Planning chemical reservoir stimulation, technical steps and risk mitigation

Kristian Bär,

with contributions of John Reinecker, Katja Schulz, Marlene Stark, Clement Baujard, Eléonore Dalmais, Albert Genter, Regis Hehn, Nils Recalde-Lummer, Ingo Sass

MEET Project – Geothermal Winter School – February 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792037

Enhancement of Open Geothermal Systems

➔ use of any technique / physical process to enhance either the reservoir permeability or the hydraulic link between well and reservoir

proposed application order

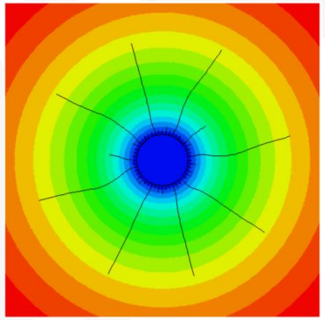
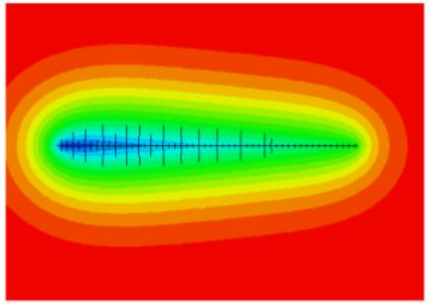
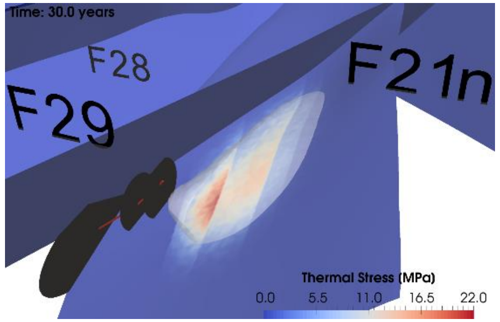
Technique	Description	Benefits	Disadvantage	Risks
well cleaning	part of the well testing procedure	part of	none	none
shock pumping	cleaning of fractures in the vicinity of the borehole by pulsed pumping (sucking)	can be part of the well testing procedure	?	none
thermal stimulation	opening of preexisting fractures by thermal contraction of the formation through cold water injection; needs propping material	easy to perform	- only on the injection side - needs permanent cold water injection if not propped - scaling issues	- undesired induced seismicity
chemical stimulation	dissolution of fracture clogging minerals	no induced seismicity	- needs proper handling of chemicals - spatially limited extend of effect - contaminated flowback	- no public acceptance - chemical reactions not as predicted - spill of stimulation acid
hydraulic stimulation	open preexisting fractures in the near borehole vicinity by pressurising the well; needs propping mechanism	relatively easy to perform	- induced seismicity - not applicable in unfractured reservoirs	- no public acceptance - undesired fluid pathways and contamination
hydraulic fracturing (fracking)	creating new fractures to engineer the reservoir by pressurising packered sections of the well	applicable in tight reservoirs	- induced seismicity - not applicable in naturally fractured reservoirs - contaminated flowback	- no public acceptance - undesired fluid pathways and contamination
drilling a sidetrack	increasing open hole section within the reservoir	predictable added value	costly	- drilling risks - limited added value due to proximity to the first borehole (hydraulics)
drilling additional wells	increasing open hole section within the reservoir at considerable distance to other wells	flexibility in managing well use (change injection-production, workover/maintenance)	very costly	- drilling risks - POS

Stimulation treatment options

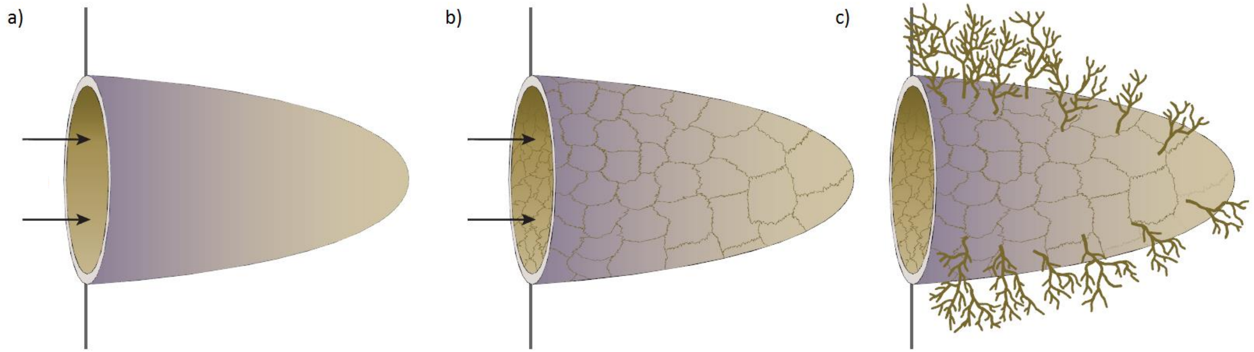
Geothermal Winter School 2021

proposed application order

Thermal
- Continuous
- intermittent

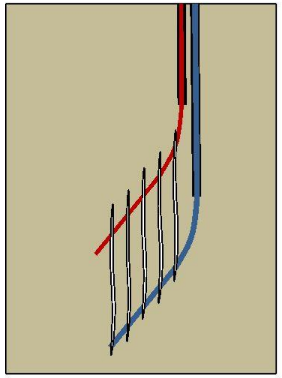
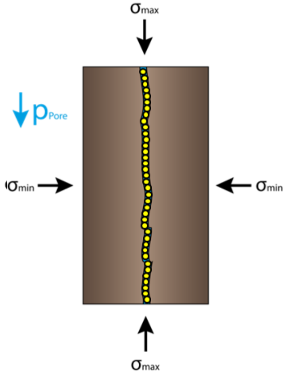




Chemical
- Acid washing
- Matrix acidizing
- Fracture acidizing

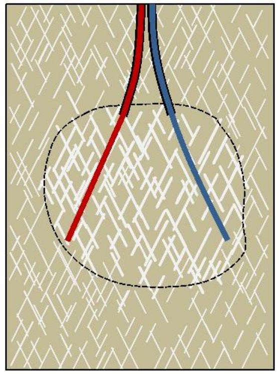
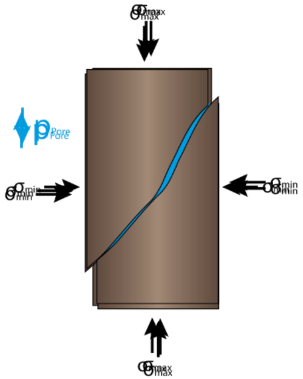


Hydraulic
- Waterfrac
- Hybrid
- Gel-proppant

unfractured

fractured

After Davies and Kelkar (2007), Jung (2013), Ghassemi and Tarasovs (2015), Hoffmann et al. (2018)

Introduction to Hydraulic Stimulation

Enhancement of pre-existing fracture permeability

Reactivation of pre-existing fractures

- **Increase of pore pressure**
- **Slip of pre-existing mechanical discontinuities**
- **Generation of larger apertures**

Mohr-Coulomb Criterion

$$\tau = c + \tan(\varphi) \cdot \sigma_n$$

$$\sigma_{eff} = \sigma_n - p$$

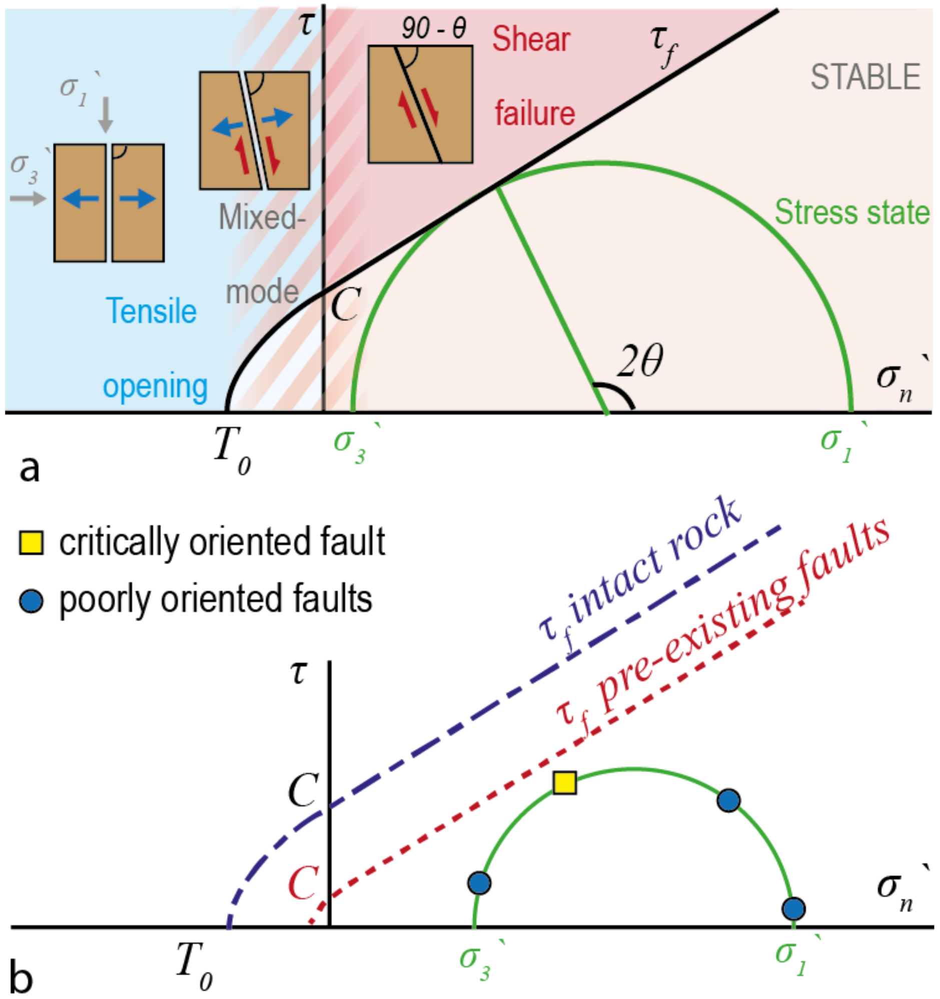
μ = coefficient of friction [-]

$$\mu = \frac{\tau_{eff}}{\sigma_{eff}}$$

Microseismicity

- **Identification of large structures**
- **Identification of hydraulic diffusivity**

The goal is the stimulation of the fracture network, mostly in crystalline rock



After: Buijze et al. (2019)

Introduction to Chemical Stimulation

‘**Matrix acidizing**’ is performed below fracturing rate and pressure,
‘**Fracture acidizing**’ is performed above fracturing re-opening rates and pressure.

Enhancement of fracture permeability by **dissolving vein mineralization** and by associated well cleaning removing the reservoir damage in the near-wellbore area.

Acidization / Chemical stimulation

- **removal of skin damage** caused by drilling operation.
- increase the **connection between well and reservoir (near-well permeability).**
- **increase of formation permeability** in undamaged wells.

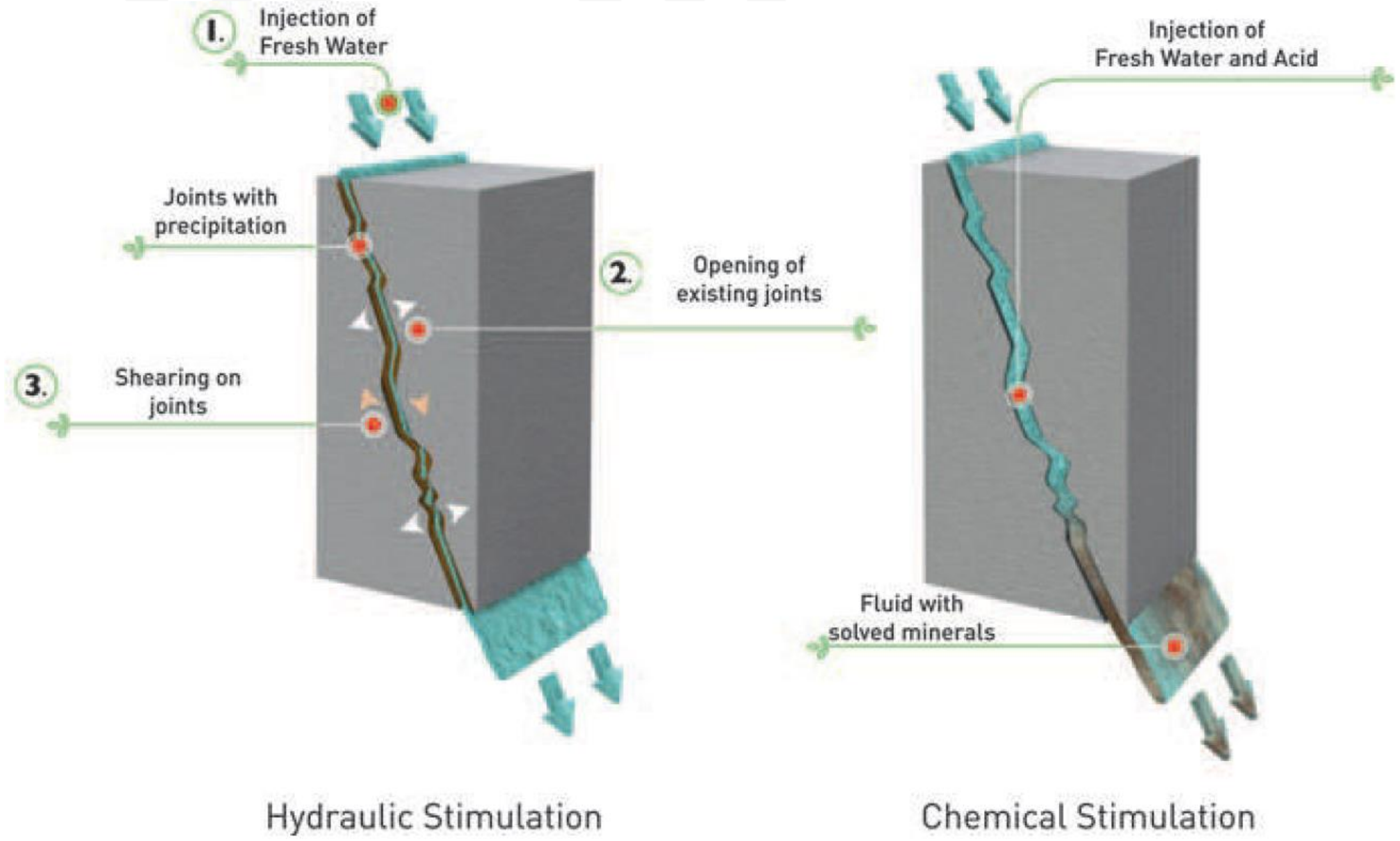
Acids are to be selected for the reservoir geology and mineralization.

The injection of acids is performed

- **at modest flow rate (below pressures for hydraulic stimulation)**
- **Pre-flush, usually with hydrochloric acid (HCl) or strong organic acids (SOA)**
- **Main-flush usually with a HCl or SOA – hydrofluoric acid mixture (HCl-HF/SOA-HF).**
- **Post-flush/over-flush usually with weakly concentrated HCl acid solutions or with KCl-, NH_4Cl- solutions and freshwater.**

Improvement of the well conditions can be generally observed (largely varying success).

Schematics of Chemical Stimulation



Kölbel & Genter (2017)

Hydraulic stimulation effectiveness

Comparison of pre- and post-**hydraulic stimulation** equivalent porous medium permeabilities, mostly from well injectivity indices measured in low-pressure tests.

Projects and wells	$K_{pre\text{-}stimulation}$ [10^{-15} m²]	Q_{inj} [l/s]	ΔP-cs [MPa]	V_{inj} [m³]	$K_{post\text{-}stimulation}$ [10^{-15} m²]	Increase
Hijiori, Japan (Granodiorite)						
SKG-2: 14 m open hole below 1788 m	0.13	9.2	10	126	2.4	18
SKG-2: 14 m open hole below 1788 m		98	??	1,080	6.6	51
HDR1: 54 m open hole below 2158 m	0.02	72	16	2,100	2.0	10
Rosemanowes (Granite)						
RH11: 722 m open hole below 1413 m TVD	0.01	195	25	400	~1.0	100
RH12: 357 m open hole below 1750 m TVD	0.002	90	14	12,000	1.0	500
RH11-12 inter-well (170 m) permeability	0.002		numerous injections		0.5	250
Soultz, France (Granite):						
GPK1: 650 m open hole below 2750 m	0.013	36	9	20,000	3.1	238
GPK1: 850 m open hole below 2750 m with fault	0.19	36	8.5	40,000	3.5	18
GPK2: 638 m open hole below 4402 m	0.06	51	13.5	23,400	1.6	27
Basel (Granite)						
Basel-1: 371 m open hole below 4629 m	0.01	55	30	11,600	6.0	600
Bad Urach (Gneiss)						
Urach-3: 1125 m open hole below 3320 m	0.004	30-40	34	6,000	0.03	8

After: Keith Evans, ETHZ, 2016

Chemical stimulation effectiveness

Comparison of pre- and post-**chemical stimulation** injectivity indices measured in low-pressure tests.

Chemical Stimulation	Date	Well	Quantity in m^3	Flow Rate in l/s	Injectivity in l/(s·bar) before	Injectivity in l/(s·bar) after	Increase
HCl (0.18%)	Feb 2003	Soultz-GPK-2	650	30	0.4	0.5	1.25
HCl (0.18%)	Feb 2003	Soultz-GPK-2	810	15			
HCl (0.09%)				30			
HCl (0.45%)	June 2003	Soultz-GPK-3	865	20	n.d.	n.d.	
HCl (0.20%)	Feb 2005	Soultz-GPK-4	4700	27.5	0.2	0.3	1.5
Regular Mud Acid (RMA): HCl (12%), HF (3%)	May 2006	Soultz-GPK-4	200	22	0.3	0.4	1.33
Nitrotriacetate Acid (NTA): Na_3NTA (19%), NaOH	Oct 2006	Soultz-GPK-4	200	35	0.4	0.3	0.75
Organic Clay Acid (OCA): $C_6H_8O_7$ (5-10%), HF (0.1–1%), HBF_4 (0.5-1.5%), NH_4Cl (1-5%)	Feb 2007	Soultz-GPK-3	250	55	0.35	0.4	1.14
Organic Clay Acid (OCA): $C_6H_8O_7$ (5-10%), HF (0.1–1%), HBF_4 (0.5-1.5%), NH_4Cl (1-5%)	March 2007	Soultz-GPK-4	200	55	0.4	0.5	1.25
biodegradable chelating agent GLTA (glutanic acid N, N – diacetic acid)	June 2013	Rittershoffen-GRT-1	250	5	1.0	1.7	1.7
Methanesulphonic acid, Ammonium hydrogendifluoride	December 2019	Soultz-GPK-4	100	10	0.59	0.63	1.07

After: Nami et al. (2008), Baujard et al. (2017) and Hehn et al. (2020)

Some requirements for commercial EGS

Target temperature, flow rate and reservoir hydraulics

Production temperature: >180°C
...for more efficient electricity production.

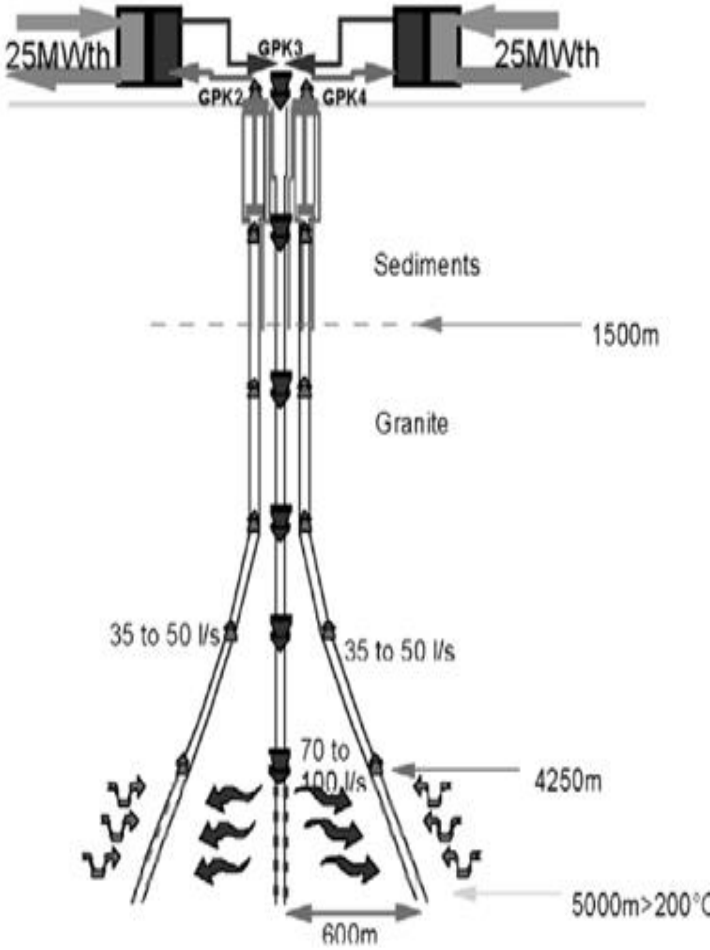
Production flow rate: > 40 l/s
...to give adequate energy yield per well.

Surface area of rock in the reservoir > 10^6 m^2 (1 km^2)
...to give adequate lifetime of production (> 20 years) before cooling reaches the production well.

Reservoir impedance to flow, Z_R < 0.2 MPa/l/s
This is the pressure difference between the wells required to drive a circulation of 1 l/s.

To produce 40 l/s, the pressure difference at reservoir depth should be < 8 MPa.

➔ reservoir impedance determines pumping power required to operate a system.



After: Keith Evans, ETHZ, 2016

How close have we come to the targets?

Result from prototype (research) EGS built and circulated to date

Projects and wells	Wells	Well sep. [m]	Duration [days]	Q_{prod} [l/s]	Res. Imp* [MPa/l/s]
Targets				>40	<0.2
Fenton Hill, New Mexico (1972-1996)					
upper 2-well system (2.8 km)	GT2a-EE1	200	282	[illegible]	1.7
deep 2-well system (4.2 km)	EE3a-EE2a	[illegible]	[illegible]	[illegible]	4.0
Hijiori, Japan (Granodiorite)					
upper 4-well system (1.8 km)	[illegible]	[illegible]	[illegible]	[illegible]	0.4-0.7
deep 3-well system (2.2 km)	[illegible]	[illegible]	[illegible]	5.8	1.4/2.1
Rosemanowes, Corn[illegible]					
3-well system (2[illegible]	[illegible]H12-11/15	120/135	300	2.3/14.0	4.1/0.7
Soultz, France (19[illegible]					
upper system (3.[illegible]	GPK1-GPK2	450	120	25	0.2
deep 3-well system (5.0 km): 2005	GPK3-GPK2/4	600	~150	12/3	0.6/1.9
deep 2-well system (5.0 km): 2008	GPK3-GPK2**	600	~160	25**	~0.55
deep 3-well system (5.0 km): since 2017	GPK2-GPK3/4	600	~	35	~0.4
Habanero-Cooper Basin, Australia (2003-2014)					
2-well system (4.2 km): 2009	Hab1-Hab3	560	60	15	0.7***

Stimulation is a basic requirement in basement reservoirs to reach economic flow rates!

**pressure difference across reservoir / production flow rate; **with downhole pump; ***surface impedance*

After: Keith Evans, ETHZ, 2016

Enhancement of Open Geothermal Systems

Key questions and requirements

Which strategy is the best

to **mitigate induced seismicity**

and **enhance efficiency of stimulation**

in **various geological settings?**

What information is needed

for the **proper planning** and **risk assessment**

of **safe stimulation** operations?

Operation plan for chemical stimulation

Pre-investigations, work flow and technical considerations (based on the UDDGP demosite)

1. Aim and background
2. Technical assessment of site
3. Reservoir assessment to define stimulation targets
4. Chemical treatment design
5. Technical operation
6. Documentation and Monitoring
7. Risk assessment

1. Backgrounds to be considered

What limits and constraints are to be considered while planning an operation?

Physical limits to stimulation treatments:

- Maximum allowable treating pressure limits injection rates and type of treating fluids.
- Casing size limits flow rates and might enhance pipe erosion.
- Well design (diameters, deviations) limits the equipment and materials that can be used.
- Casing integrity prevents or limits the type of treatments that can be employed without compromise.
- Completion tools and their location limit where the treatment is placed and the possible rates and volumes.
- Can target zones be isolated from other intervals through packers, perforation etc.?

Typical reservoir constraints:

- Production failures: skin zone from drilling or previous injection, low natural permeability
- Physical location of the target zones and their thicknesses: pay zone qualities limit or dictate treatments

After: Economides & Nolte (2000)

1. Definition of stimulation aims

Enhancement of primary permeability of **fractured reservoir** by **dissolving vein mineralization or the rock itself** by chemical treatment in order to **improve wellbore hydraulic performance**.

The requirements on the stimulation fluid(s) are:

- Dissolve near wellbore skin
- Far reaching (retarded) acid system to enhance well connection to the fracture network
- Prevent precipitation of secondary minerals in the near field of the well
- Environmentally friendly / biodegradable to reduce environmental risks
- Suitable for reservoir conditions (high temperature, high pressure, compatibility with reservoir fluids)

General requirements on the operation are:

- No stimulation above fracturing rates and pressures ➔ no induced seismicity
- In case of induced seismicity: define thresholds, traffic light system and reaction and mitigation plan

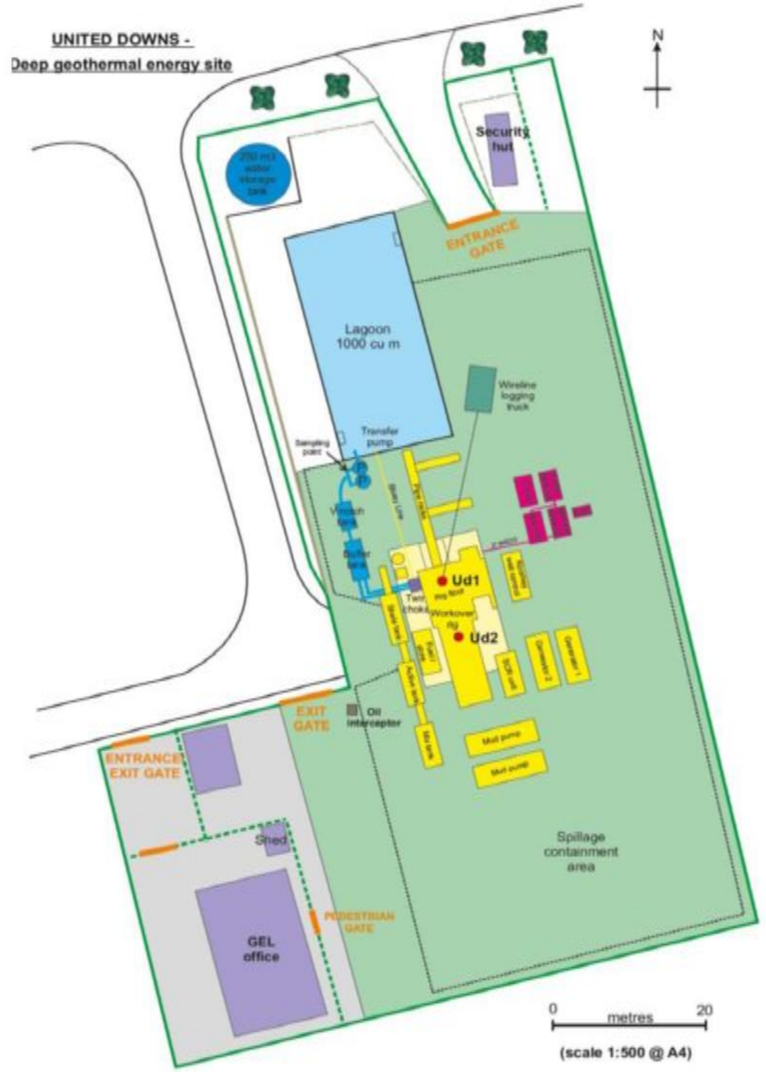
Geothermal Winter School 2021

2. Technical assessment of the target site

Detailed analyses of the well location and site specific availabilities.

Well site:

- What water and power supply is available?
- What water storage capabilities are available?
- Who quickly can the water storage be replenished?
- How is the sealing of the drill site?
- How is the drill site protected against chemical spills?
- What waste treatment is possible on or near site?
- How are storage and parking capacities?
- Crew containers, sanitary units, lighting?
- Are working hour or noise restrictions in place?



2. Technical assessment of the target well

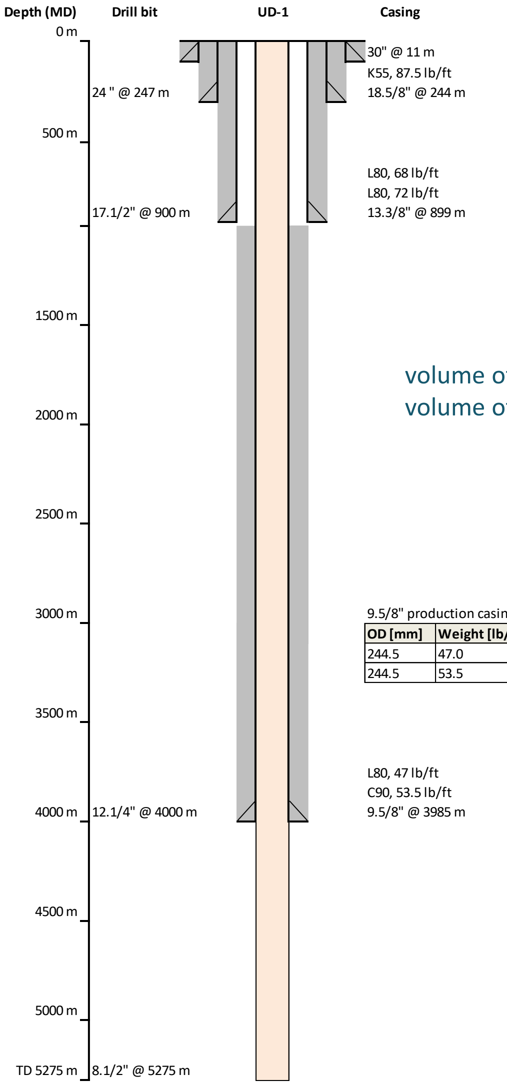
Surveys on well condition, well integrity, well damage and well hydrology

Well design, condition and integrity:

- Wellhead configuration, casing and cementation:
  Has a well integrity assessment been performed e.g. cement bound logs, multi-finger calipers, borehole-image loges, assessment of joints and casing quality (erosion or tool wear)?
- Have pressure tests been performed after cementing of each section?
- For the open hole section: Is a well deviation survey, dog-leg survey, break-outs etc. available?

Well damage and hydrology

- Are any indications of well or reservoir damage present from the open hole section?
- Drilling mud or additives used in the reservoir section?
- What kind of hydraulic test data is available?
  Injection tests, formation integrity tests, drill stem tests, production tests etc.



volume of 9.5/8” casing ≈ 150 m^3
volume of 8.1/2” open hole: ≈ 47 m^3

9.5/8" production casing

OD [mm]	Weight [lb/ft]	Grade	ID [mm]
244.5	47.0	L-80	220.5
244.5	53.5	C90	216.8

KOP @ 3390 m MD

14° @ 3973 m TVD

final inclination:
33.5° @ 5067 m TVD

3. Reservoir assessment to define stimulation targets

Target zones are defined/selected using log data derived while drilling and from wireline.

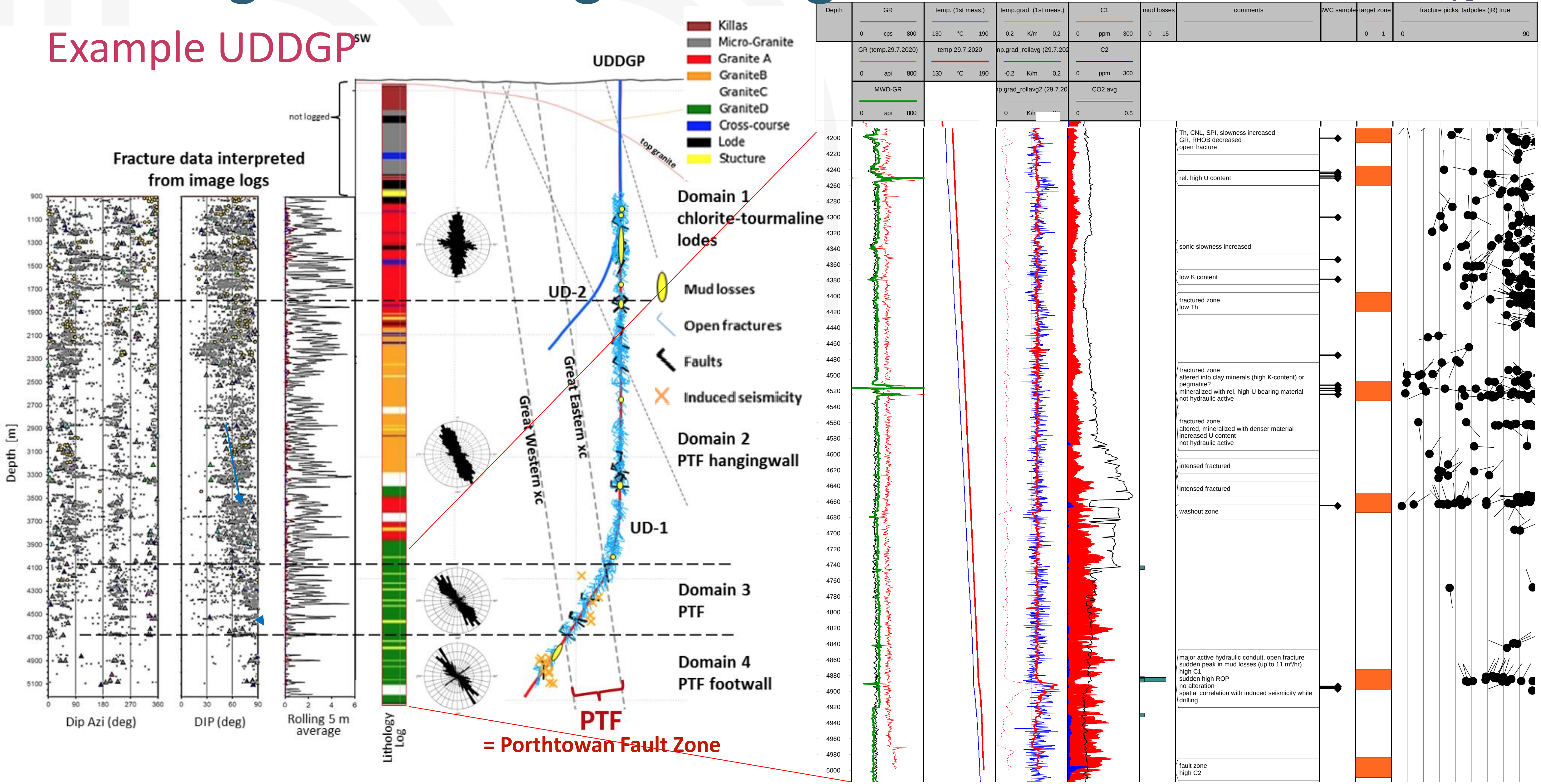
Main goal is to identify fractures as these do represent the only pathways for fluid in granite.

This is mandatory for target selection. Additional there must be **at least one sign of influx into or losses from the well**.

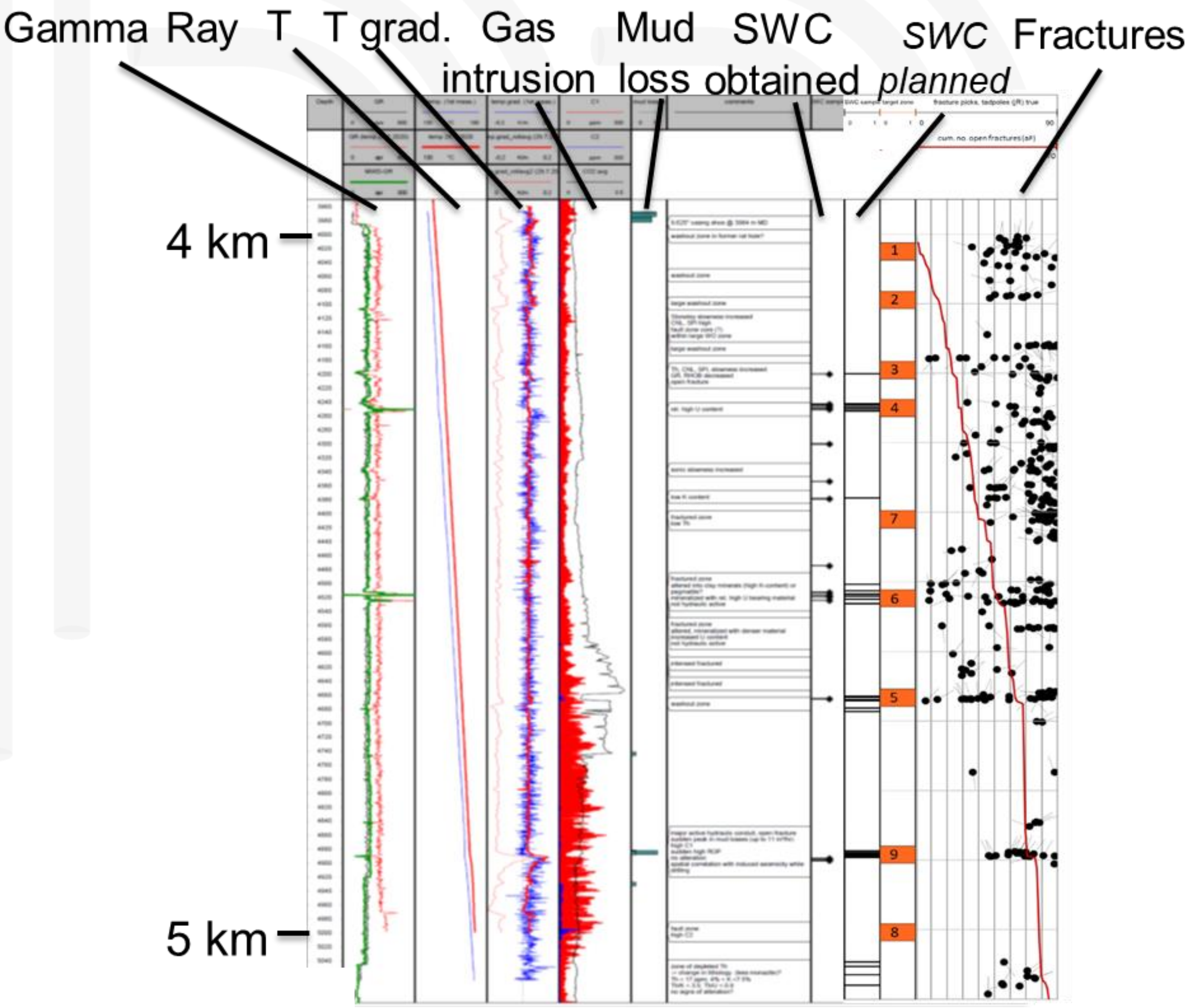
Log	Simplified interpretation
Spectral gamma ray log	Negative anomalies indicate open void spaces, Positive anomalies (increase in radioactive decay) indicate **hydrothermal alteration zones**
Temperature and geothermal gradient	Anomalies indicate circulation of fluids (convective heat transport)
Gas logs (while drilling): **Methane (C1), Ethane (C2) and CO_2**	Gas intrusions indicate permeable zones
Mud losses (while drilling)	Mud loss indicates permeable zones
Ultrasonic televiewer: **Fracture pics,** **especially open fracture pics**	Local increase of open fractures indicates permeable zones. Fractures can be used to localise fault- or damage zones, Closed fractures can also indicate hydrothermally altered zones, assuming closure due to mineralisation or stress field rotation
Caliper logs (multi-arm)	Borehole geometry, borehole breakouts
Flowmeter, Spinner, PTS, PLT log	Infiltration or production zones
Induced seismicity	Event location might allow to identify fractures and fault zones

3. Using borehole logs for target identification

Example UDDGP[SW]



3. Using borehole logs for target identification



Target zones defined using:

- temperature log,
- gamma log
- mud losses,
- gas influx,
- drilling breaks and
- fracture density and UXPL log

Targets:

- all granite varieties
- open fracture zones
- mineralized fracture zones

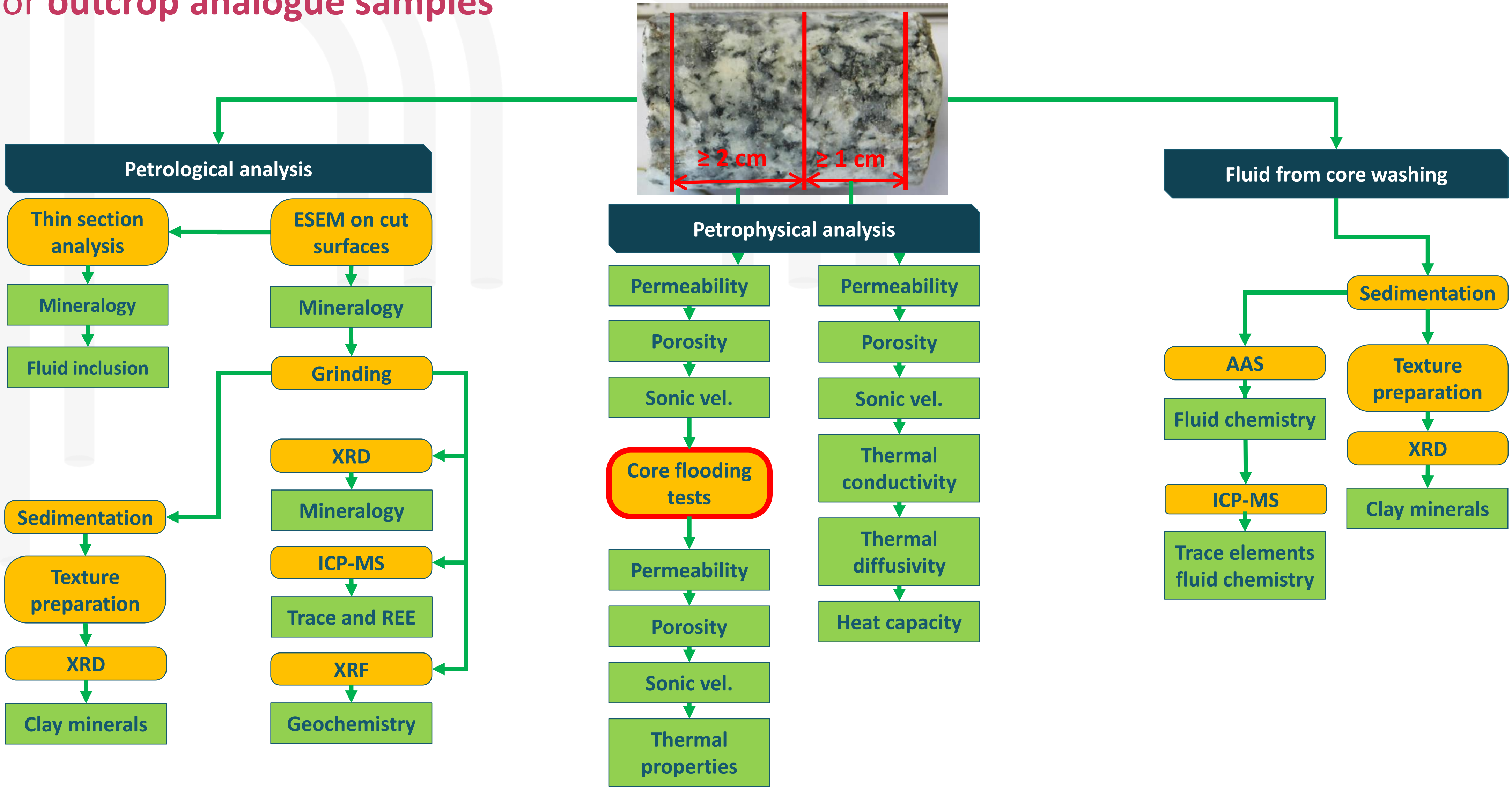
Risks to be avoided:

- doglegs,
- borehole breakouts or washouts
- open fractures

Geothermal Winter School 2021

3. Laboratory pre-investigations

Reservoir assessment can be complemented by analysis of **reservoir samples** (cuttings or cores) or **outcrop analogue samples**



4. Acid selection for granitic reservoirs

Which acid(s) are suitable for chemical stimulation of granitic reservoir rocks and their typical (hydrothermal) alteration minerals?

Biotite and plagioclase are the **least stable mineral phases** in granite and break down easily through **hydrothermal alteration along fault zones forming secondary clay minerals** (illite, montmorillonite, kaolinite and chlorite).

Brine composition is in particular affected by hydrolysis of plagioclase (Ca, Na) and dissolution of biotite (alkali metals, Cl, F, B).

Secondary clay minerals reduce fracture permeability. Crystallisation of carbonates, fluorite, barite, and sulphides along fractures clog them as well.

Acidizing aims to dissolve especially the clay and vein minerals. Host rock mineral assemblage should not be attacked much.

Reactions may be affected by CO_2 and CH_4 in the system. Both have to be monitored while drilling whether they are present or not.

Portier et al. (2007)

4. Acid selection for granitic reservoirs

Which acid(s) are suitable for chemical stimulation of granitic reservoir rocks and their typical (hydrothermal) alteration minerals?

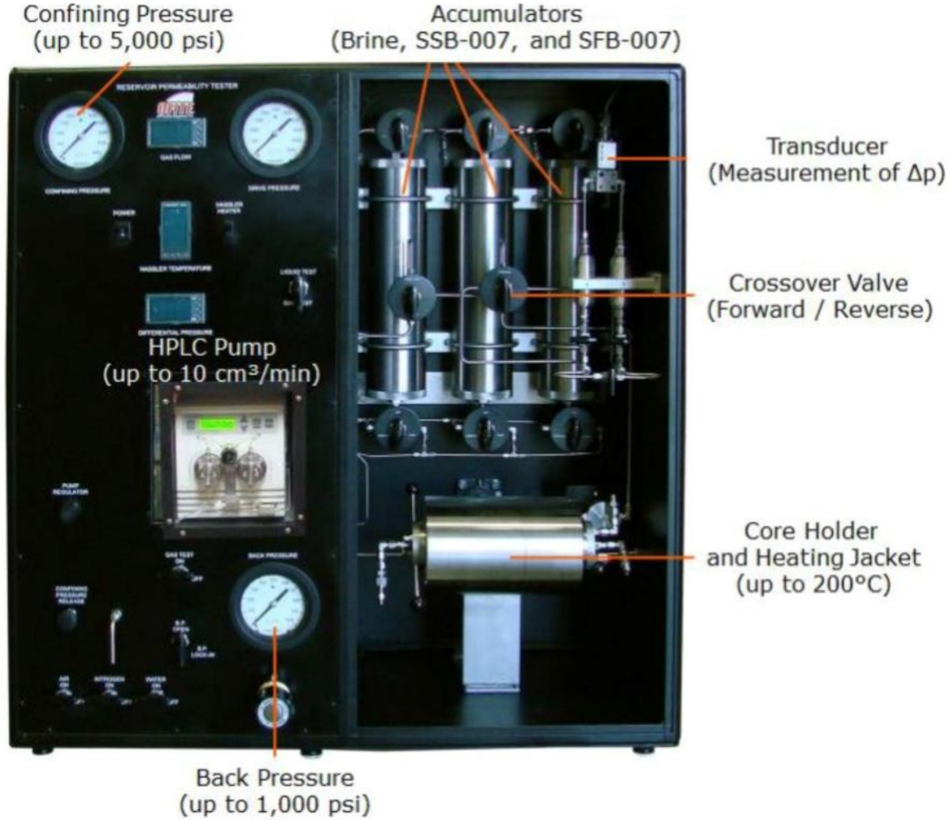
Minerals	**Solubility**	
	HCl	**HCl-HF**
Quartz	No	Very low
Felspars	No	Low to moderate
Micas	No	Low to moderate
Kaolinite	No	High
Illite	No	High
Smectite	No	High
Chlorite	Low to moderate	High
Calcite	High	High, but CaF_2 precipitation

Portier et al. (2007)

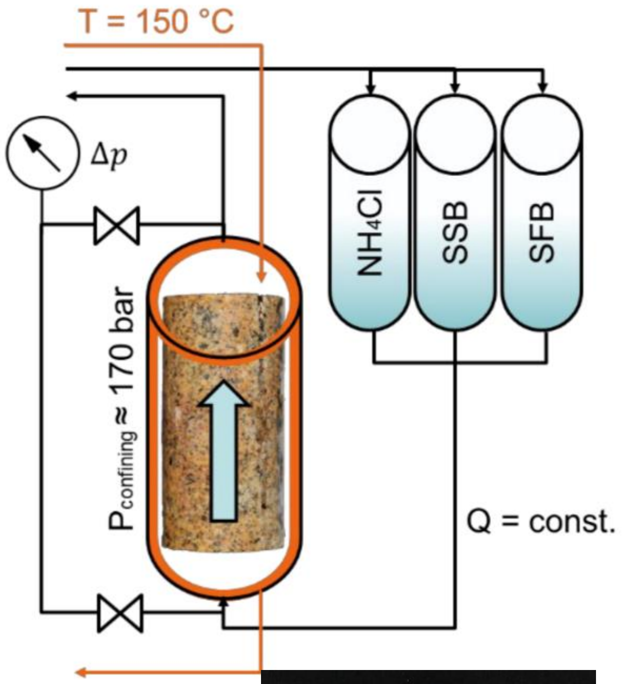
4. Acid selection - Core Flooding Tests

Acidification experiment under reservoir pressure and temperature to evaluate the efficiency of the acid to increase fracture permeability

- Can be performed on reservoir or outcrop analogue samples
- Temperature: 150 °C
- Confining pressure: 2500 psi (172.4 bar)
- Back pressure: 500 psi (34.5 bar)



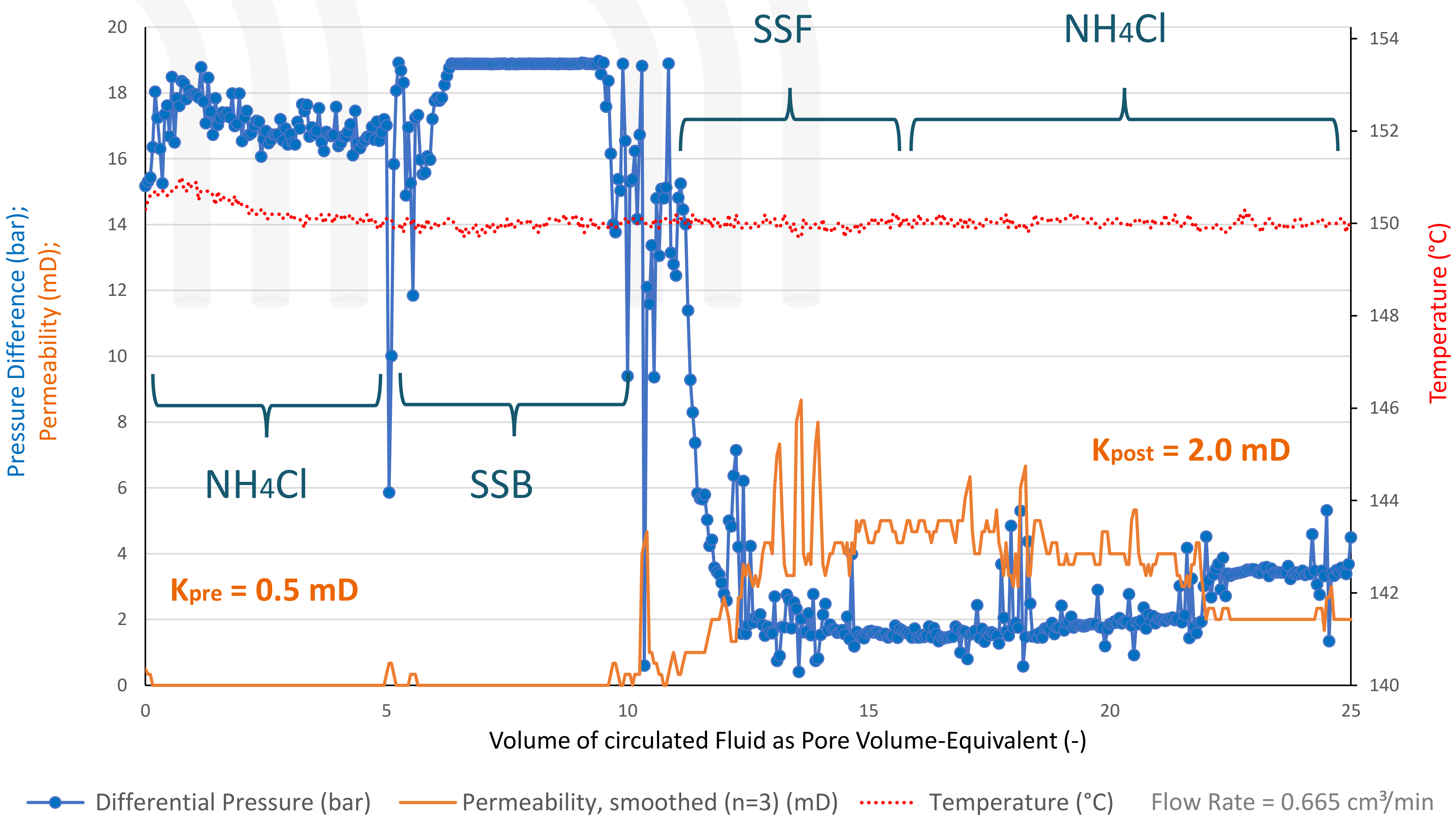
After: Lummer et al. (2018)



Permeability measurement before and after the acidification experiment

4.Core Flooding Test

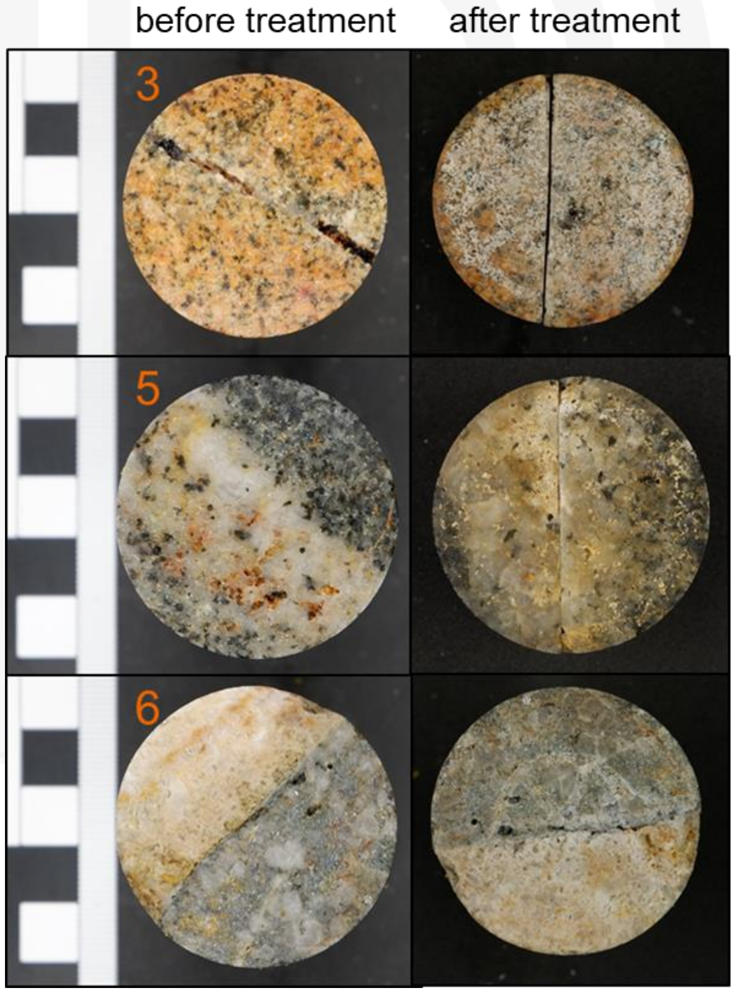
Example of an outcrop analogue sample with quartz vein

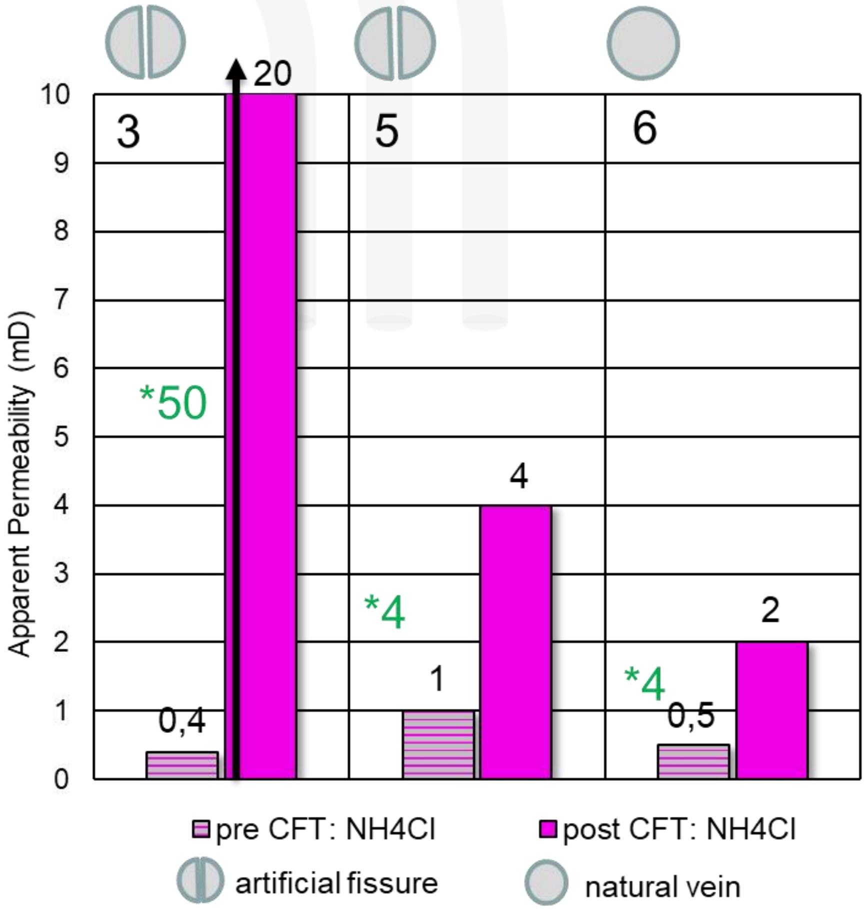


Geothermal Winter School 2021

4. Core Flooding Tests: before and after

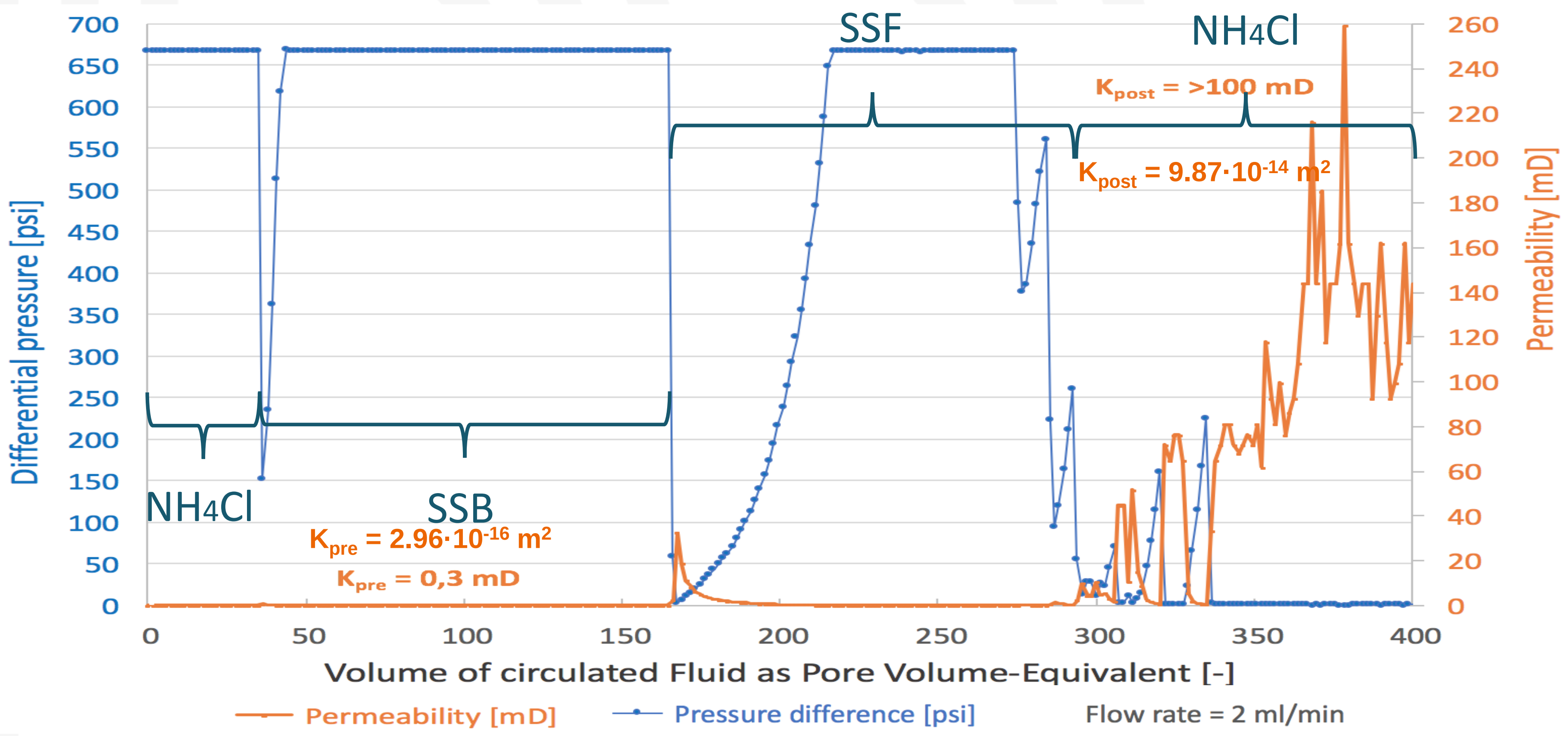
Overview of results on outcrop analogue samples





4. Core Flooding Test

Example of hydrothermally altered reservoir sample



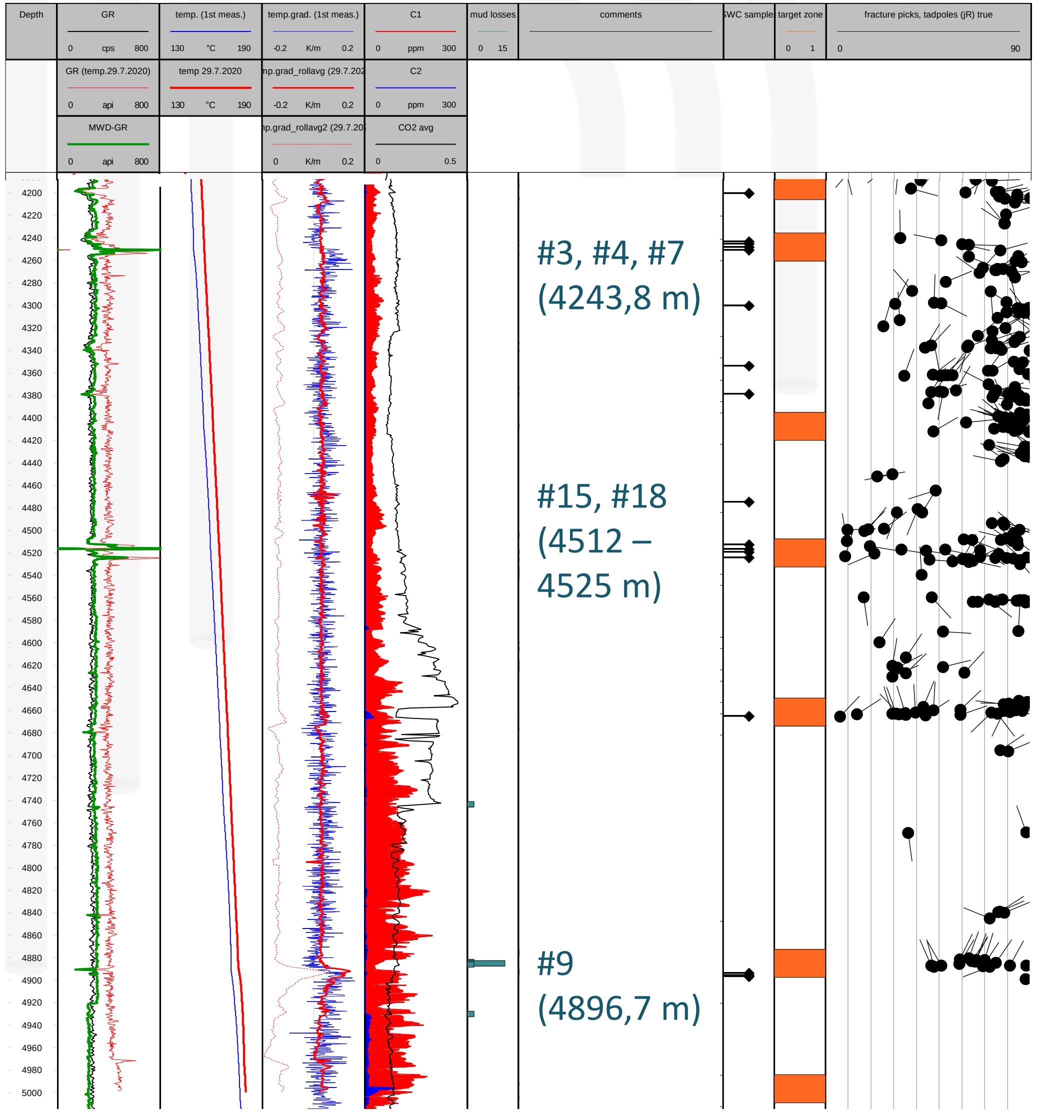
Before CFT

After CFT

Geothermal Winter School 2021

4. Results of Core Flooding Tests

All reservoir samples show significant increase in permeability by acidification



	Depth	Rate	Delta weight	Pore volume	Initial permeability	Final permeability	Permeability increase
Core	m MD	ml/min	g	ml	mD	mD	-
#3	4243.0	1.25	0.663	1.25	0.4	10.9	**27**
#4	4244.8	4	0.637	0.49	0.5	2	**4**
#7	4253.4	1	0.235	0.34	0.2	6.3	**31.5**
#9	4896.7	2	0.66	0.52	0.3	>100	**>300**
#15	4512.6	2	0.226	0.58	0.2	0.4	**2**
#18	4524.2	2	0.52	0.68	0.3	>100	**>300**
#19	4199.3	2	0.766	0.45	0.2	10.7	**53.5**

artificial fissure natural vein

4. Acid compatibility tests

Prior to operation all components should be tested with selected acids

This usually includes:

- Geothermal water compatibility tests,
- Compatibility tests with drill cuttings) and outcrop analogue or core samples,
- Cement compatibility tests,
- Casing compatibility test,
- Fresh water compatibility tests.

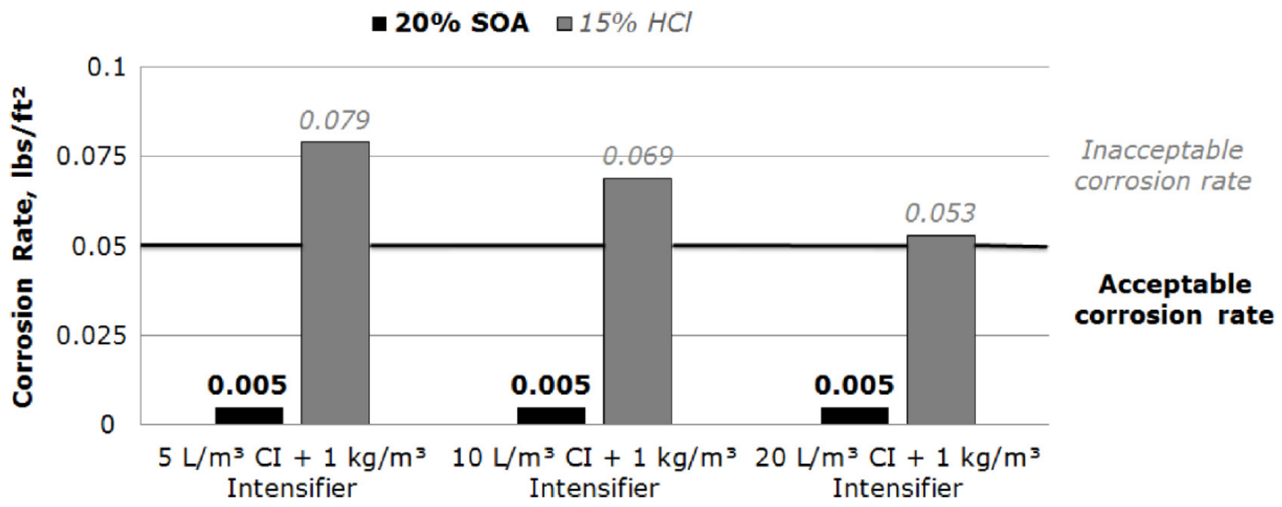


Figure 5—Corrosion rate for L-80 after 6 hours at 150°C and 1000 psi N_2.

After: Lummer et al. (2015)

If corrosion of either the casing or the cement **is too severe**, **inhibitors** need to be added to **protect the well** AND/OR either an **injection pipe, coiled tubing** or **suitable packers** to separate the stimulation fluid from the casing and cement needs to be used.

If unwanted chemical reactions between the geothermal fluid and the stimulation fluid or the formation occur, the acid blend has to be adjusted accordingly or the chemical stimulation needs to be separated into several steps to control the chemical reactions within the reservoir and of the fracture fillings.

5. Design of technical operation

Overview of technical operation on site

1. **Mobilization and setup installation.**
2. **Pressure test of installations and safety pre-job meeting**
3. **Pre acid short step rate injection test**
4. **Chemical stimulation (number of steps defined based on target zones or target injectivity):**
    1. **Pre-flush:** Inject fresh water to cool down the well, evaluate injection pressure and flowrate to be sure that acid can be pumped.
    2. **Acid mixing and main flush:** Injection of the acids 1 and 2 under maximum allowed pressure. Volume defined on open-hole volume plus reservoir fracture porosity to be treated.
    3. **Post-flush**: Displacement of acid out of the CT or drill string.
    4. **Reaction time:** After post-flush the well will be shut-in and the acid will be given time to completely react with mineral phases in fractured zones.
5. **Post acid short step rate injection test**
6. **Demobilisation**

6. Documentation and monitoring

Geothermal Winter School 2021

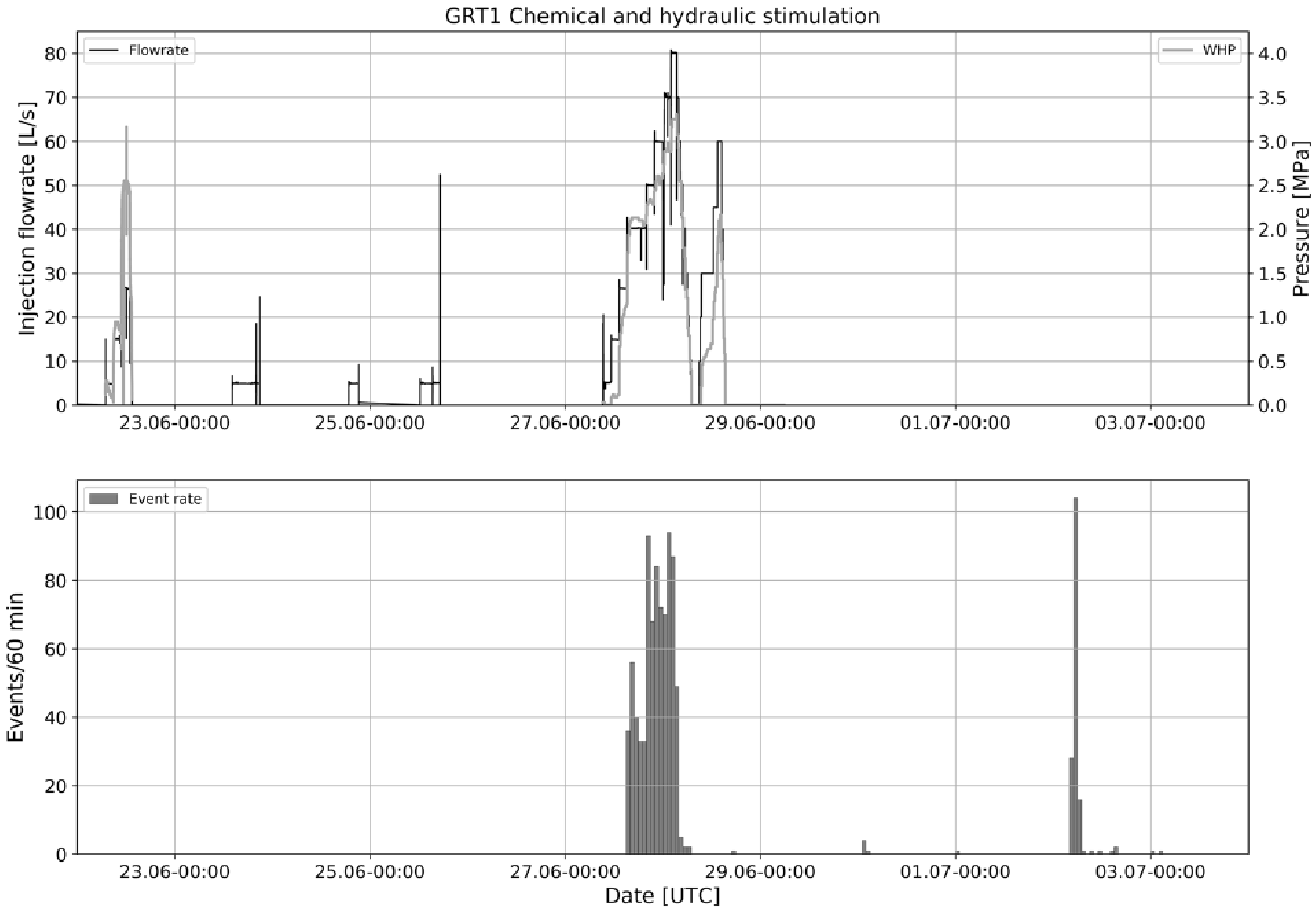
The chemical stimulation has to be thoroughly documented and monitored

Following **operational parameters** will be collected for documentation and further analysis:

- Pressure (coiled tubing or drill string, wellhead and annulus)
- Temperature and density of injection fluid
- Injection rate
- Net volume of pumped fluids
- Type and concentration of acid(s)
- Reaction time
- Total time of treatment

Monitoring should further include:

- Monitoring of noise emissions and working hours
- Monitoring of groundwater in nearby wells etc.
- Induced seismicity - target zone characteristics and reaction



Maurer et al. (2020)

6. Documentation and monitoring

Geothermal Winter School 2021

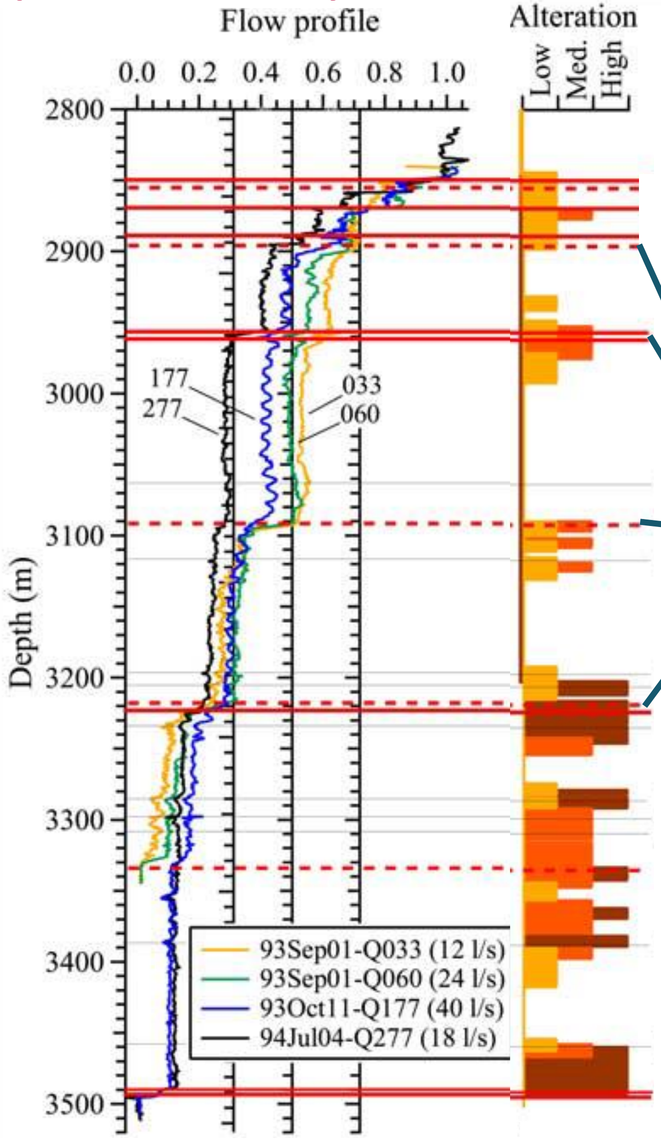
Efficiency of chemical stimulation should be proven quantitatively at reservoir scale

1. Multi-step rate injection test with PTS log prior to stimulation
2. Chemical stimulation in UD1
3. Multi-step rate injection test with PTS log after stimulation

→ **Was the stimulation effective?**

→ **Magnitude of permeability increase after chemical treatment?**

Characterization at reservoir scale:
Soultz-sous-Forêts (FR) example
Borehole geophysical logging for direct reservoir characterization e.g. flowmeter log



Natural flow and improvement of flow paths linked to altered fracture zones

After: Evans et al. (2005)

Geothermal Winter School 2021

7. Risk assessment

Risk is the product of the probability of occurrence and the extent of damage

The risk assessment includes all kind of risks related to the operation, i.e.:

- risk to people (health),
- risk to environment (air, soil, groundwater, biosphere)
- project risk (performance, technical, geological)

All kinds of risks have a financial impact.

This usually complex to quantify.

Serious risks need to be avoided by adapting the operation design.

For all other risks, mitigation measures and reaction schemes have to be planned.

			likelihood of occurence				
		example	< 0,01 %	0,01 % - 1 %	1 % - 10 %	10 % - 90 %	> 90 %
extent of damage	serious	Time delay > approx. 3 months, severe injury, very high additional costs due to time delay and equipment (> 60% of the calculated costs of a well), loss of the well, very high damage to image					
	great	Time delay > approx. 1 month, moderate injury, large additional costs due to time delay and equipment (approx. 10% to 60% of the calculated costs of a bore hole), partial loss of the bore hole					
	moderate	Time delay > approx. 1 week, slight injury, moderate additional costs due to time delay and equipment (approx. € 300,000, - to approx. 10% of the calculated costs of a drilling)					
	minor	Time delay > approx. 1 day, no personal injury, low additional costs due to time delay and equipment (approx. € 50,000.- to € 300,000.-)					
	insignificant	Low time delay, no personal injury, hardly any additional costs					

	The risk falls within the broadly acceptable region, i.e. either the extent of damage and/or the probability of occurrence of an event is so low that the risk can be neglected in comparison to the risks of other hazards. Risk reduction is not necessarily required for this hazard.
	The risk falls within the yellow ALARP (As Low As Reasonable Practicable) region; i.e. the risk is reduced to the lowest reasonably practicable level. Risks in this area must be carefully weighed against the useful effect of the product and the cost of risk reduction.
	The risk falls into the red, hardly acceptable range (intolerable region); i.e. the risk of hazard is serious. A risk in this area must be reduced by reducing the extent of the damage and/or the probability of occurrence of the hazard.

7. Risk assessment

Example of different risk categories, which need to be managed

risk to people:

- injuries with hazardous chemicals,
- injuries due to work with heavy equipment and with pressurized pipes,
- and common hazards resulting from working conditions (drill site);

risk to the environment

- spills or leaks of hazardous chemicals,
- explosions due to chemical reactions or of pressurized pipes,
- induced seismicity,
- noise,
- gas kick / blow out;

project risks:

- ineffective chemical treatment,
- undesired chemical reactions within the reservoir resulting in clogging fractures or sanding,
- corrosion of subsurface installations (casing, liner, tubing, packers, cement…),
- equipment lost in hole,
- damage/loss of the well,
- unproductive time;

The financial impact to the operator resulting from these risks is high enough to ensure that the mitigations measures will be followed, at least down to an acceptable level.

Summary

Geothermal Winter School 2021

Technical prerequisites for chemical stimulation

The well has to be cleaned. All mud cake has to be removed.

The well needs to have an initial injectivity, otherwise acid will not be able to enter the formation/fractures.

Minimum of required injectivity of about **0.1 l/s per bar**. If this threshold is not satisfied then chemical stimulation may not be efficient.

Well integrity must be ensured and proven by logging.

Casing pressure test to ensure safe operation has to be performed.

A PTS log in the open hole should be run with hydraulic tests.

A reservoir fluid sample and a hydrochemical analysis has to be provided for compatibility testing.

Fresh water supply of at least 2 m^3/min has to be ensured.

Summary

Prerequisites for chemical stimulation

- Fresh water sample has to be provided for chemical analysis and compatibility testing.
- A drilling engineer has to be on-site in case to guide risk mitigation measures in case of incident.
- A coiled tubing engineer has to be on site in case of using CT for the operation.
- Site owner has to ensure the required permits for chemical stimulation and its boundary conditions.
- A water segregation area has to be provided on the drill site for the mixing and the injection of the acid.
- A waste management plan has to be provided for tank cleaning after the acid job and treating HF containing acid waste.
- Sufficient power or fuel supply needs to be provided on site.
- A container for safe temporarily storage of dry chemicals has to be provided.
- All technical handling equipment, like forklift, crane, coil tubing tower (size depending on the weight of the material to be lifted) has to be provided.

Conclusion and Outlook

Plans for the United Downs Project

- Preliminary operation plan is finalized
- Laboratory results are very promising
- Tenders have been run for all parts of operation
- Evaluate bids on tenders (Coil tubing unit)
- Contract coil tubing, PTS logging and chemical stimulation operators
- Finalize operation plan based on results of current injection tests
- Finalize risk assessment and reaction scheme for final operation plan
- Performing chemical stimulation in UD-1 May or June 2021
- Evaluation of the stimulation operation (July to August 2021)

Geothermal Winter School 2021

Thank you very much for your attention!

This work was performed in the framework of the H2020 MEET EU project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792037