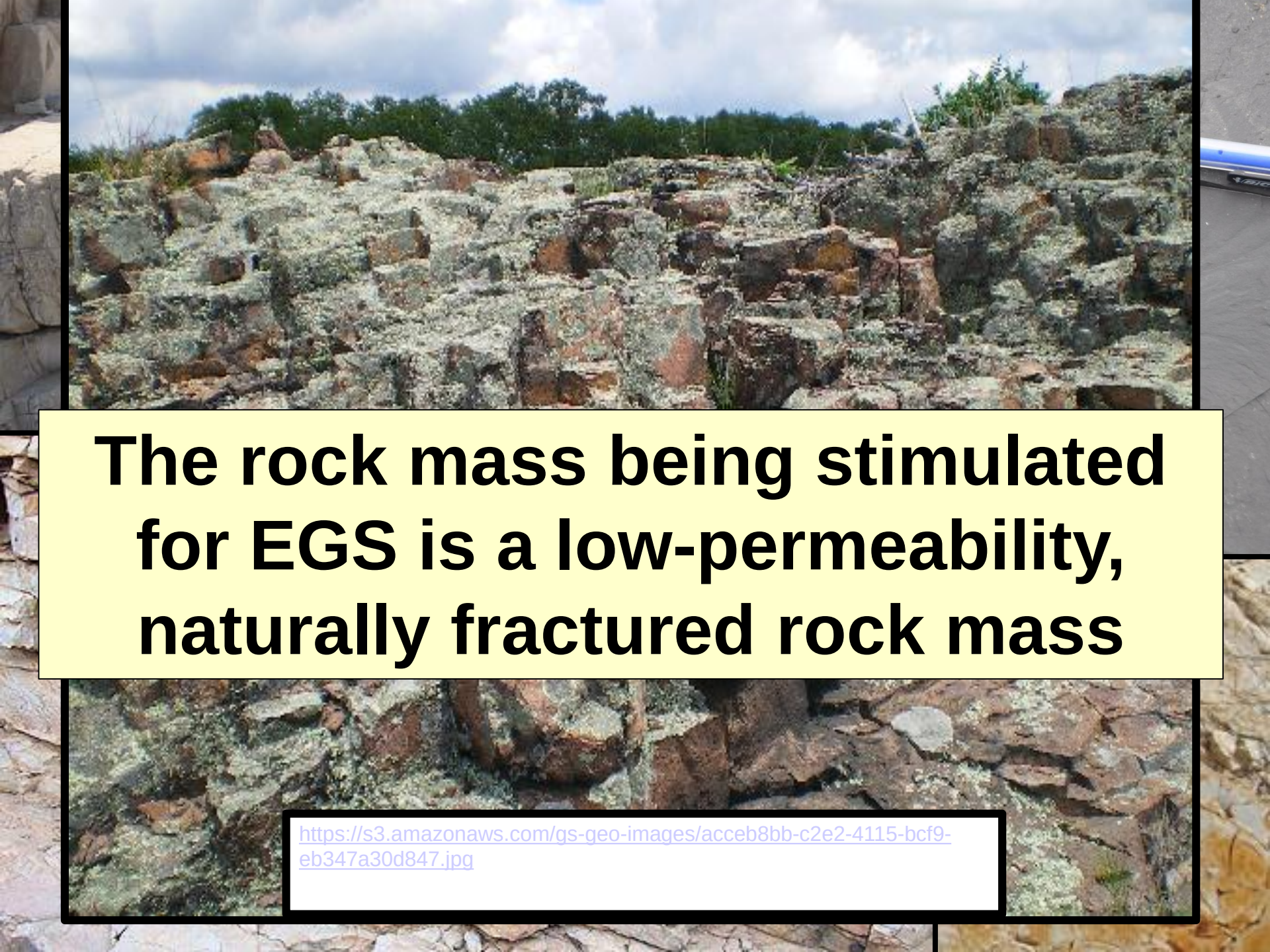
- **Hydraulic fracturing** (HF) to open pathways for conductive - convective heat flux from a large rock mass volume
- **Hydroshearing** (HS) to generate shear and dilation for conductive/convective heat flux from a large rock mass volume

Rankine Cycle engines for some power

Direct heat use for buildings and homes

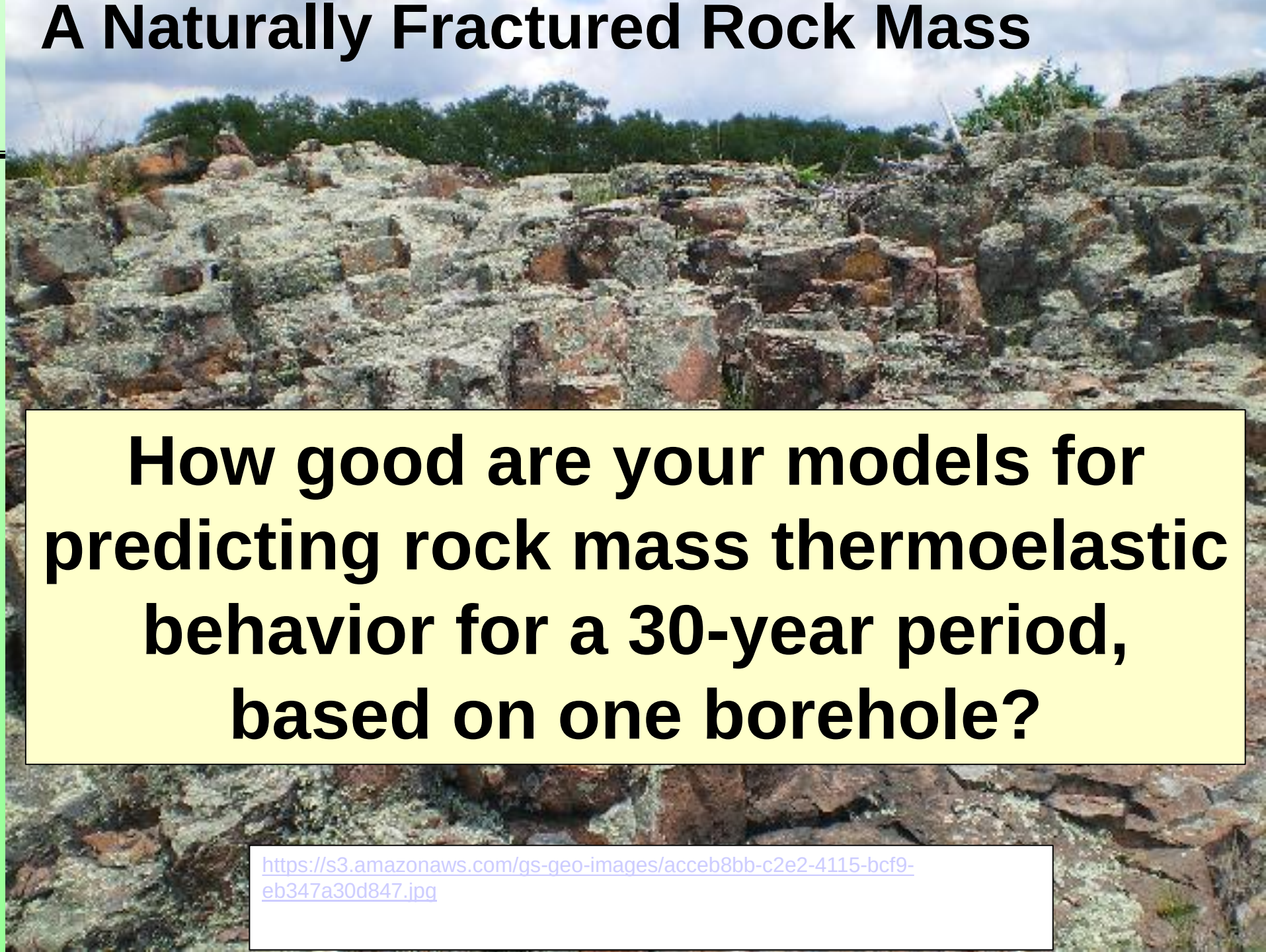
Fracturing and Shearing for Rock Mass Stimulation in EGS Projects



The rock mass being stimulated for EGS is a low-permeability, naturally fractured rock mass

https://s3.amazonaws.com/gs-geo-images/acceb8bb-c2e2-4115-bcf9-eb347a30d847.jpg

A Naturally Fractured Rock Mass



How good are your models for predicting rock mass thermoelastic behavior for a 30-year period, based on one borehole?

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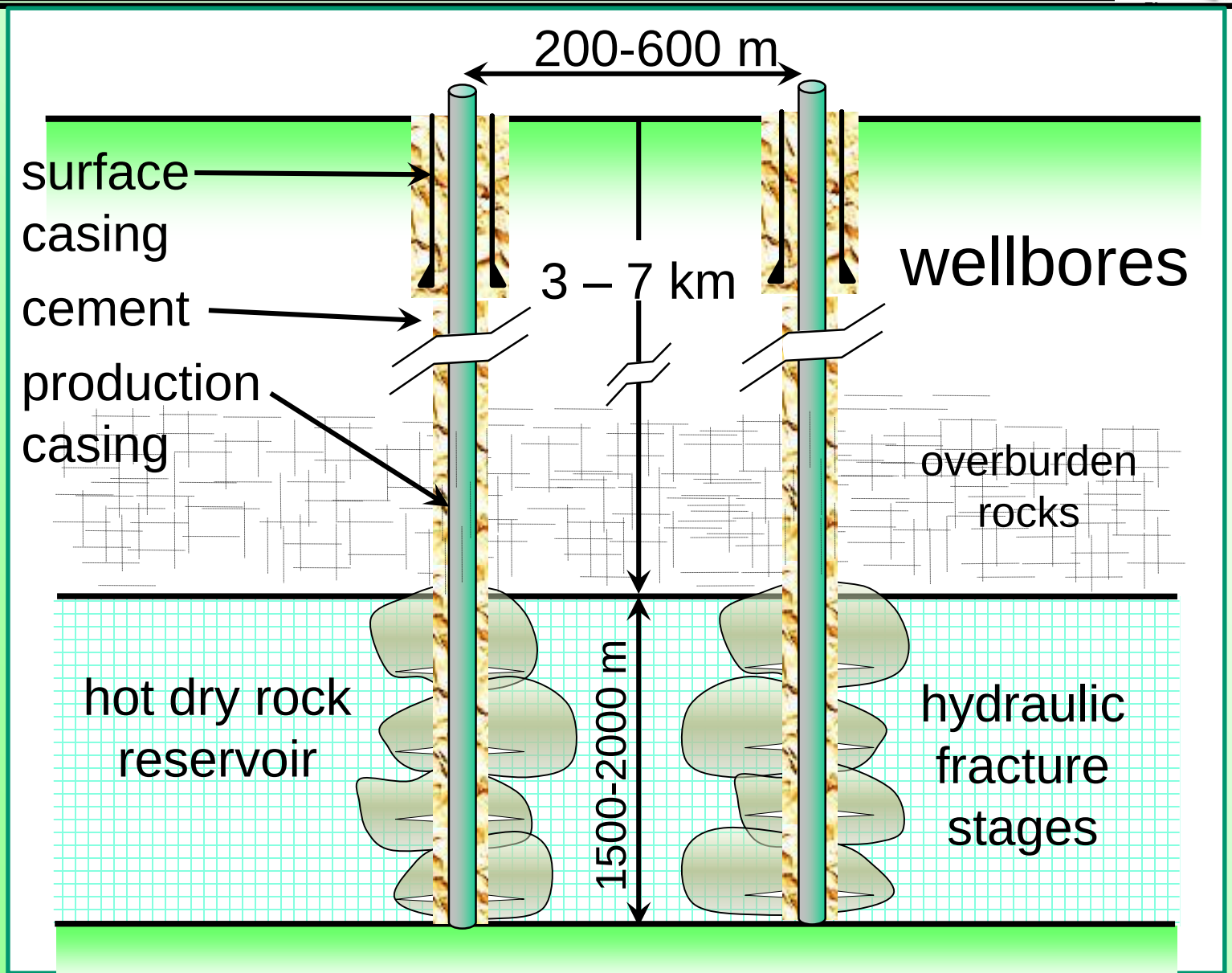
Interwell Communication…

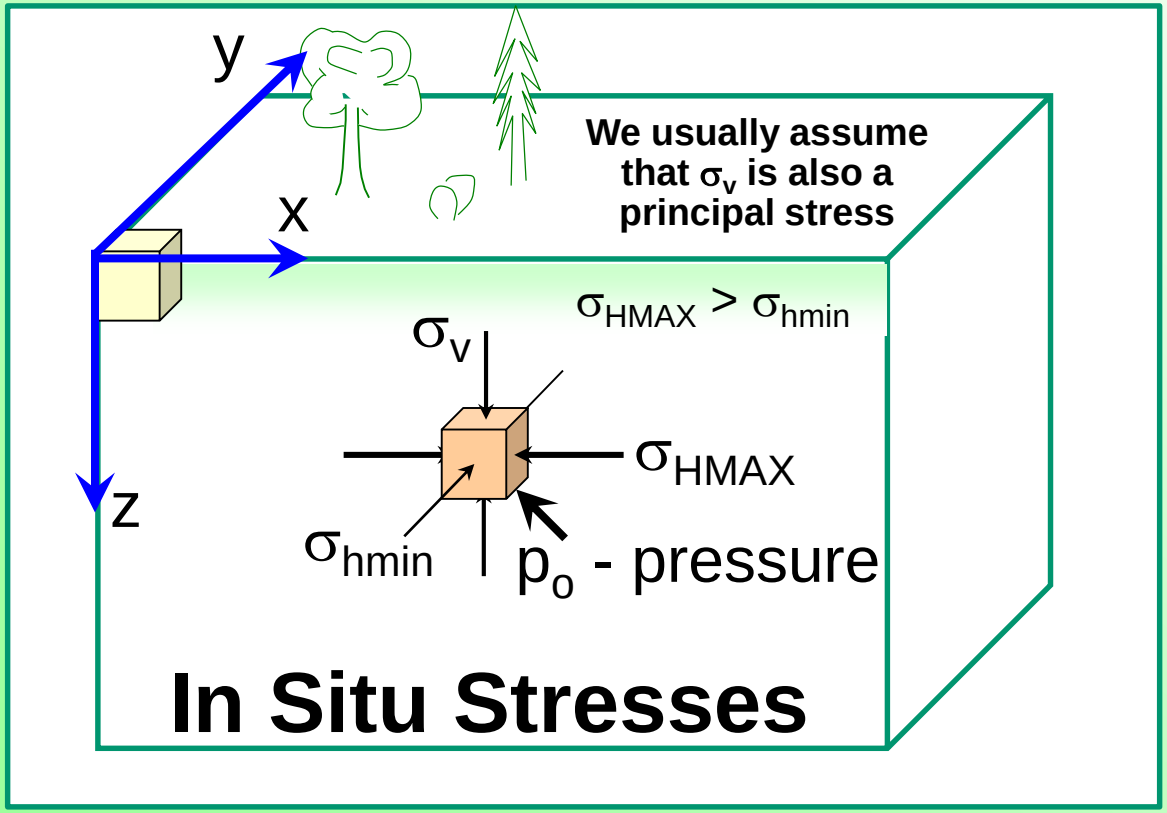


The Main Issues…

- *In Situ* Stresses
- Naturally Fractured Rock Mass Properties
- Stimulation Process (rates, pressures, time)
- Exploitation Schedule

In Situ Stresses

- The stress state in the ground is a fundamental factor in stimulation
- A three-dimensional stress state exists



Stresses and Stimulation

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- Value of σ_3 dominates HF behavior
- Orientation of σ_3 controls well placement
- Deviatoric stress (σ_1 - σ_3) magnitude and stress ratio (σ'_1/σ'_3) control HS effects
- And rock & joint properties also…
- Stresses change during stimulation!

We understand HF much better than HS. Is HS viable?

Enhanced Flow Capacity

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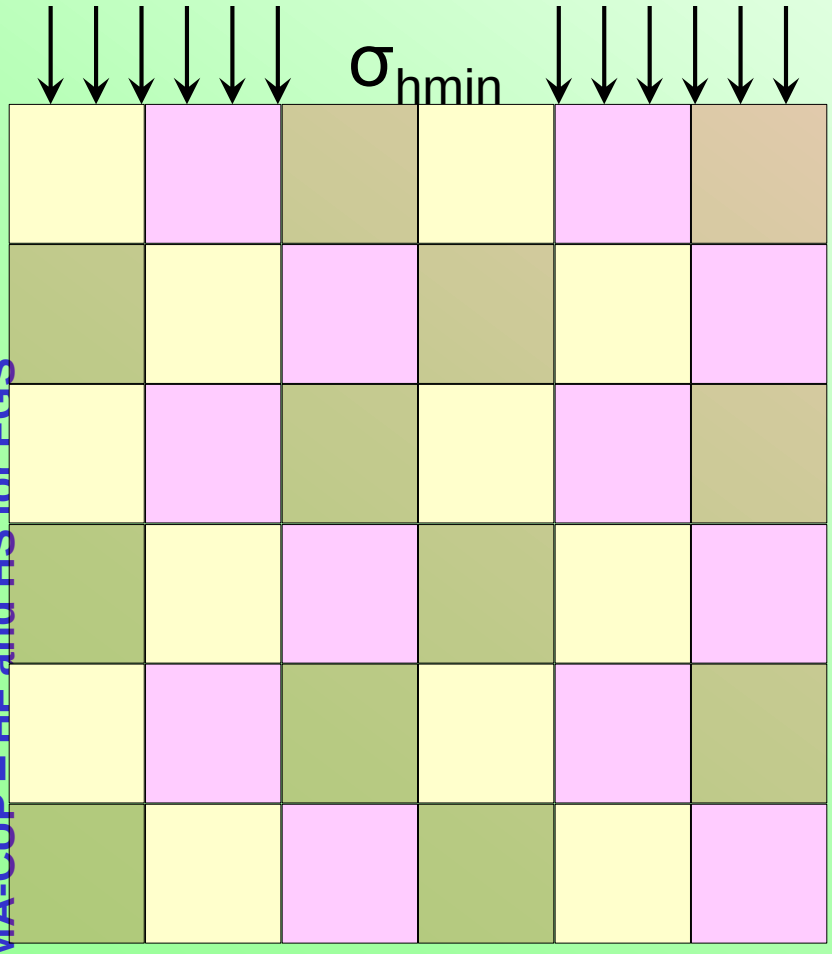
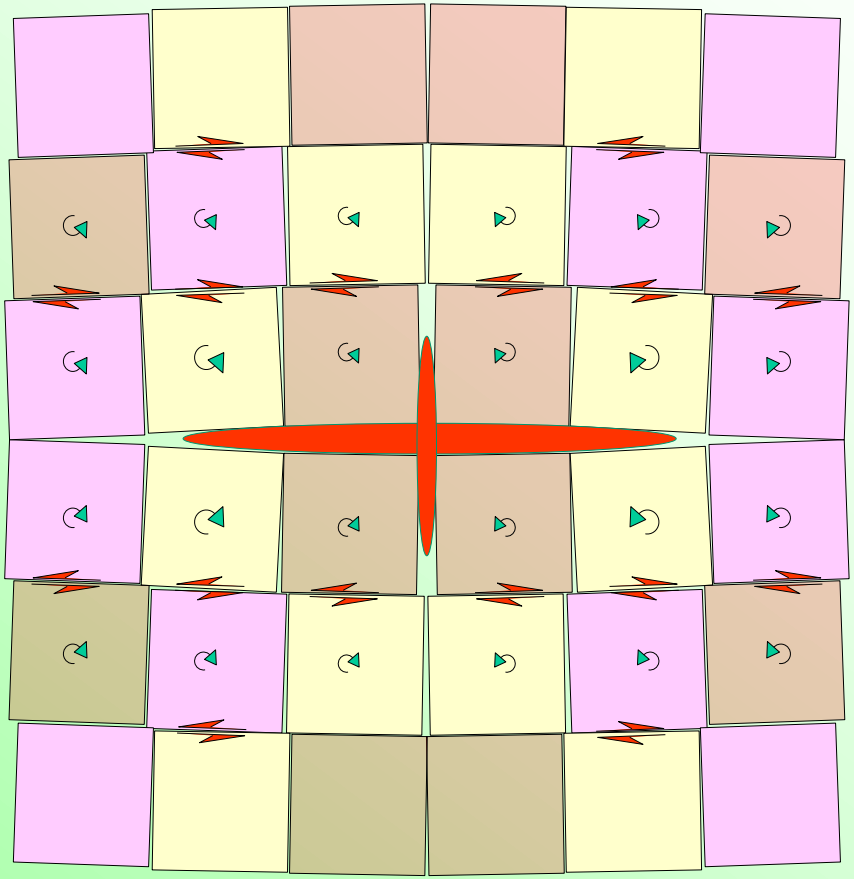
- The effect of HF and Hydroshearing





Wedging and Propping…

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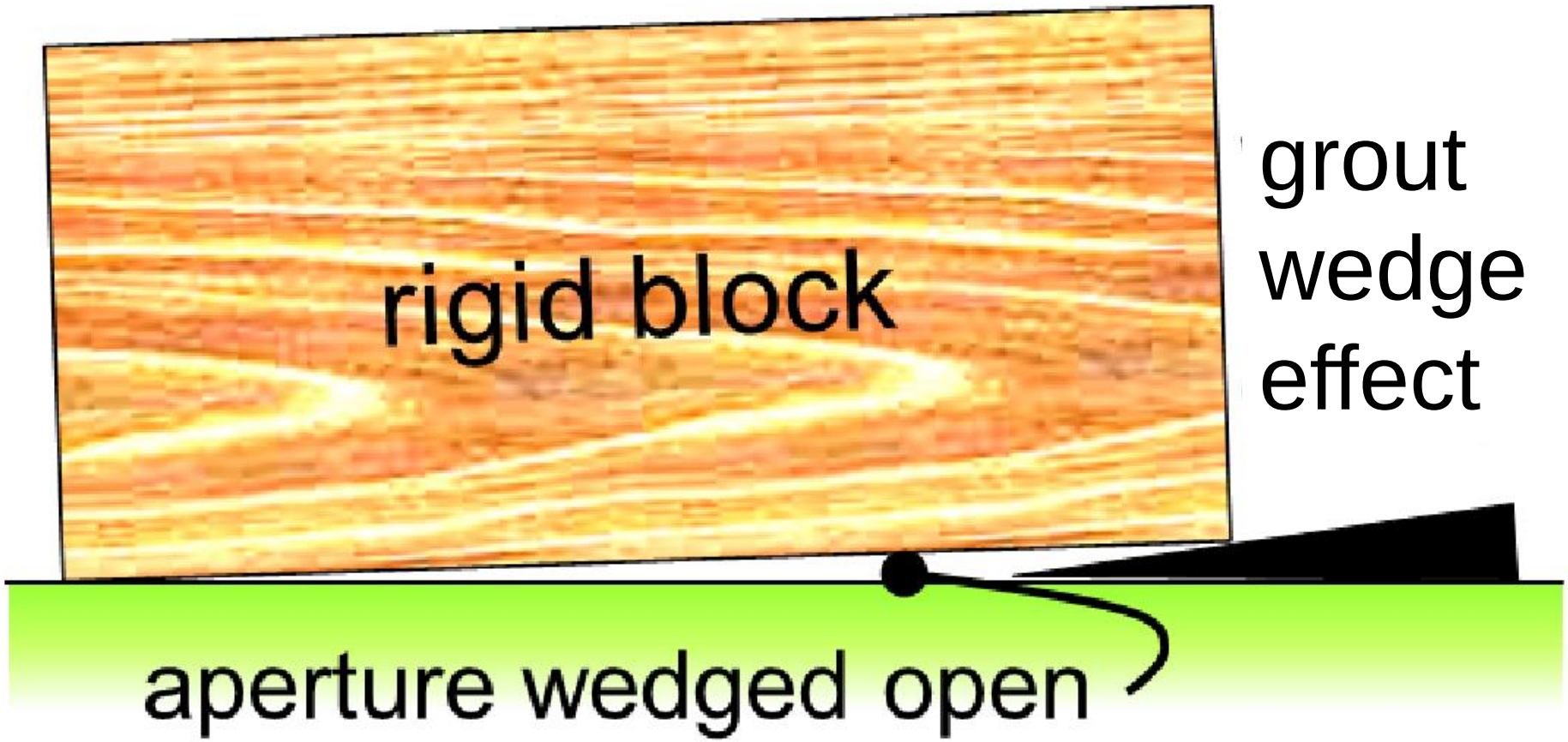
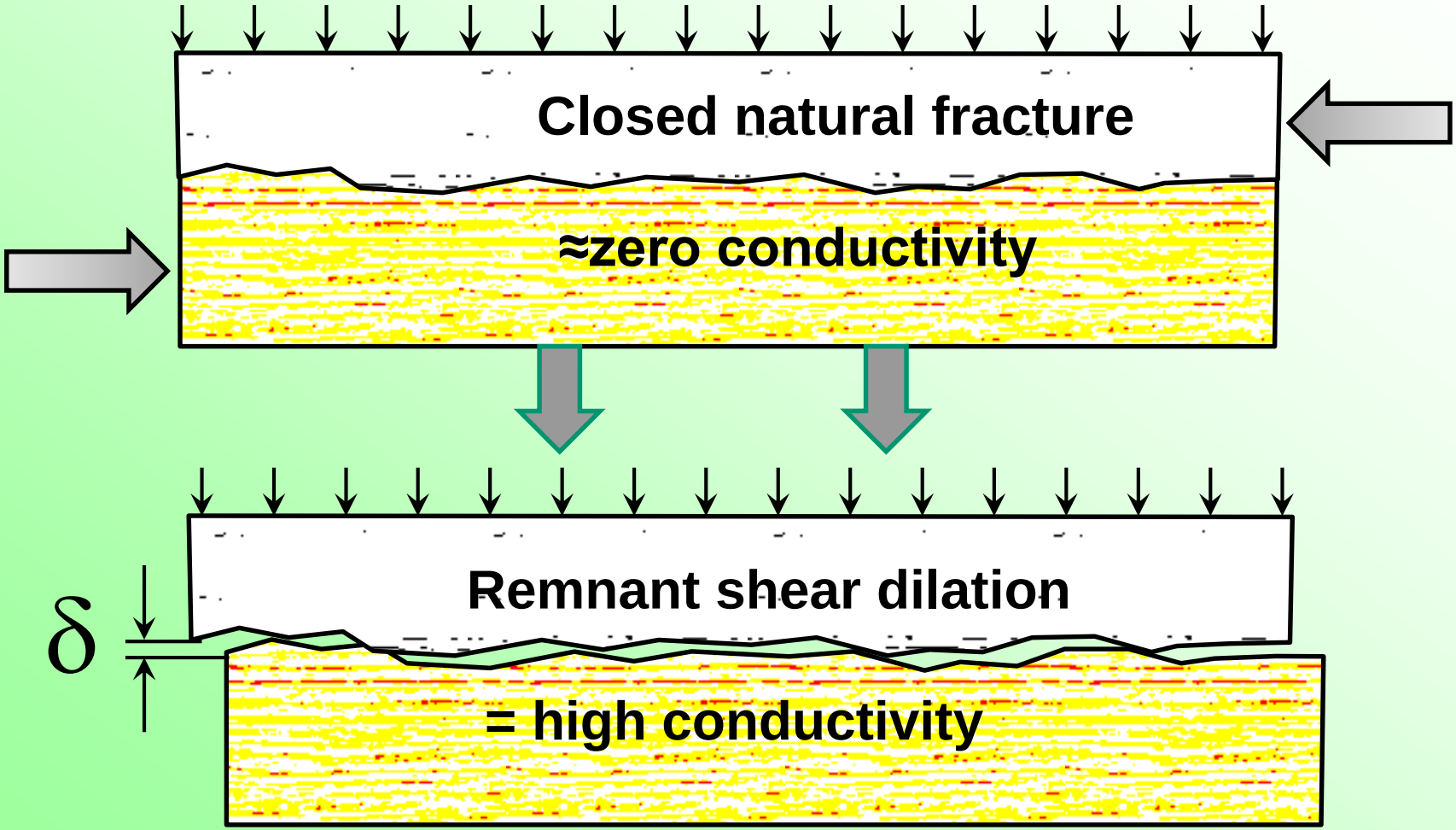
- HF pries open natural fractures, proppant can be carried part way into the opening



Shear Dilation



Shear Dilation in Hydroshearing

Dilation Impact?

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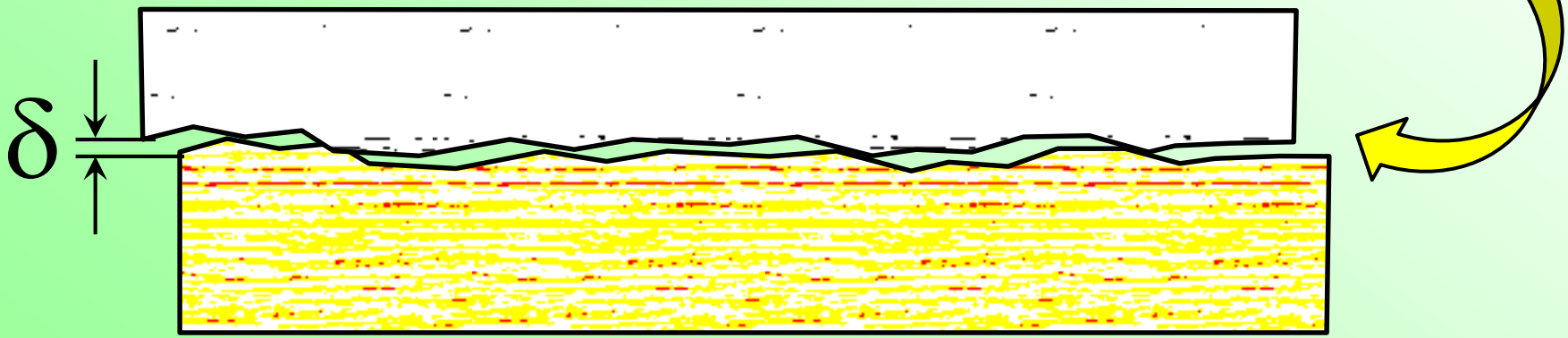
- A small **aperture** increase…

$$Q = \frac{\gamma}{\mu} \cdot G a^3 \Delta p$$

remnant effective aperture



- …has a great effect on joint conductivity

δ and Effective Stress Ratio

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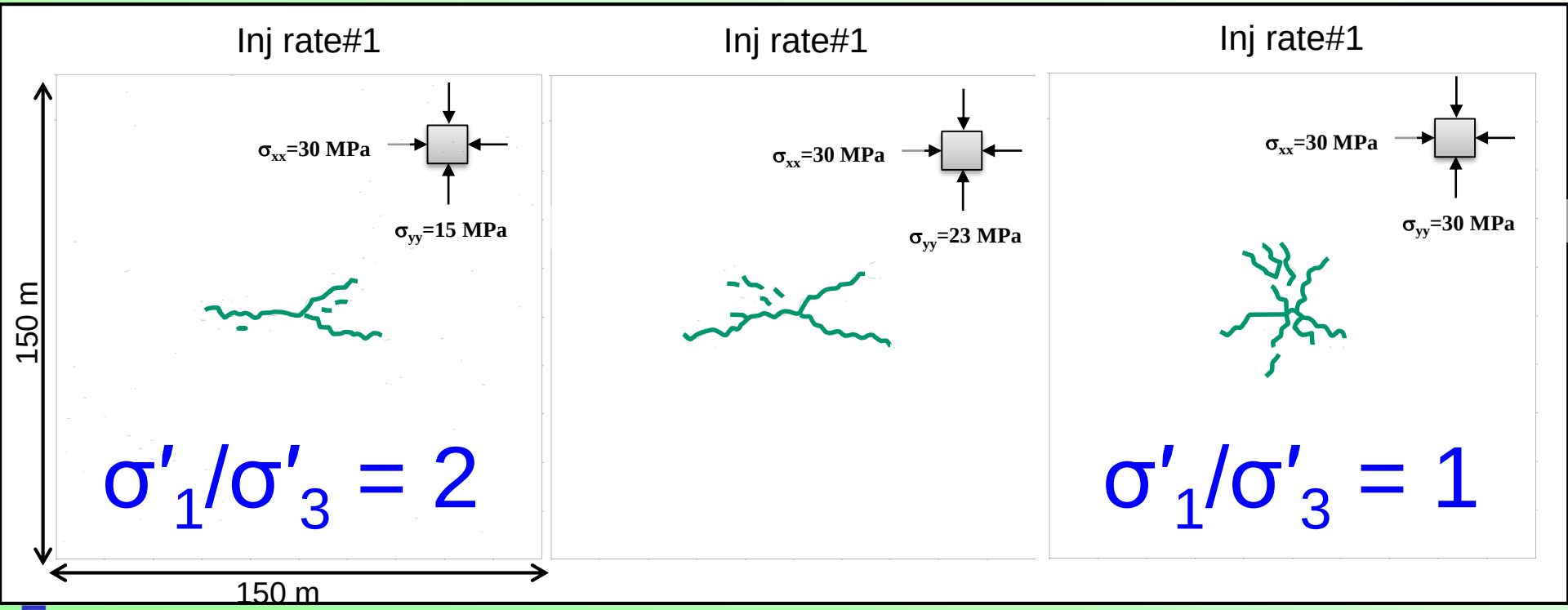
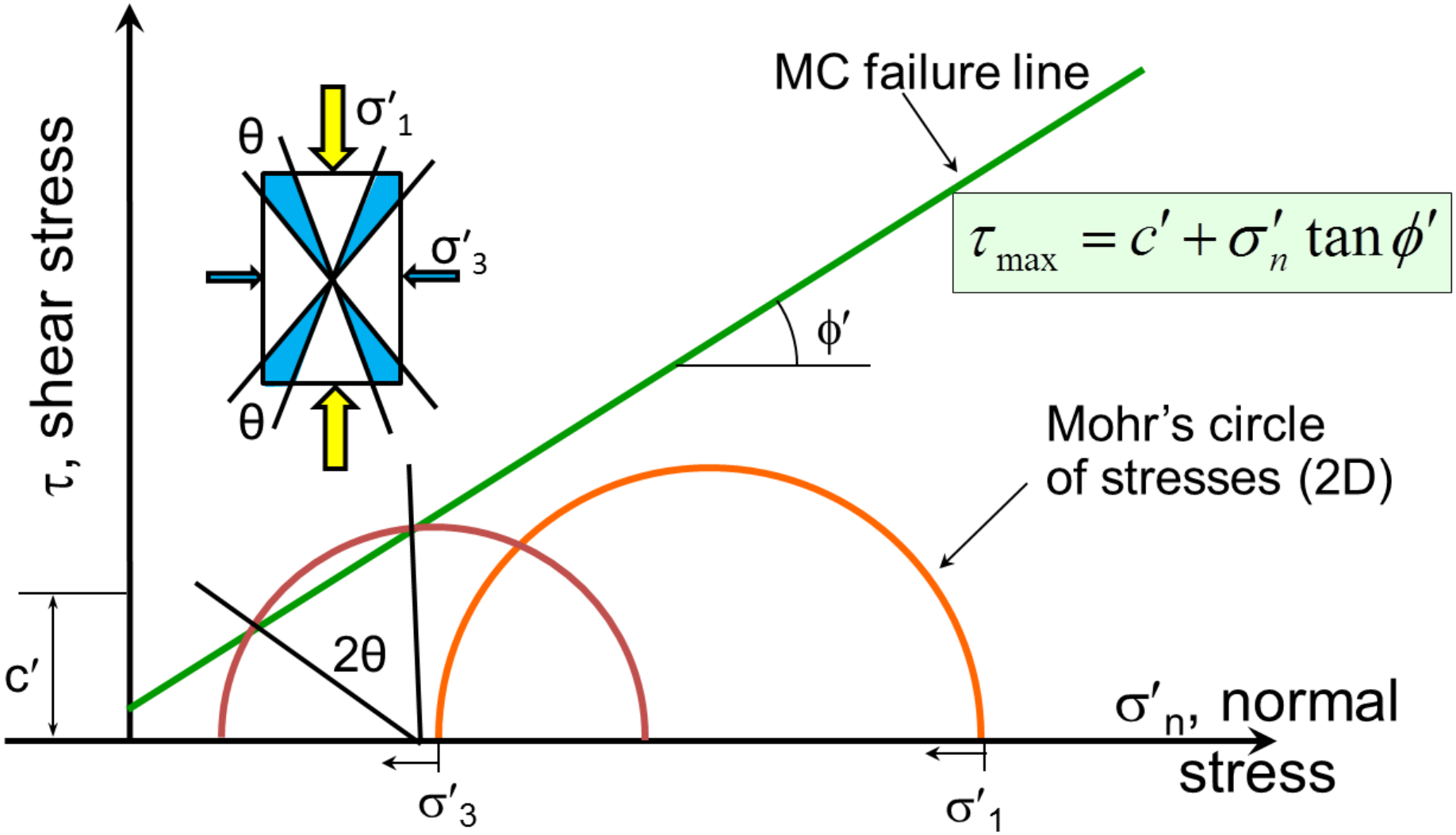
- σ'_1/σ'_3 & σ'_3 impact shearing, dilation & complexity of the shearing zone.
- …in ways that are not yet entirely clear…



UDEC™ simulations of HF in NFR

ARM

Which Joints Slip?

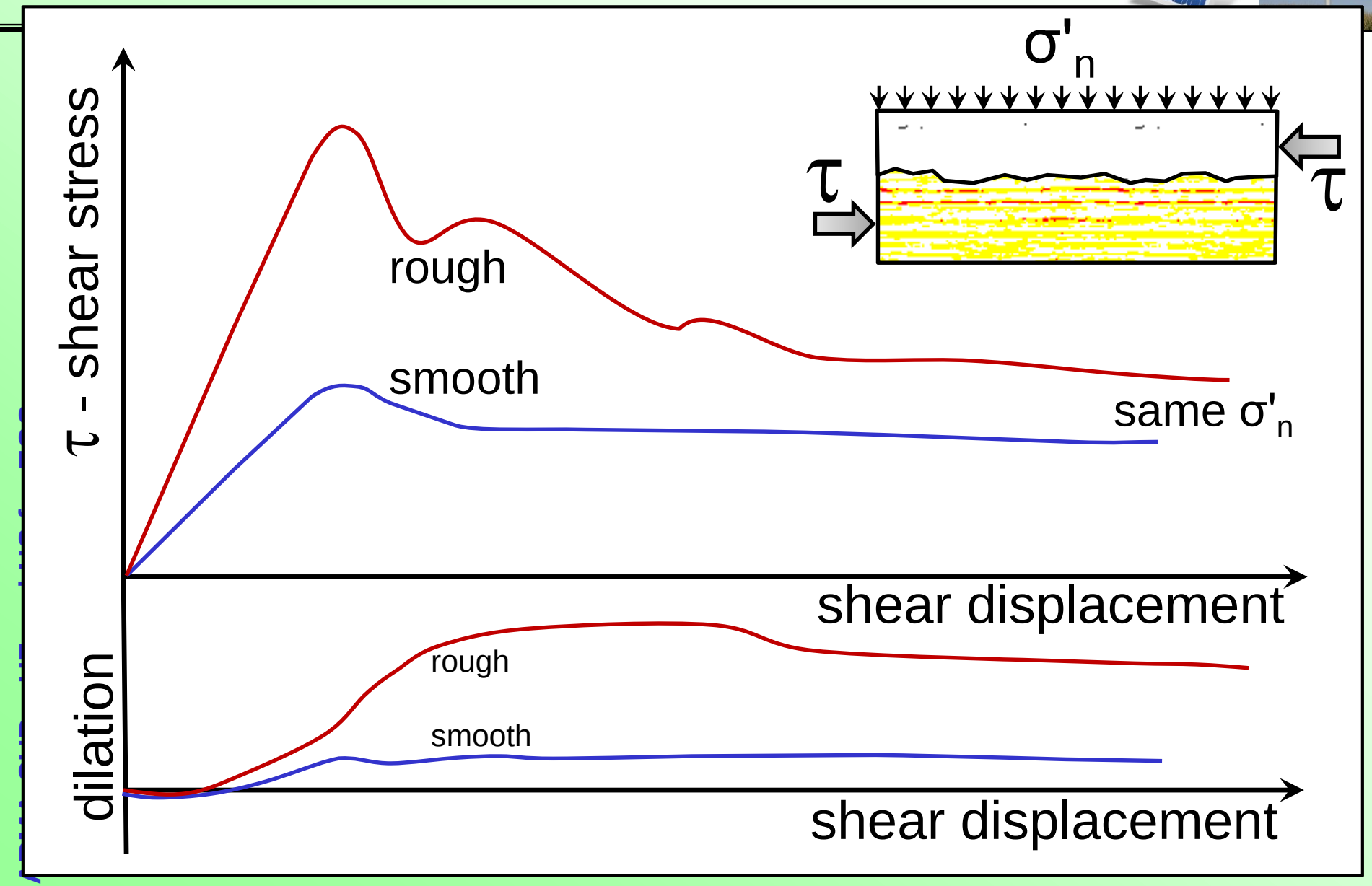


Increasing p and reducing σ'_n leads to slip of critically oriented joint (blue areas).

Are Joints Rough or Smooth?

Source: N. Barton and A. Makurat

Rough and Smooth Joints



Hydroshearing?

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- Hydroshearing: injection at pressures (p) just below the HF pressure ≈ σ_3
- As high p propagates, Biot mechanics tells us that V↑, thus local σ_3 must ↑
- …and near-field [$\Delta\sigma_{ij}$] are different than farther out
- …and stresses propagate "instantly", but pressures do not (diffusion)
- …and apertures, and therefore "[k_{ij}]" also changes with injection time

What Happens During HS,HF?

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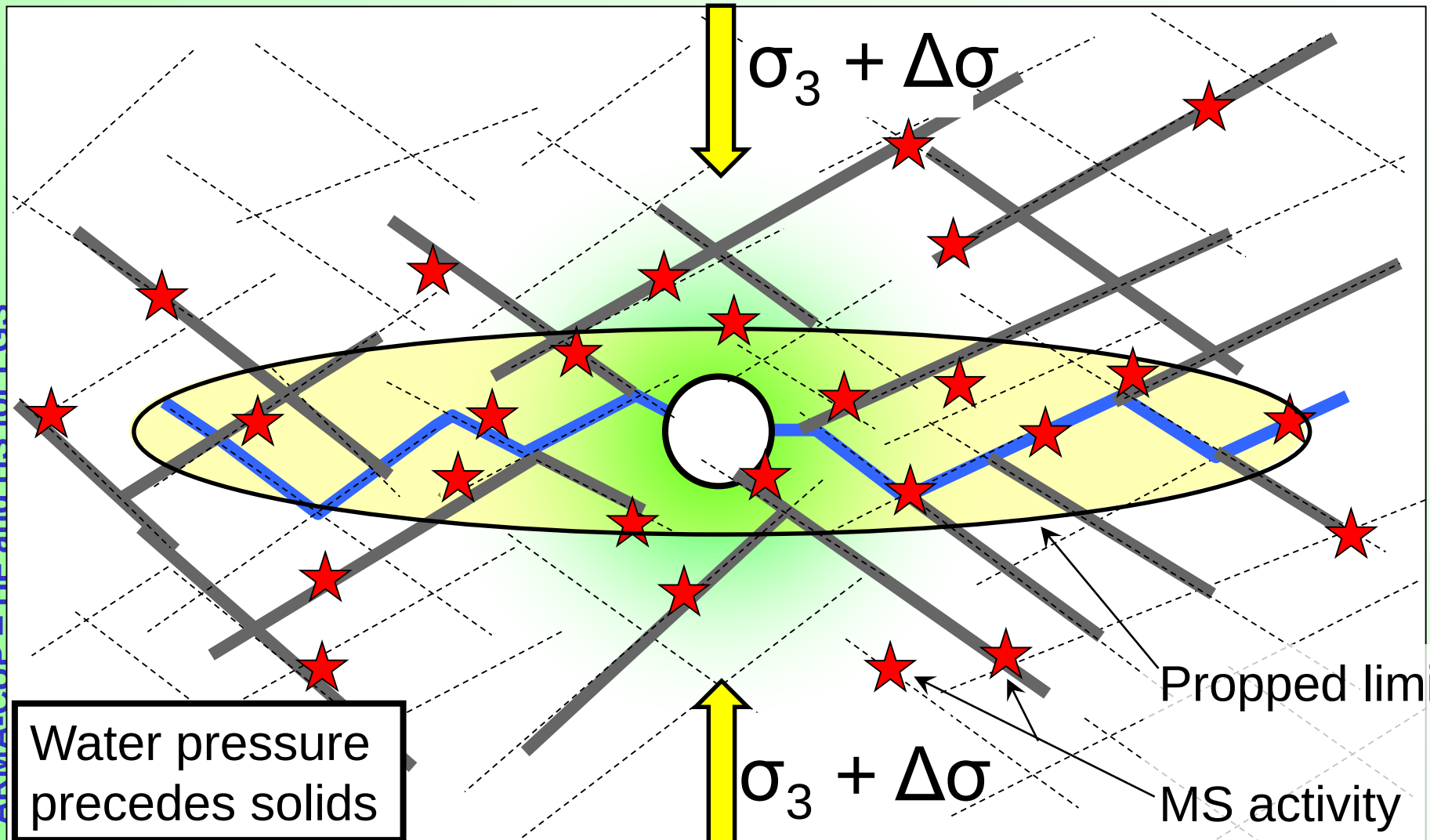
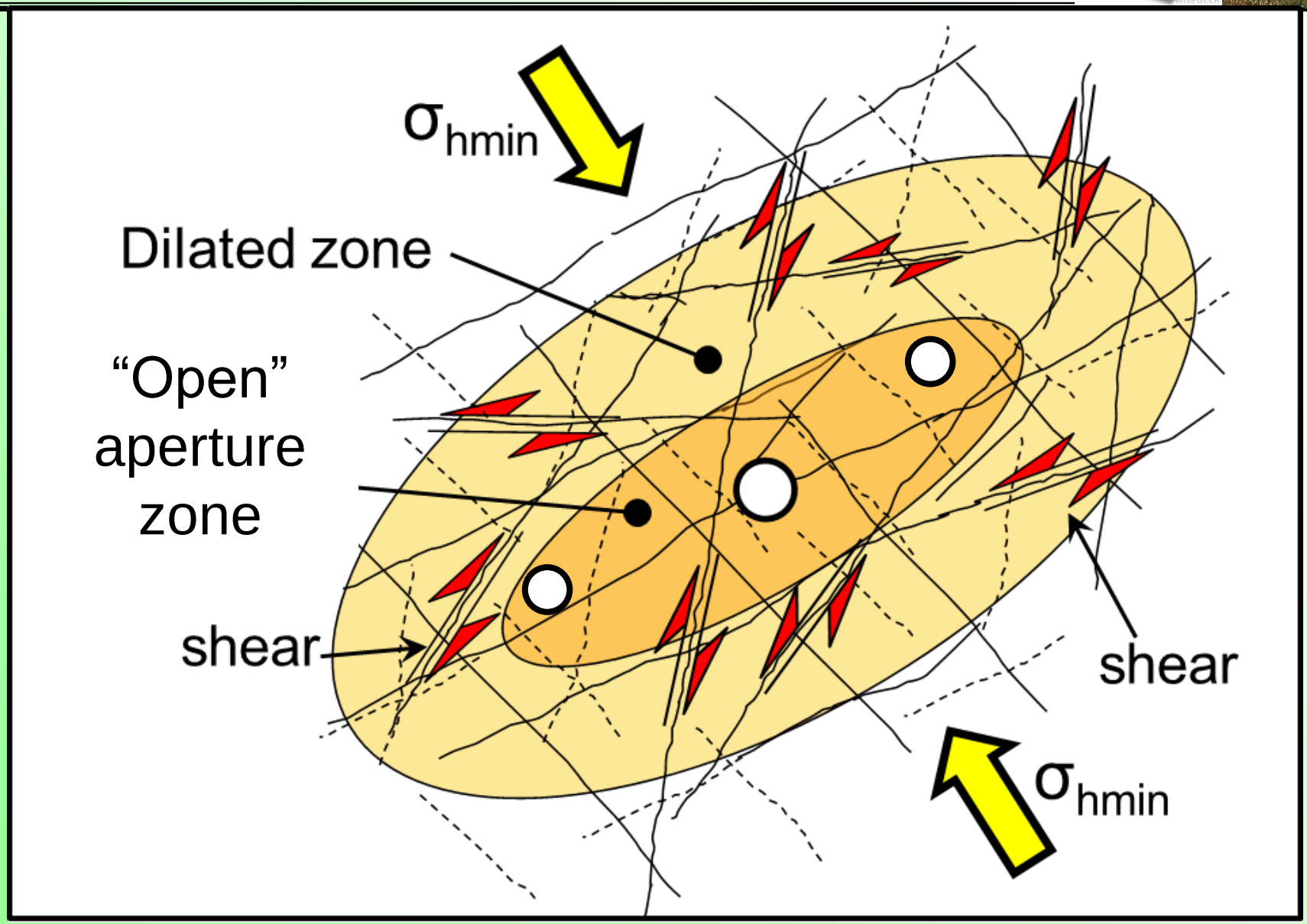
- Stick-slip shearing outside propped zone



The Stimulated Volume



Some Additional Commments…

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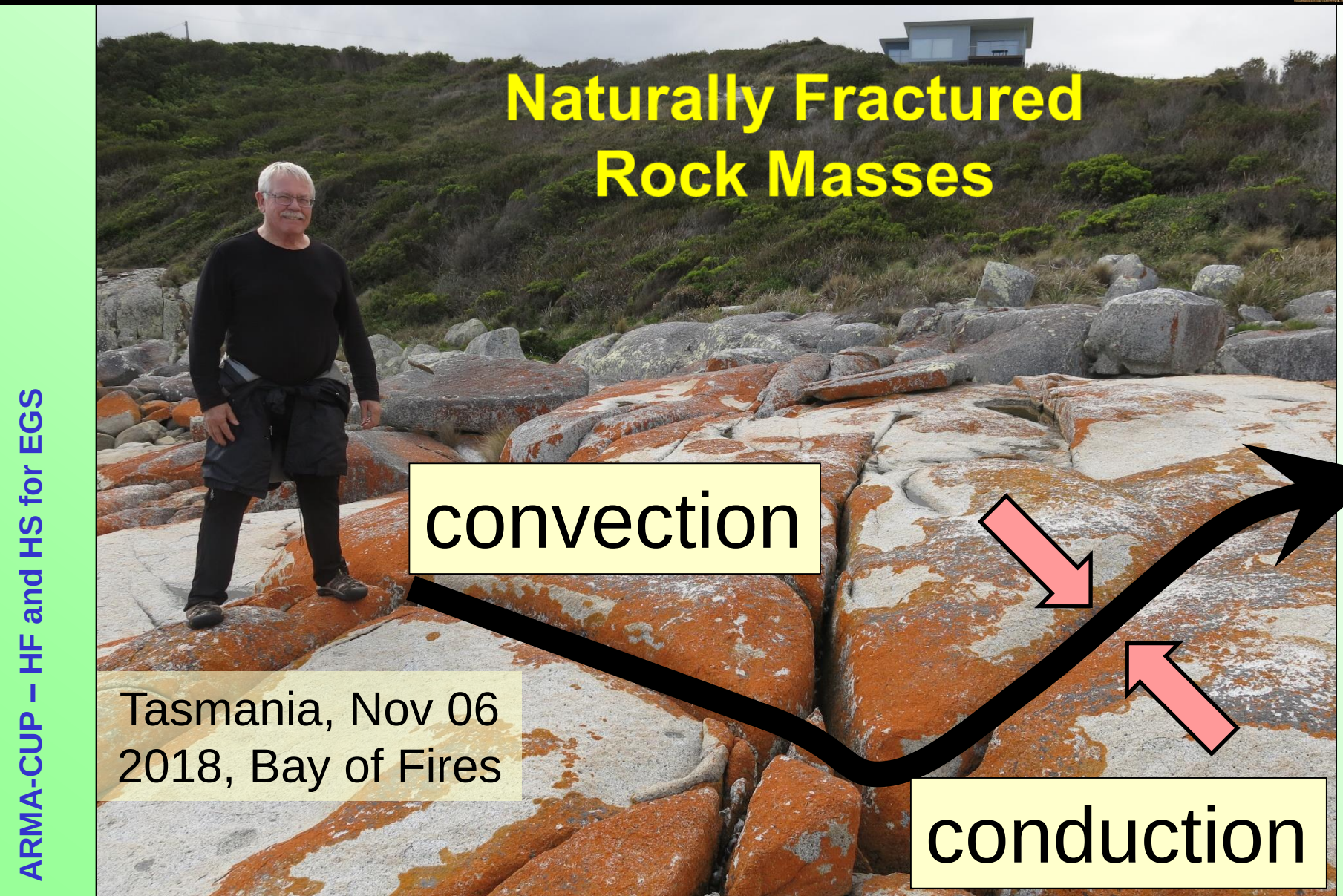
- HF, HS modeling in NFR is challenging
- HF, HS models are getting better slowly
- Yet, because of uncertainty…
- No one can closely predict the effect of HS on the convective flow field
- I would suggest that on the next large-scale EGS projects…
- A period of HS with controlled injection
- Injectivity monitoring, then HF later

Heat Flux, Fractured Rock

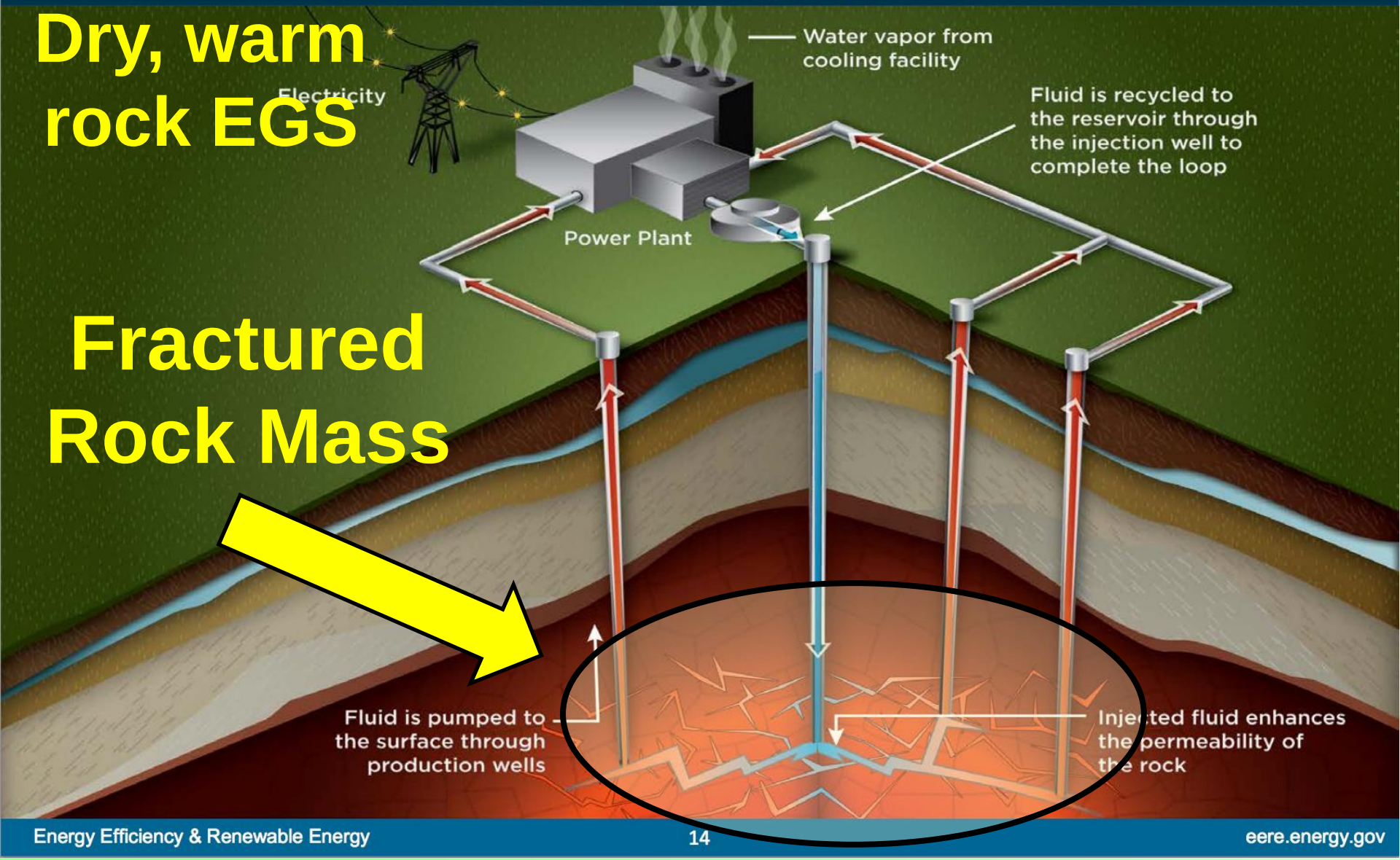


Enhanced Geothermal Systems

The Future: Creating power from hot, tight rocks

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

EGS uses advanced technologies to access the heat of the earth and produce electricity.



Geomechanics Issues

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- **THM coupling** in jointed rock masses
  - ⇨ Highly non-linear joint conductivity
  - ⇨ Conductive-convective heat transport
  - ⇨ Channeling through dilated fractures
- **Induced seismicity** predictions: ΔT, Δp
  - ⇨ No good link between MS and RM
  - ⇨ Cannot yet predict Mmax, recurrence
- **Monitoring**
  - ⇨ Microseismic monitoring is not good enough
  - ⇨ Deformation monitoring is needed for geomechanics
  - ⇨ Fibre optics, tiltmeters, LIDAR (surface)…?

Challenges in EGS Evaluation

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- **MODEL-BASED** assessment is vital…
  - ⇨ To make life predictions for $$ assessment
  - ⇨ To perform sensitivity analysis so that probabilistic predictions are possible
  - ⇨ To track EGS evolution, improving predictions during the project life
- **BUT**, this is very challenging.
- I will describe several big issues in modeling that face us…

Some Big Issues

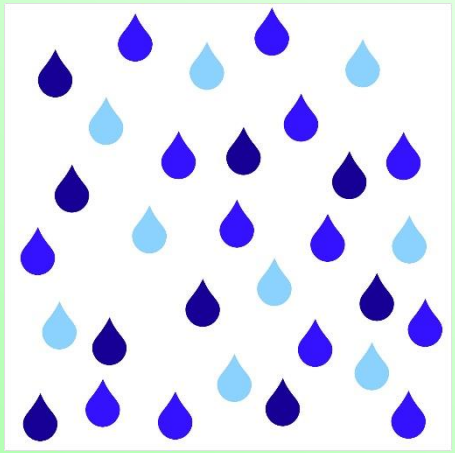
Scale Effects and Rock Fabric

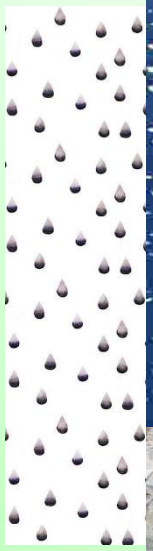
Channeling (and **Q**) Predictions

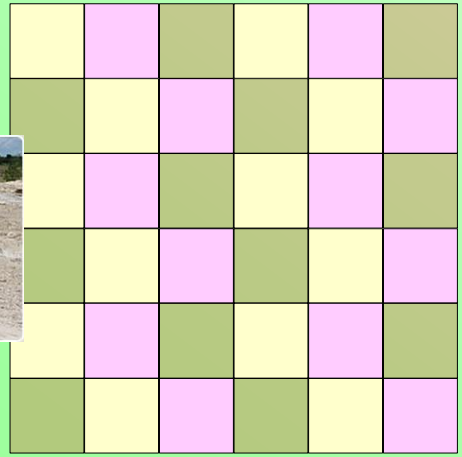
Predicting Seismicity Response

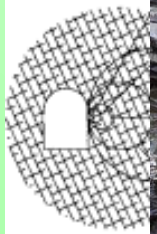
Geomechanics Monitoring

Scale and Analysis (Simulation)



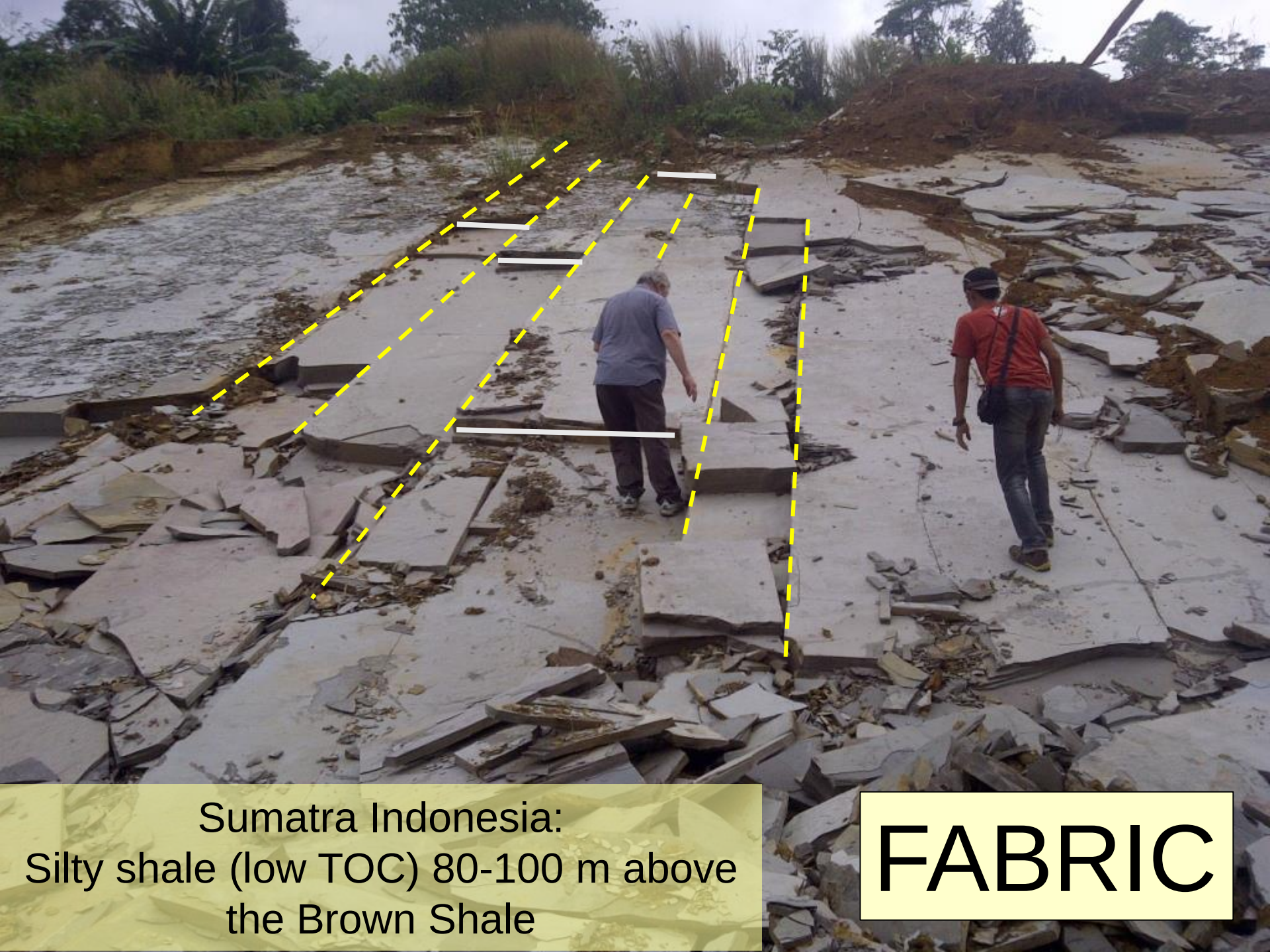






ARMA-CU HS for EGS

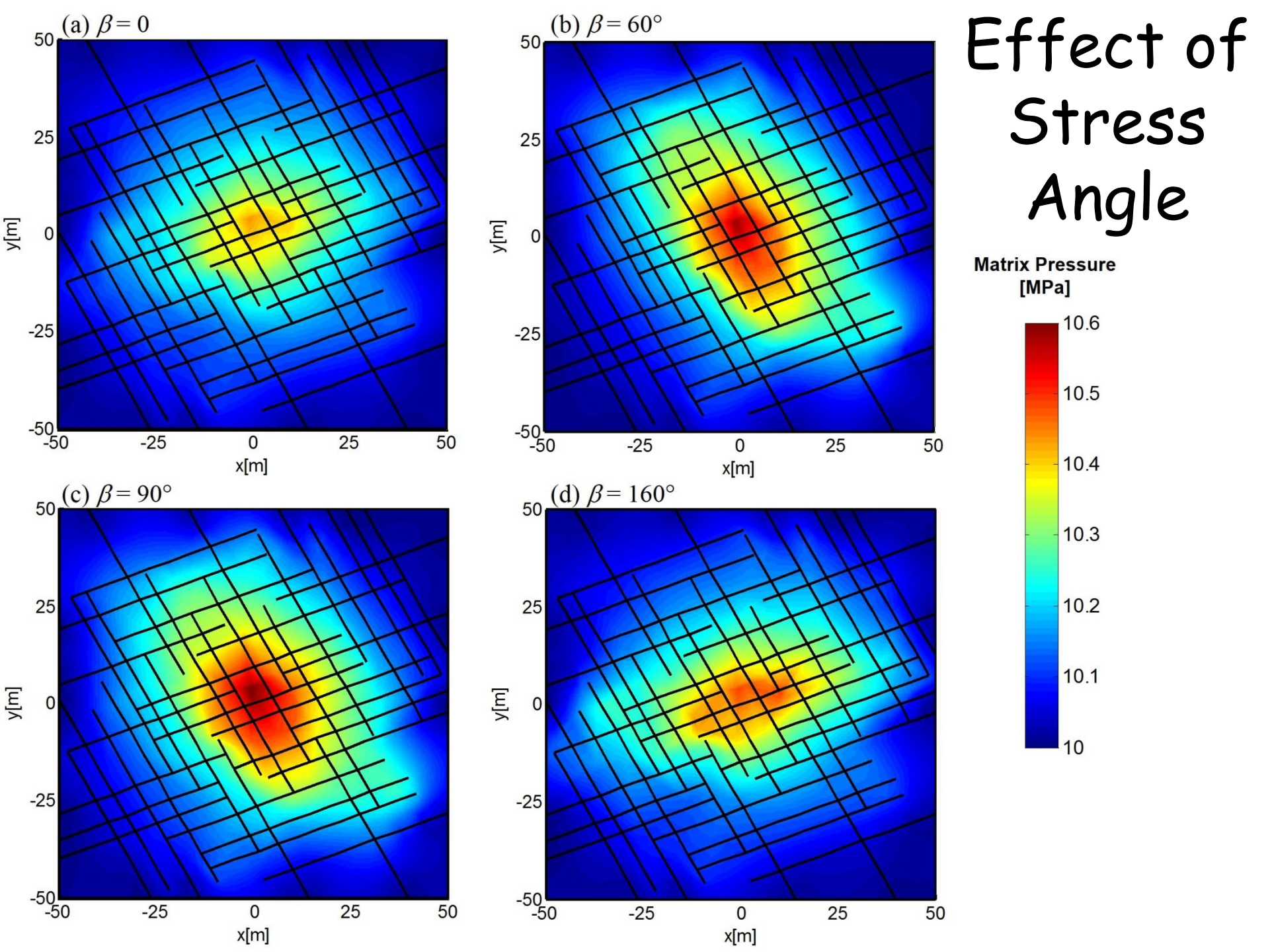
Wang, Zhao
Engineer



Sumatra Indonesia:
Silty shale (low TOC) 80-100 m above the Brown Shale

FABRIC

Effect of Stress Angle



HS Changes Properties (DEM)

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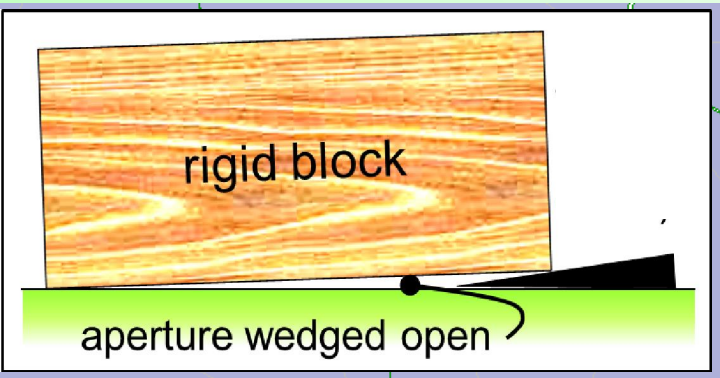


σ_{xx}=30 MPa

σ_{yy}=23 MPa

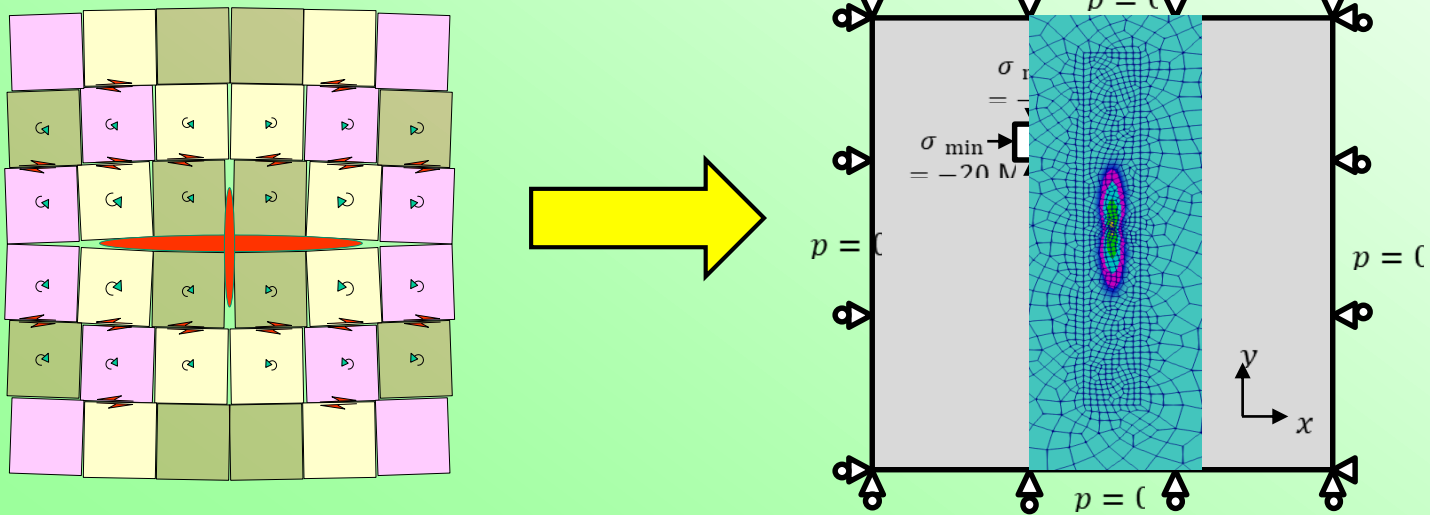
aperture
- Δa

Wedged natural fractures

$$Q = \frac{\gamma}{\mu} \cdot G a^3 \Delta p$$

Comments on Where We Are…

- Upscaling is a useful option
- Computationally tractable for large cases
- Allows detailed stochastic analysis of many cases for risk analysis
- …but these are early times as well…



Channeling and Q Prediction…

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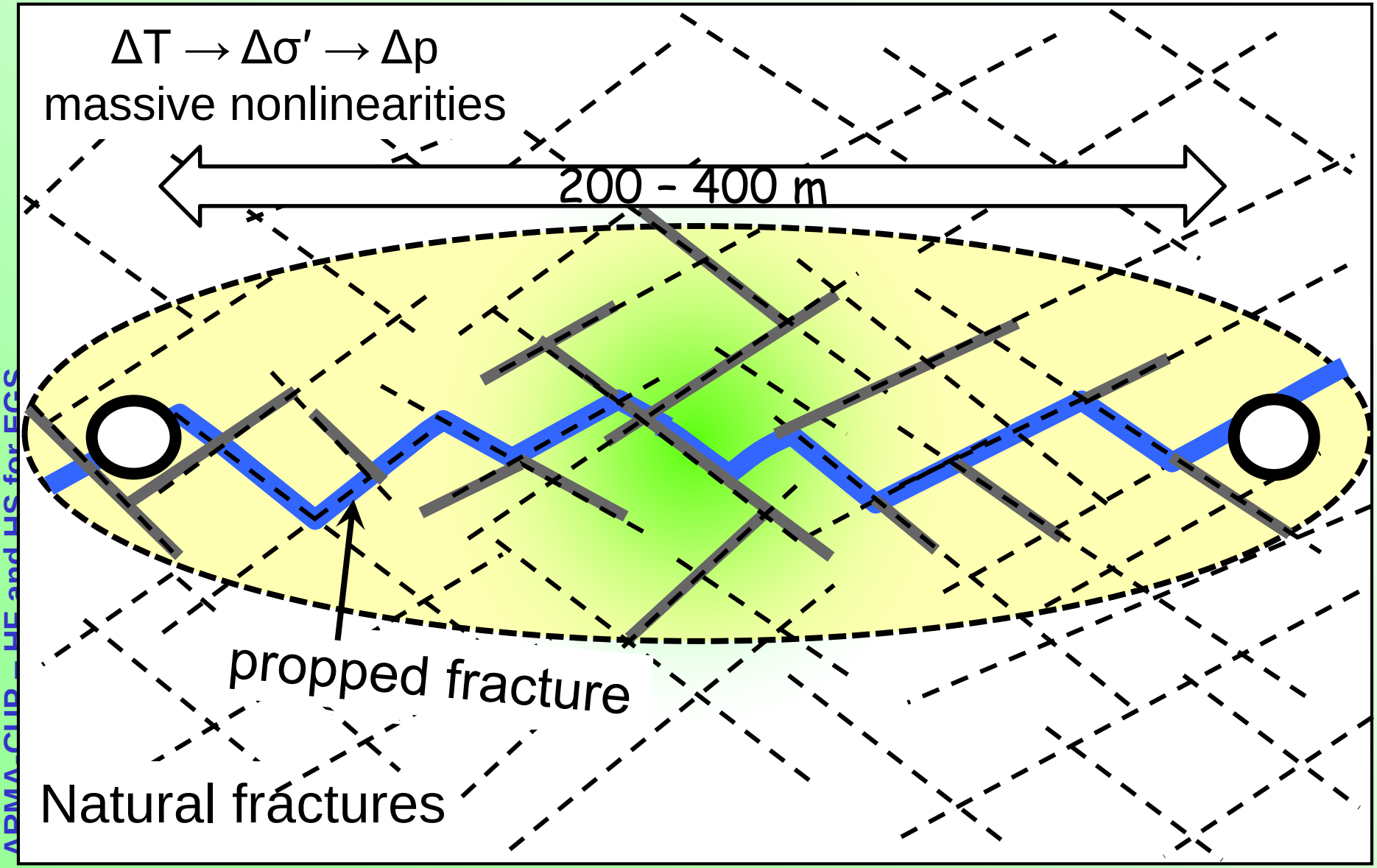
- Injecting cold water to extract heat will lead to "short circuiting"
- Cooling of the rocks leads to preferred expansion of a single fracture path
- Flow becomes concentrated along the single fracture path
- So the heat exchange **Q** with the rock mass declines, …
- …the system loses efficiency
- …and 30 year predictability is desirable

Thermoelasticity & Channelling



Seismic Predictions

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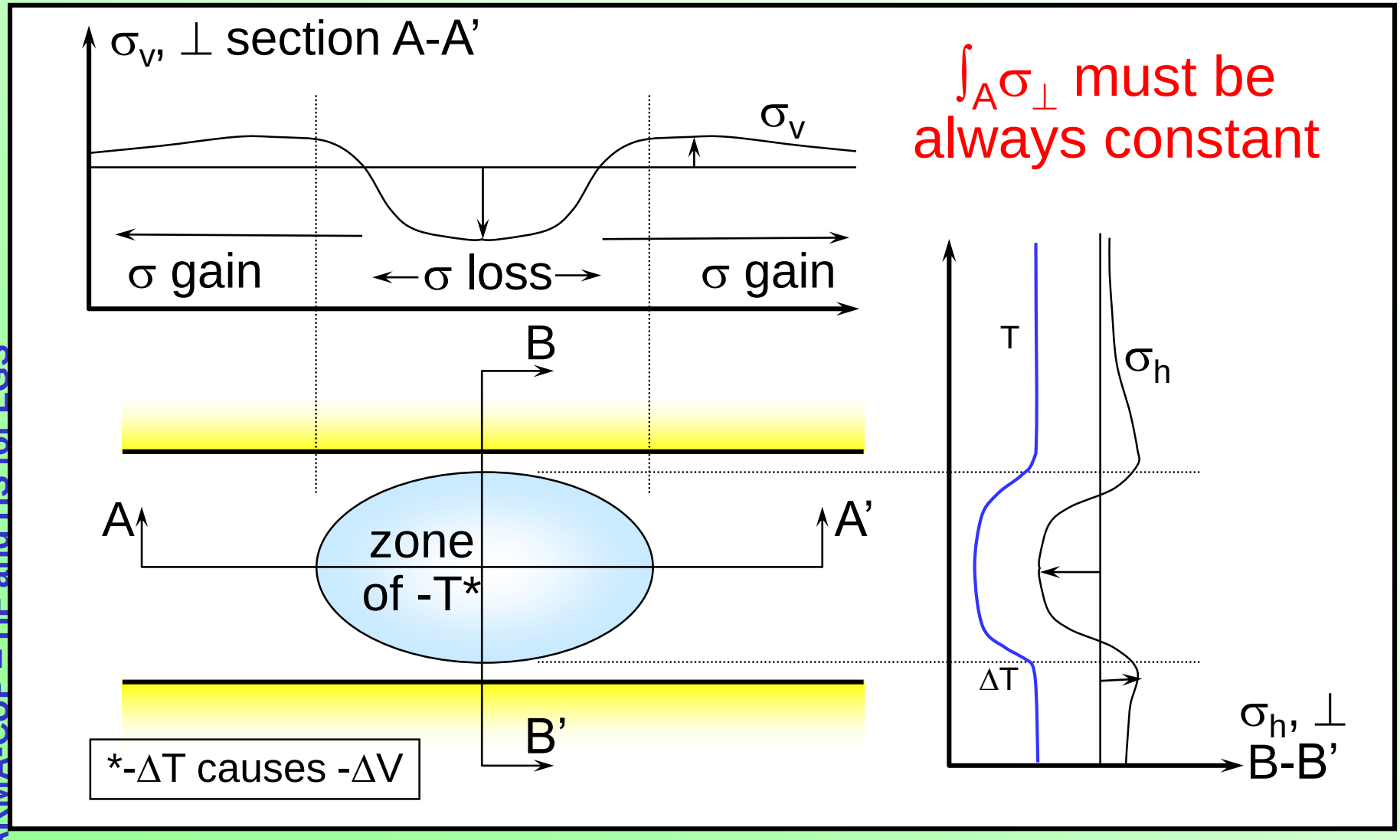
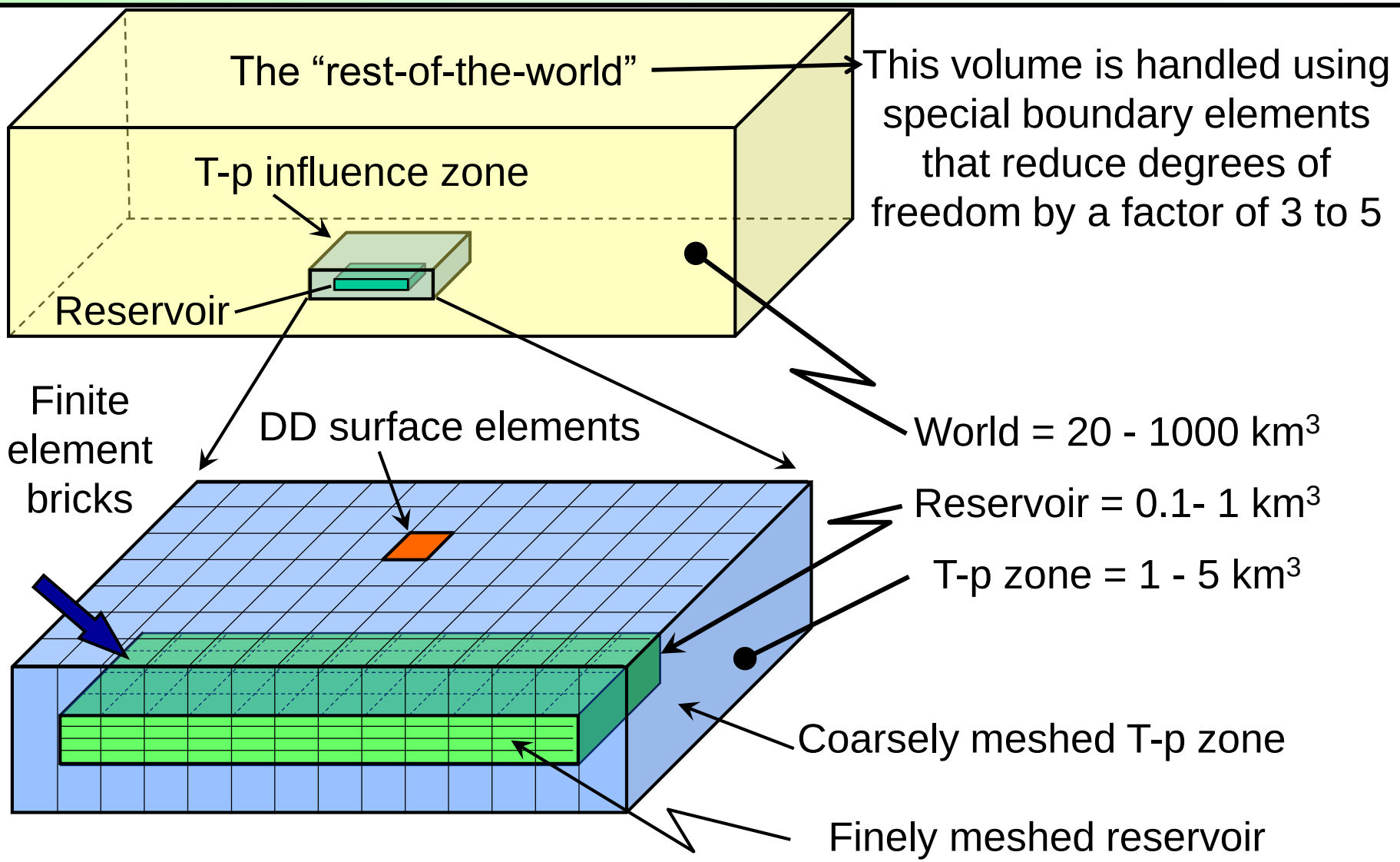
- $\Delta T \rightarrow$ thermoelastic contraction - ΔV
- $\Delta V \rightarrow$ large stress changes
- If the size of the project is large… **seismicity will be generated**
- Can we predict this?
- How large, how often?
- Can we control it?
- This is an important issue.
- Modeling and measurements are needed

Example of [σ] Redistribution



Hybrid Coupled Simulations…



Monitoring the EGS System

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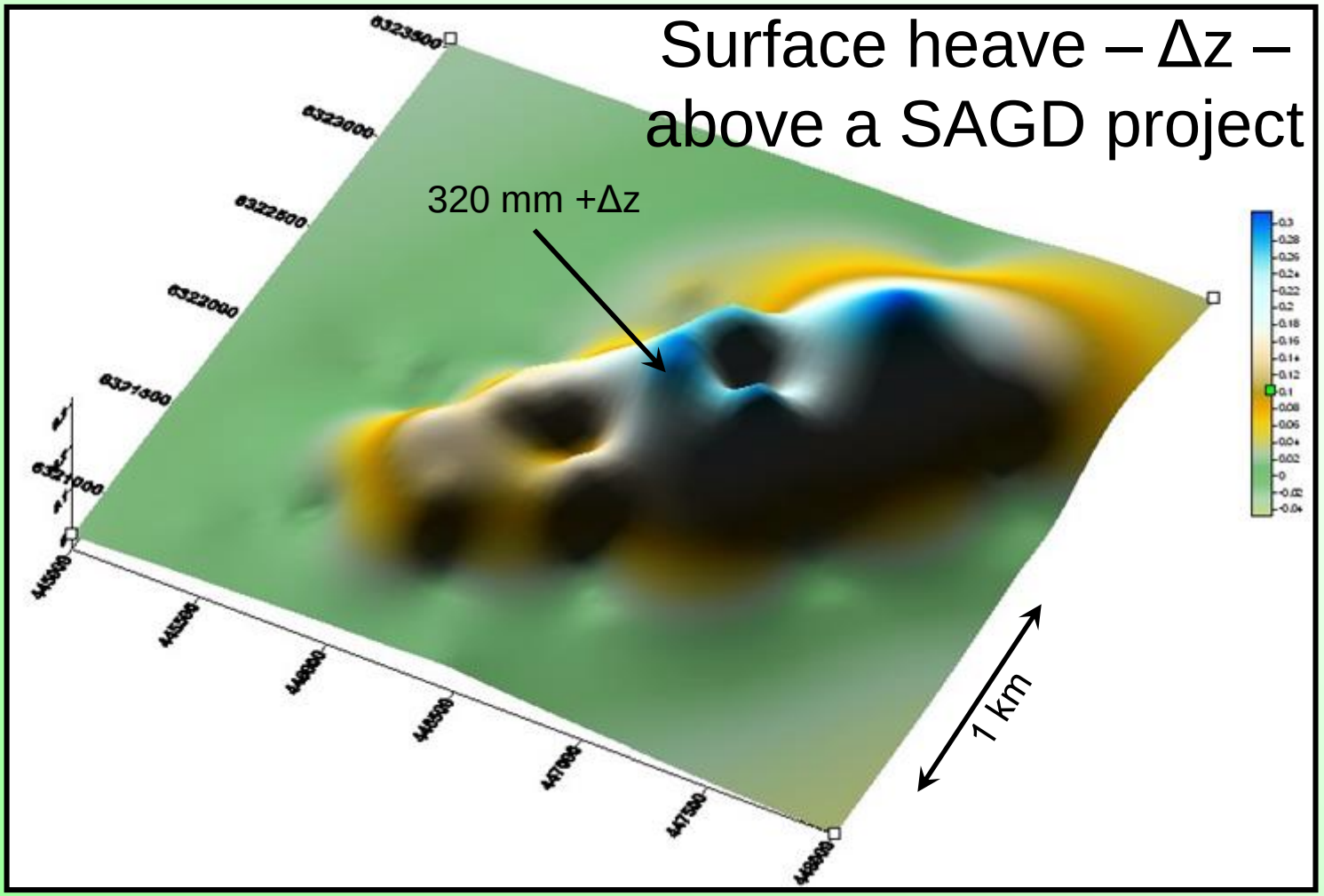
- P, T, rate are standard measures…
- Microseismic monitoring is good, but…
- We need **deformations** in order to:
  - ⇨ Track what is going on at depth
  - ⇨ Calibrate and use geomechanics models
- Options?
  - ⇨ Precision tilt measurements
  - ⇨ Fibre-optics cables in shallow slim holes
  - ⇨ 3-D active seismics (stress changes)

Surface Heave from ΔT & Δp

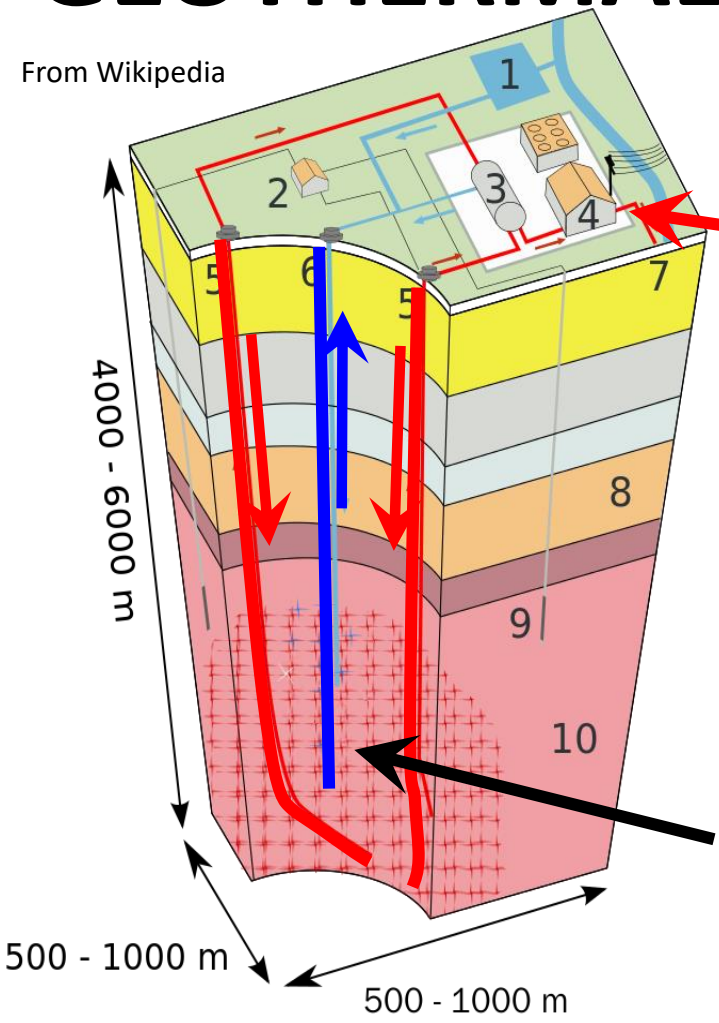


Deformations to monitor deep projects

Geothermal Heat Storage??

GEOTHERMAL

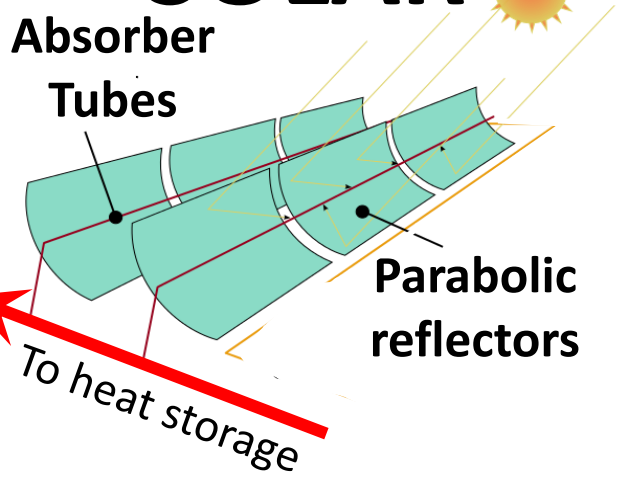
From Wikipedia



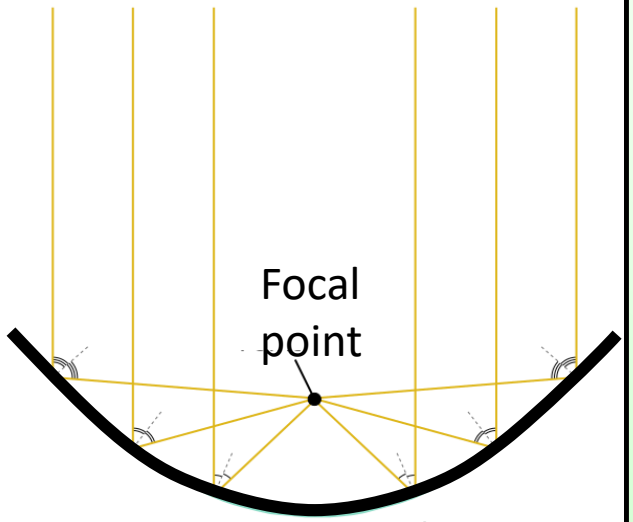
150-200°C

Deep reservoir 0.5 km³

SOLAR



https://upload.wikimedia.org/wikipedia/commons/b/b5/Parabolic_trough.svg



ARMA-CUP – HF and HS for EGS

IIT-B

Challenges

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- Large challenges face us in trying to achieve EGS predictive capability
- Is HS viable, or is it always HF + HS?
- Rock fabric and scale effects
- Channeling, flow and heat flux effects
- Predicting seismicity (when, how big?)
- Real-time EGS management w. monitoring

These challenges are central to the future of EGS implementation

Acknowledgements

- ARMA and CUPB
- The Organizers, including Han Gang, Jiang Shu, Song Xianzhi, John McLennan
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