HEATSTORE WEBINAR SERIES

HOW TO DEVELOP UNDERGROUND THERMAL ENERGY STORAGE (UTES) PROJECTS?

Learnings from the European HEATSTORE project

Host: TNO, The Netherlands

heatstore
High Temperature Underground Thermal Energy Storage

GEOTHERMICA

7, 14, 21, 28 Sept. and 5, 12 Oct. 2021 | all 15-16 h (CEST)

Register on www.heatstore.eu

HEATSTORE WEBINAR SERIES 2021

All webinars are at 15 – 16 h CEST

Tuesday 7 Sept. (Holger Cremer, TNO): Challenges in Underground Thermal Energy Storage (UTES)

Tuesday 14 Sept. (Thomas Driesner, ETH Zurich): Advances in subsurface characterization and simulation

Tuesday 21 Sept. (Koen Allaerts, VITO): Integrating UTES and DSM in geothermal district heating networks

Tuesday 28 Sept. (Florian Hahn, Fraunhofer IEG): Abandoned coal mines – promising sites to store heat in the underground

Tuesday 5 Oct. (Bas Godschalk, IF Technology): The ECW Energy HT-ATES project in the Netherlands

Tuesday 12 Oct. (Joris Koornneef, TNO): The role of UTES in the future EU energy system – a moderated table discussion.

heatstore High Temperature Underground Thermal Energy Storage

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HEATSTORE

- HEATSTORE = GEOTHERMICA ERA-NET co-fund project
- 16.3 M€ | 23 partners in 9 EU countries
- 6 demonstration sites, 8 case studies.
- Coordination: TNO Netherlands Organization for Applied Scientific Research)

heatstore High Temperature Underground Thermal Energy Storage

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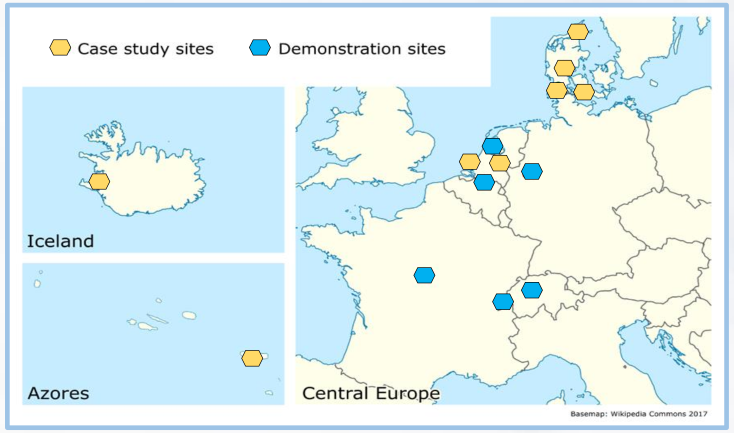


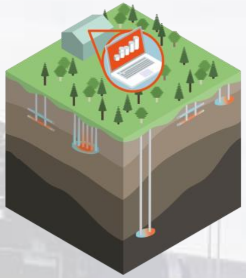
- **Best practice guidelines:** Design & System integration | Business models | Regulatory framework | Stakeholder perception & engagement | Monitoring technical, economic and environmental performance

- Proof and operation of UTES and DSM technologies

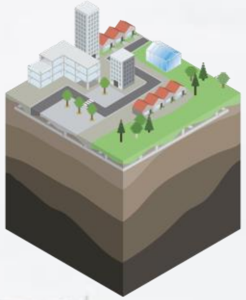
Fast track market uptake

Model & design validation

Characterization of UTES



Modelling sub-surface dynamics



Heating system integration & design optimisation

Demonstration

System performance monitoring

- **Roadmap Europe**: Technical future potential UTES and DSM in Europe | New business models | Stakeholder engagement | Roadmap for fast track uptake

Design → **Demonstration** → **Replication and scale-up**

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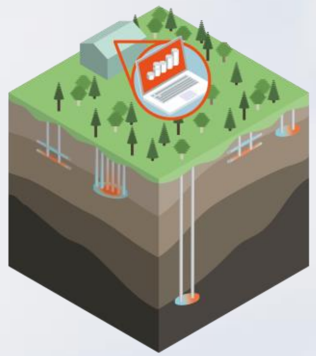
HEATSTORE – 14 Sept. 2021
Advances in subsurface characterization and simulation



- Thomas Driesner (ETHZ): Convenor & Opening
- Thomas Driesner (ETHZ): Simulating subsurface dynamics – approaches, workflows, suitable tools
- Luca Guglielmetti, Alex Daniilidis (Univ. Geneva): Integration of subsurface and energy system data for HT-ATES modelling in Geneva

HOW TO DEVELOP UNDERGROUND THERMAL ENERGY STORAGE (UTES) PROJECTS?

LEARNINGS FROM THE EUROPEAN HEATSTORE PROJECT, WEBINAR #2: ADVANCES IN SUBSURFACE CHARACTERIZATION AND SIMULATION

ALEX DANIILIDIS, THOMAS DRIESNER, LUCA GUGLIELMETTI AND THEIR COLLEAGUES FROM ETHZ, UNIGE, UNIBE, UNINE, SIG, …

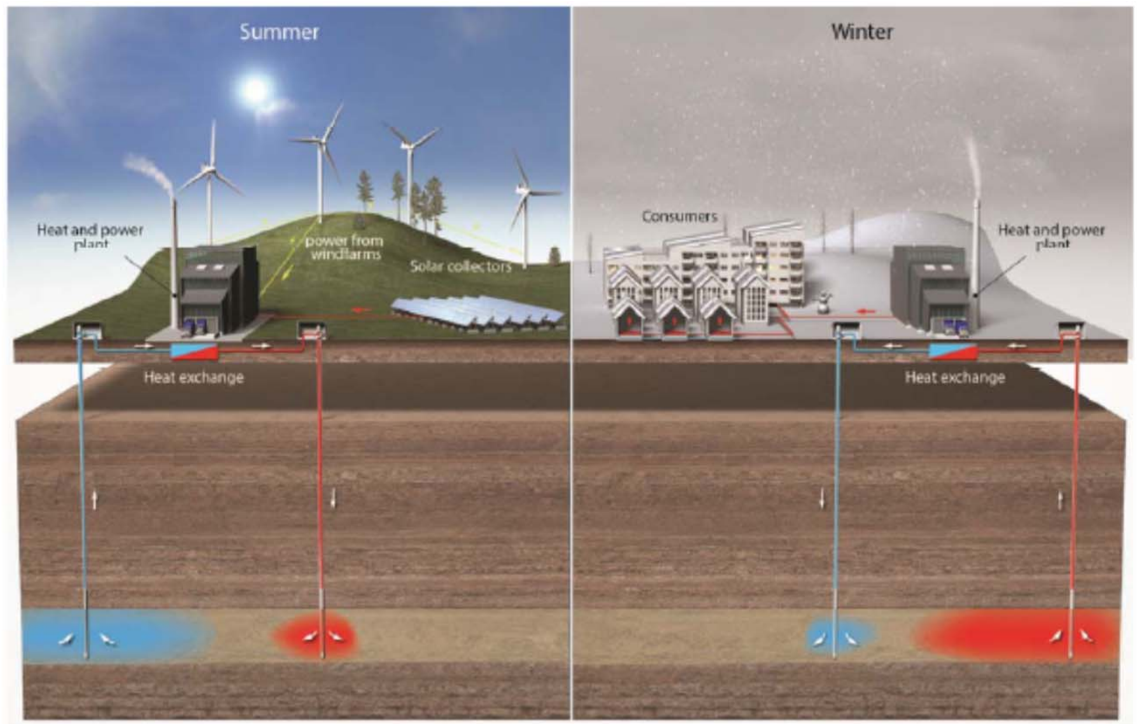
- Welcome and problem introduction (5 mins, Thomas Driesner)
- Simulating subsurface dynamics – approaches, workflows and suitable tools (15 mins, Thomas Driesner)
- The Geneva ATES project: from characterization and modelling and to system integration assessment (25 mins, Luca Guglielmetti and Alex Daniilidis)

HEATSTORE Webinar Series, Online, September 14, 2021

HEATSTORE: HIGH TEMPERATURE UNDERGROUND THERMAL ENERGY STORAGE

HEATSTORE:

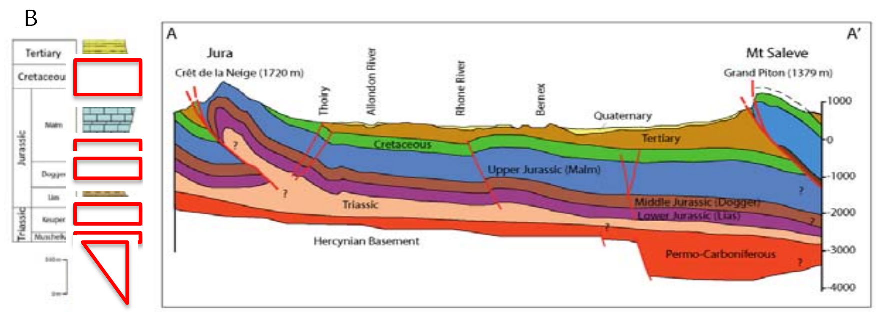
- Seasonal underground thermal energy storage using high temperature water (up to >90°)
- Different types of systems (ATES, MTES, PTES, …)
- HEATSTORE assessed different aspects of this new technology
- Today's webinar is on the aspects of characterizing the subsurface, predictive modelling its response to operation, and integration of the results into energy system modelling at the example of HEATSTORE's Geneva pilot

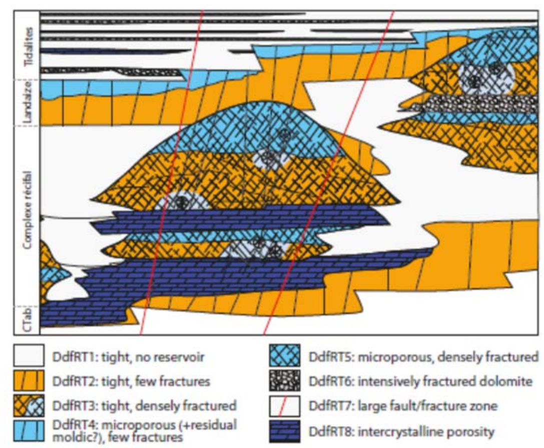


Source: GEUS, HEATSTORE deliverable D1.1

SIMULATING SUBSURFACE DYNAMICS

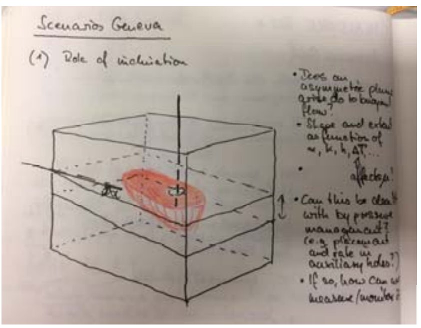
- Efficient way to assess feasibility and operation scenarios
- HT-UTES: tougher challenges than LT-UTES
  - Geologic and hydrologic complexity on different scales
  - Thermo-elastic & geochemical effects
  - Potentially stronger thermal dissipation
  - Wells more expensive
- Geneva example = the most complex of all HEATSTORE sites
  - Simplistic reservoir models may have limited value
  - Understand impact of complex geology
  - Ideally: provide input for decision making

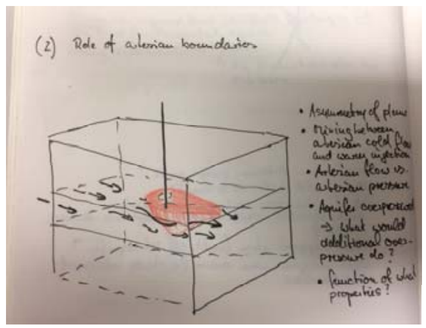


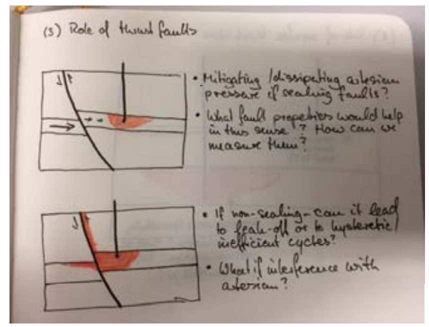


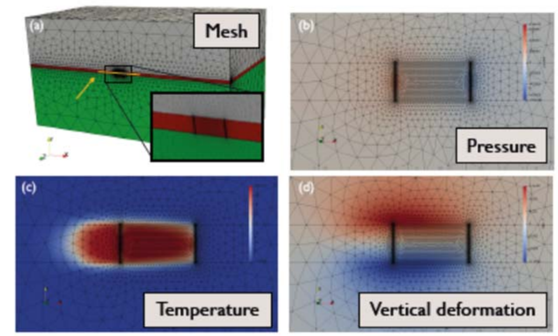
Rusillon 2017

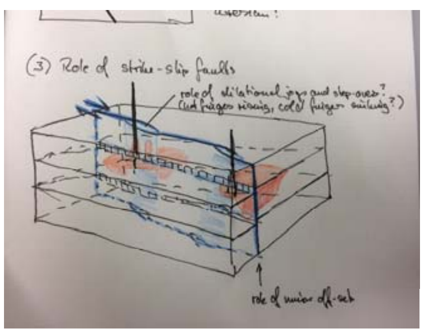
HOW DID WE APPROACH IT? – BRAINSTORMING SESSION ON GEOLOGY & HYDROLOGY TO IDENTIFY RELEVANT SCENARIOS

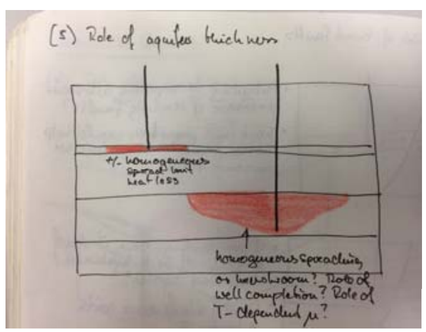








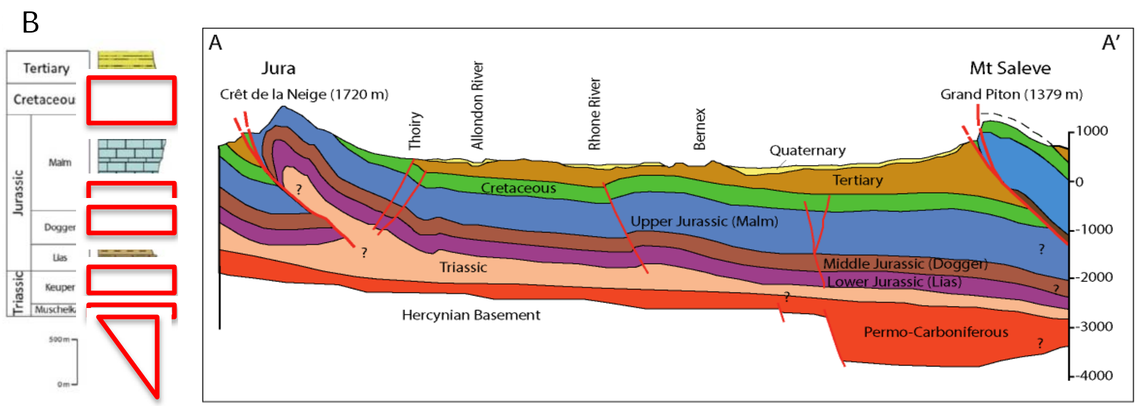


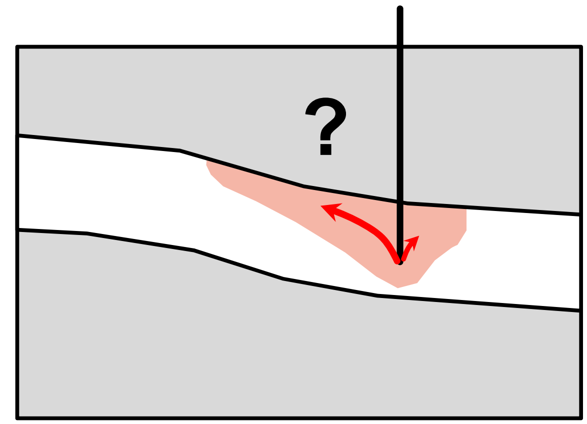


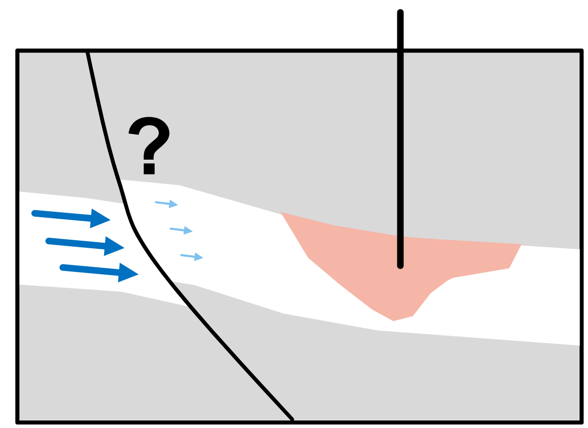
- "Eye-opener", allows identifying foreseeable problems by not limiting ourselves to simplified systems
- This should also aid developing testing/monitoring strategies
- Understanding system behavior can aid developing production scenarios even for sub-optimal cases

EXAMPLE 1:

TH SIMULATIONS – ASSESS IMPACT OF LARGE-SCALE GEOLOGY

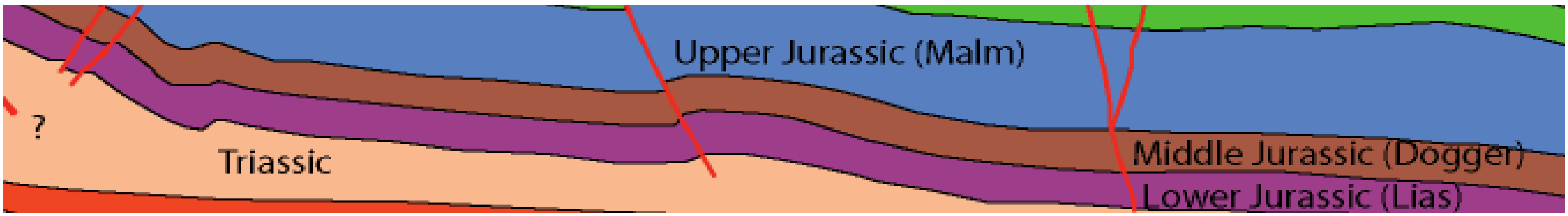




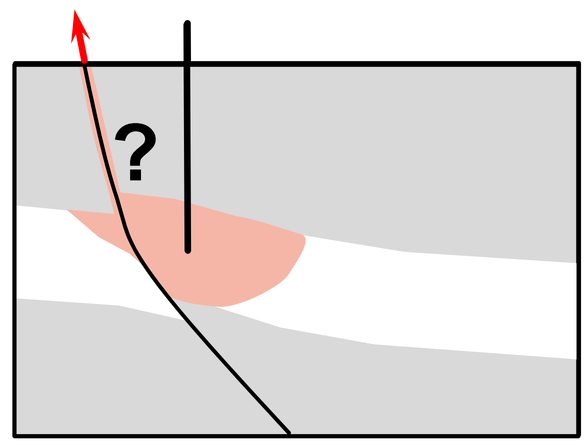


- Non-horizontal layers -> Buoyancy flow of hot water?
- Artesian boundary conditions -> Directional flow everywhere? Do faults play a role in dissipating it?
- How well is this geology established in detail? Is the buckle in the center real and optimal storage?

EXAMPLE II :TH SIMULATIONS – FAULT-AQUIFER INTERSECTIONS

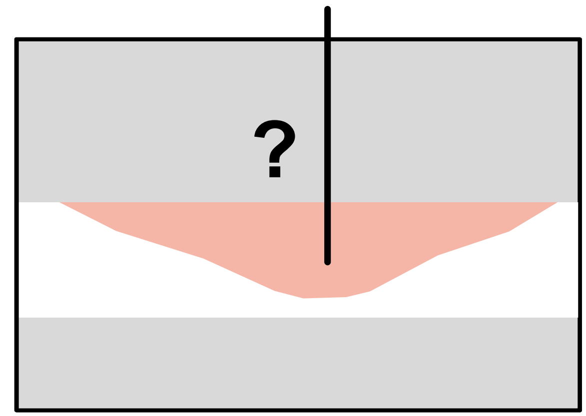


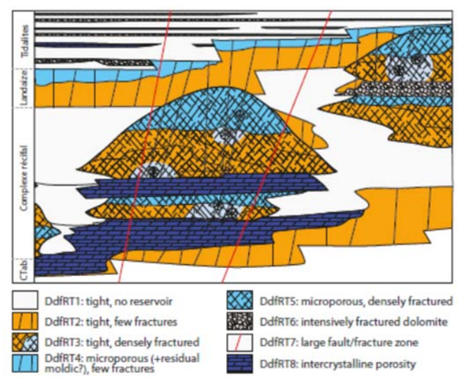
- If injecting near a fault
  - Where will the hot water go?
  - Are storage/production cycles hysteretic or not?
  - Strike-slip fault intersections? Dilational jogs? Minor vertical off-sets? Internal fracturing?
- What's the role of fault hydraulic parameters?
- What's the role of fault "size"?

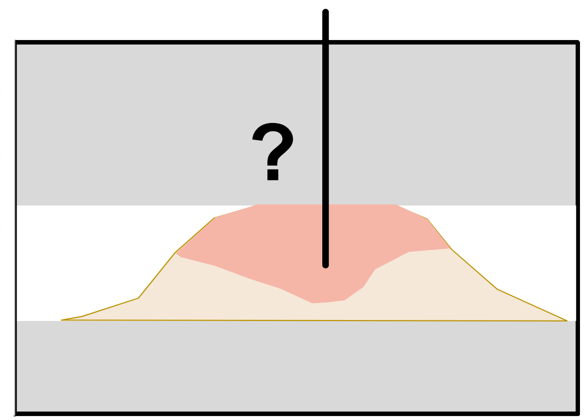


EXAMPLE III.TH SIMULATIONS – DIFFERENT TYPES OF AQUIFERS

- +/- Planar layers
  - Homogeneous plume shape or mushroom?
  - Heterogeneous permeability/porosity?
- Reef complexes
  - Thermal efficiency of "inverted mushroom" shape?
  - Permeability contrast to surroundings?
- Multiple Aquifer Storage

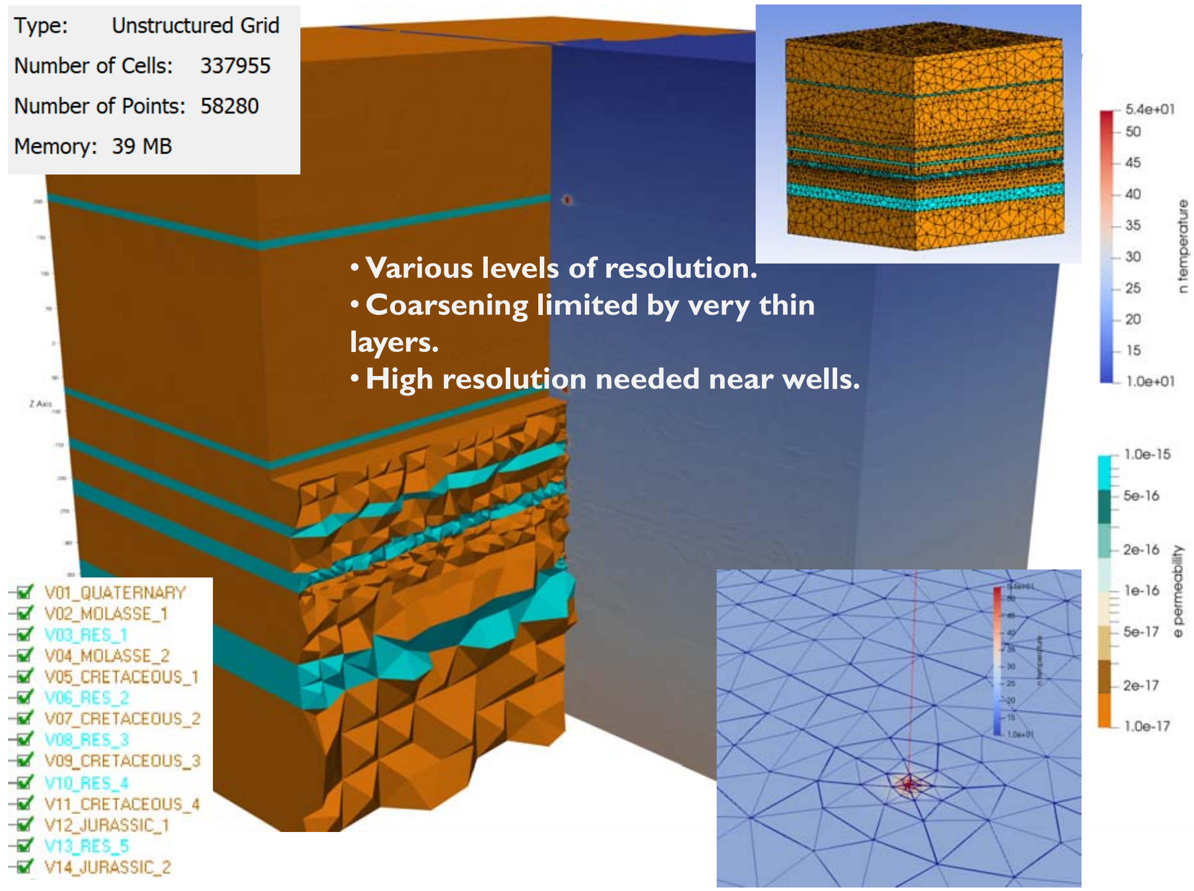






WORKFLOW

- ETH + UniGe + SIG created a TH modelling workflow.
  - UniGe: geometry/geomodel data
  - UniGe+SIG: input parameters
  - ETH: simulator-compatible geometrical model
  - ETH: meshing (ICEMCFD)
  - ETH: semi-automated simulation (n=324) setup and analysis
- PLEASE note: at this stage no truly site-specific model was run; a more abstract model aided understanding system behaviour



SCENARIOS SIMULATED FOR GENEVA CASE (J. MINDEL)

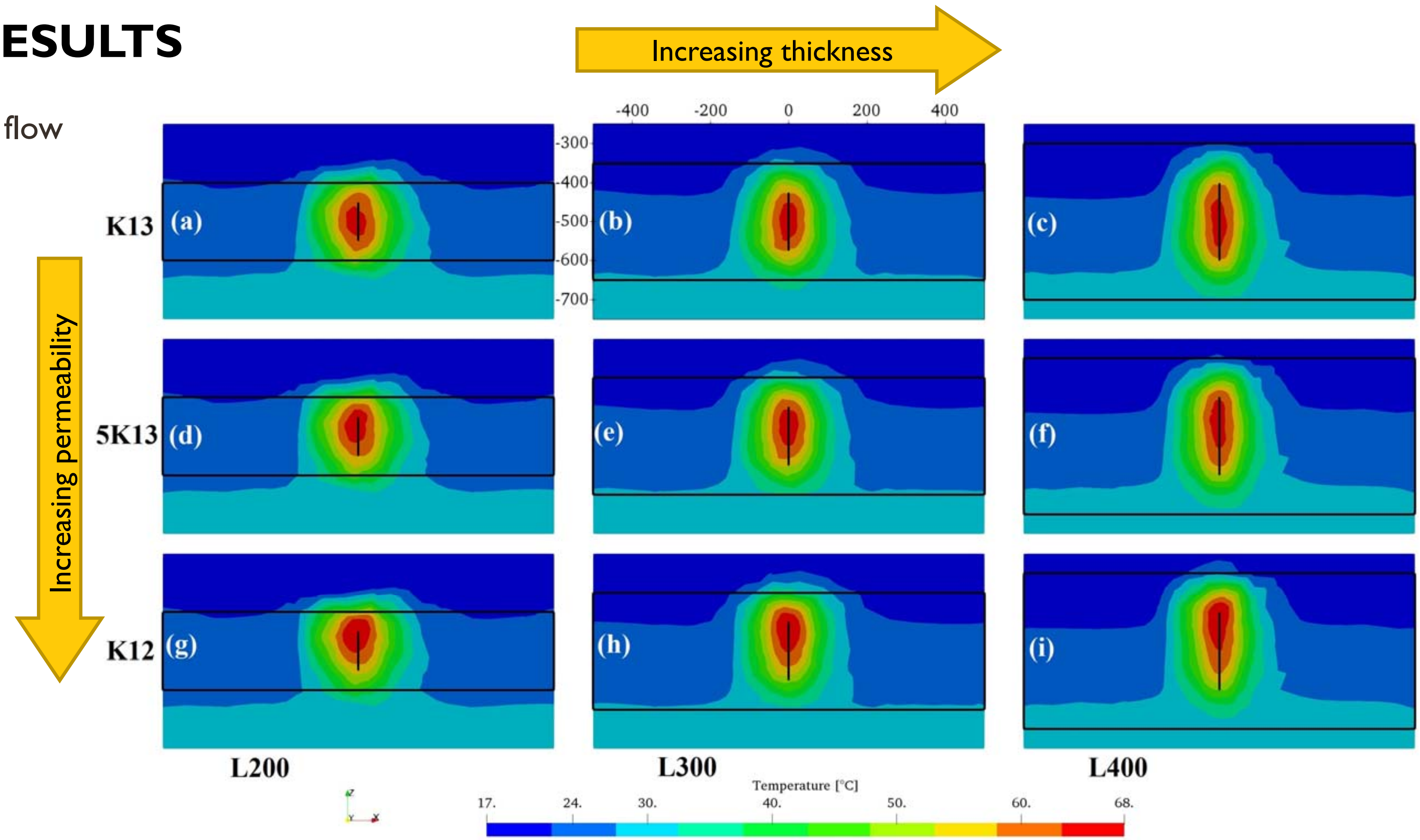
- **324** simplified model simulations were run for sub-scenario variant parameters, which are:

324

  - ✓ **Parameter 1:** Aquifer permeability ($10^{-13}, 5 \cdot 10^{-13}, 10^{-12}$ $[m^2]$)
  - ✓ **Parameter 2**: Aquifer thickness. ($200, 300, 400$ $[m]$)
  - ✓ **Parameter 3:** Aquifer dip **(0°, 15°)**
  - ✓ **Parameter 4:** Well strategy (**single, doublet, 5-spot**)
  - ✓ **Parameter 5:** Groundwater **(0 or 2 [m/yr]**)
  - ✓ **Parameter 6:** Fracture configuration (**None, 50 [m] Upwind , 50 [m] Downwind**)
    - ✓ More configurations are being run (varying distances from main well)
  - ✓ **Parameter 7:** Introduce reef structures. (centered on main well, various dimensions, i.e. $50, 100, 200$ $[m]$)
  - ⏱ **Parameter 8:** Introduce faulted geometry. (requires more meshing work).
    - ⏱ Strike-slip (possible addition of dilational step-overs), Thrust.

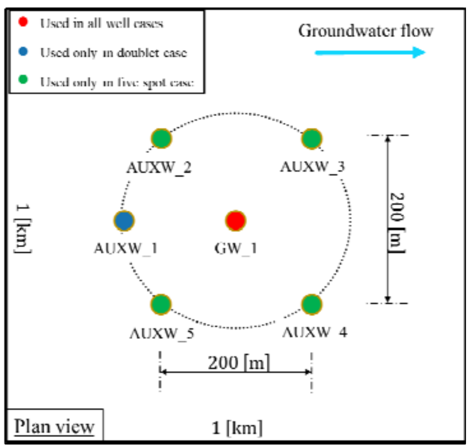
EXAMPLE RESULTS

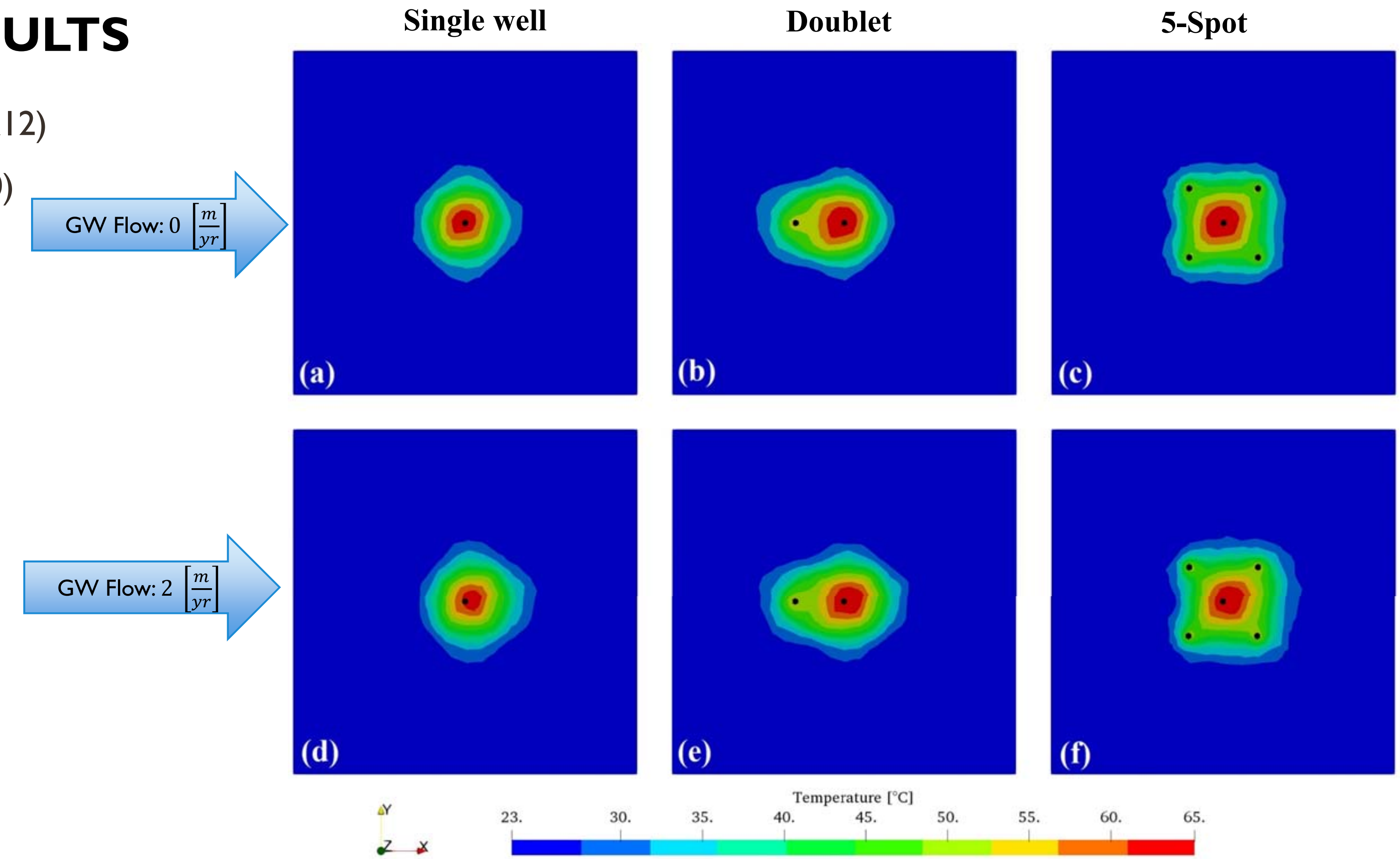
- No groundwater flow
- No dip
- No fractures
- Single well



EXAMPLE RESULTS

- Equal permeability (K12)
- Equal thickness (L200)
- No dip
- No fractures

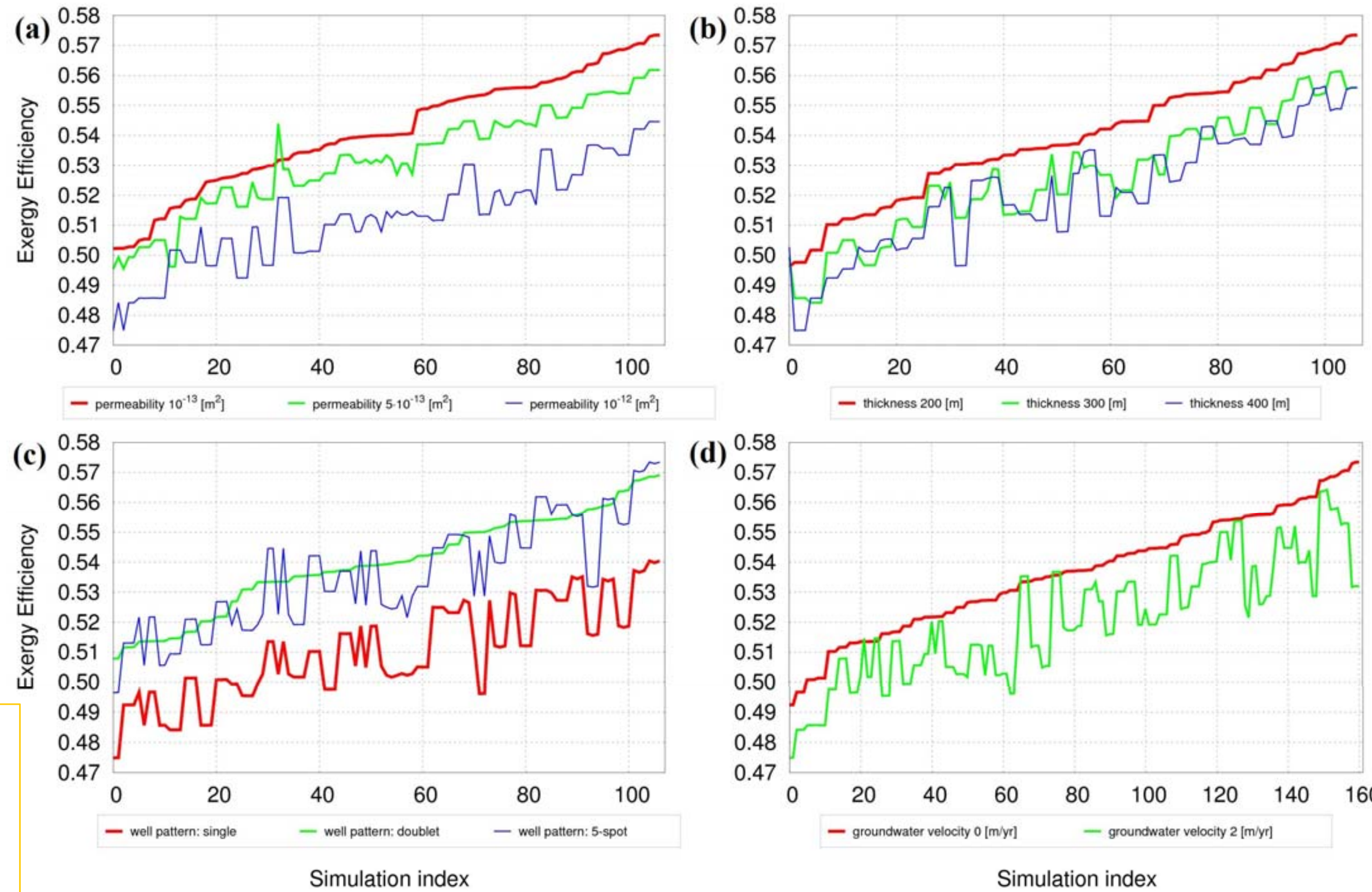




OVERALL RESULTS

- EOL exergetic analysis based on:
  (a) aquifer permeability,
  (b) aquifer thickness
  (c) well pattern
  (d) groundwater velocity
- Each graph represents the effect of a single parameter while coupled to all others.
- Simulation index is an arbitrary number assigned upon ordering.

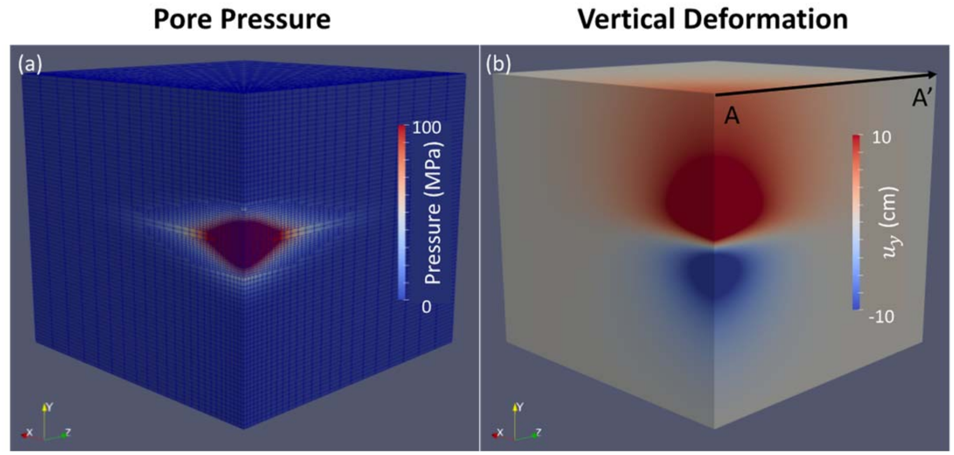
On all **324** simulations:
- 15 yearly identical cycles.
- Fixed flow rates (60 [L/s])
- Fixed input temperature (90 [°C])

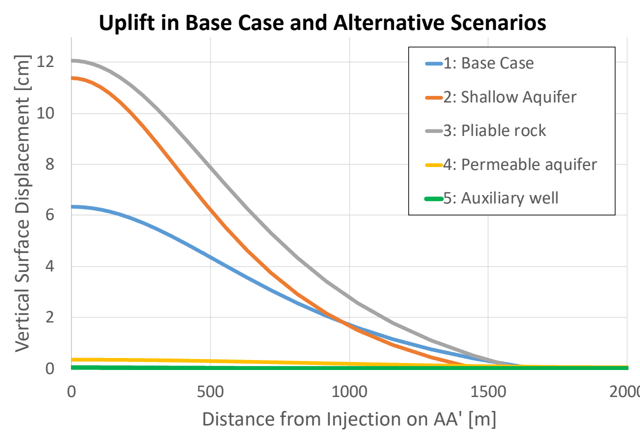


IMPACT MODELLING: THM SIMULATIONS OF THERMO- AND PORO-ELASTIC RESPONSES

(D. BIRDSELL)

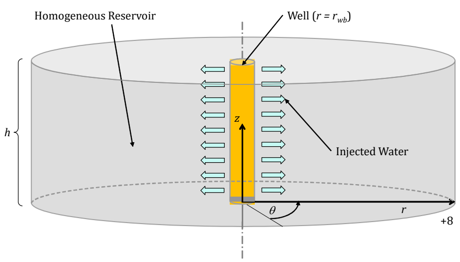
- Injection of pressurized hot water:
  - Poro-elastic response
  - Thermo-elastic response
  - Can lead to heave upon injection and subsidence upon production
- THM modelling an important tool for assessing these possible impacts, namely in populated areas or beneath surface infrastructures
- Sufficient permeability and auxiliary wells are crucial for pressure management

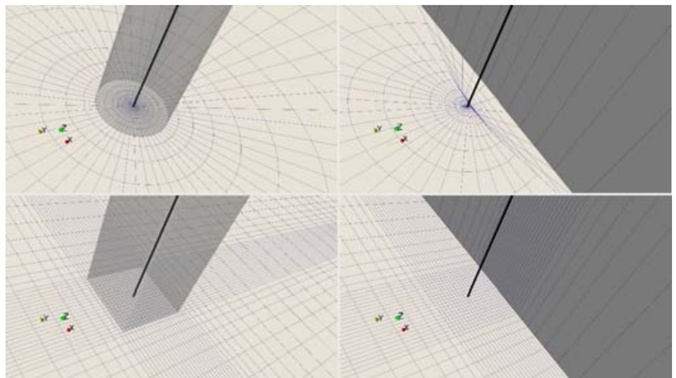


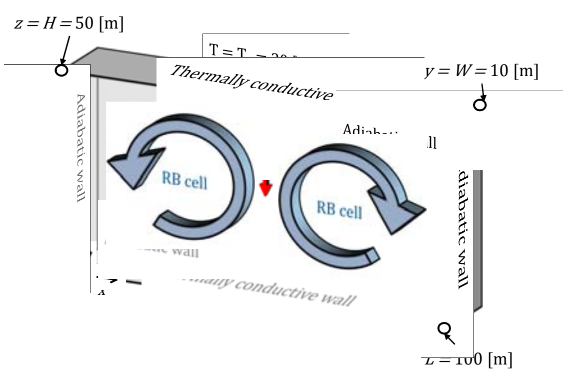


Birdsell & Saar
WGC 2020+1

WHAT TOOLS TO USE? RESULTS OF A BENCHMARKING STUDY







				Status (% of simulations complete)			
Part.	**Platform**	**Δt**	**ΔΩ**	**TC1**	**TC2**	**TC3**	**TC4**
BRGM	COMSOL v4.2a	SD	FE	[1] 100	[2] 50	[6] 100	[8] 0
	MARTHE	EI	FV	100	[3] 83	100	100
	ComPASS	EI	FV	100	100	100	100
ETHZ	Nexus-CSMP++	PE	H. FE-FV	100	100	100	100
	MOOSE	EI	FE	100	100	100	100
KWR	SEAWATv4	SD	FD	100	[3] 83	100	100
UPC	CODE_BRIGHT	EI	FE	100	100	100	100
STY	Tough3	EI	IFD	100	[3] 83	[7] 100	100
UniBe	PFLOTRAN	EI	FV	100	[4] 67	100	100
GEUS	Eclipse 100	EI	FD	[1] 100	[5] 50	[6] 100	[9] 0

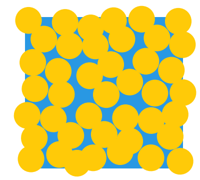
SD = Solver Depedent
EI = Euler Implicit
PE = Pseudo Explicit
FD = Finite Differences
IFD = Integrated Finite Differences
FV = Finite Volumes
FE = Finite Elements
H. FE-FV = Hybrid Finite Elements

[1] Some near-well data is missing.
[2] Cartesian mesh results are missing.
[3] Variant 3, radial mesh results are missing.
[4] Complete Variant 3 case is missing.
[5] Radial meshes cannot be constructed.
[6] Inaccurate input was used.
[7] Observed an unexplaned delay in transport.
[8] COMSOL was, reportedly, unable to converge.
[9] Eclipse 100 is, reportedly, unable to model TC4.

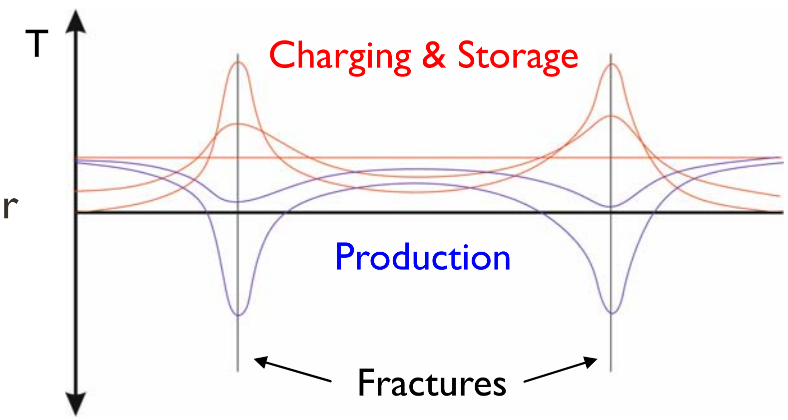
- 4 Test Cases
- 8 groups (BRGM, 2xETHZ, KWR, UPC, STY, UniBE, GEUS)
- 10 simulators (COMSOL, MARTHE, ComPASS, Nexus-CSMP++, MOOSE, SEAWATv4, CODE_BRIGHT, Tough3, PFLOTRAN, and Eclipse 100)
- Overall good agreement -> chosen workflows suited for HTES
- "Human factor" remains important, even when experienced people do the job

ONE SUGGESTION FOR FURTHER STUDY

- Can fractured media also be used for HT-UTES?
  - Porous media: grain size is so small that thermal equilibrium between water and rock is "instantaneous" upon charging and production
  - Fractured media could be "conduction limited":
    - spacing between fractures may be such that rock volume does not get completely heated, resulting in (much) lower production temperatures (thermal equilibration during storage period, need for ΔT between fluid and rock)
    - Densely fractured: better?
    - Large fractures: not favorable?



Grain size 1mm:
thermal equilibrium
in seconds or less



Fracture spacing / thermal equilibration time
10 cm / 1 hr
1 m / 3 d
10 m / 300 d