PERFORM WORKSHOP

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PERFORM database and learnings from the data

https://geothermperform.eu

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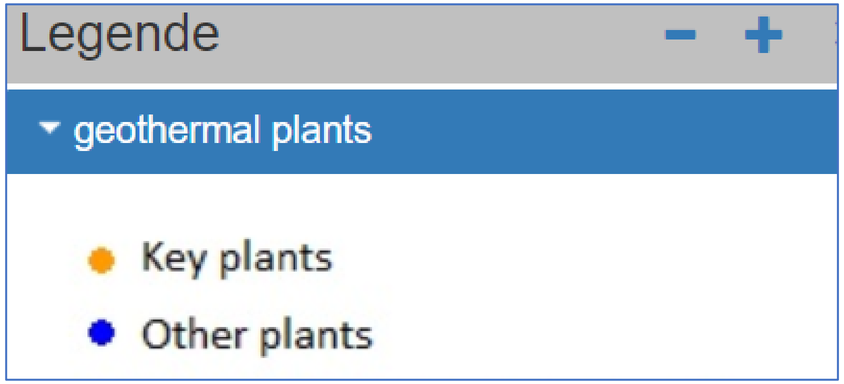
Map showing locations of plants



Key Plants (orange):

DK: Margretheholm

DK: Sønderborg

DK: Thisted

DE: Gross Schönebeck

NL: Honselersdijk

NL: Pijnacker-Nootdorp

Database combined with information from the PERFORM Website
https://geothermperform.eu
equals the full PERFORM databank

Database: Excel files and text sections dealing with;

- Plant locations and
- Fact sheets on plants with geological and technical data
- Wellbore locations (maps)
- **Excel files with:**
  - Brine analyses
  - Particle analyses
  - Mineral compositions

Website: Linked to the database, but also extra text boxes and figures dealing with;

- Learnings from the PERFORM project
- Publications and presentations prepared during the PERFORM work
- Project description and objectives
- About us – institutions and partners
- Funding (GEOTHERMICA etc.)

Notice: The full database with all collected data from the various plants can be downloaded from the website

Data types included in the PERFORM database
as published on the public website https://geothermperform.eu

The PERFORM Excel files include data from 27 plants and another 40 wells.

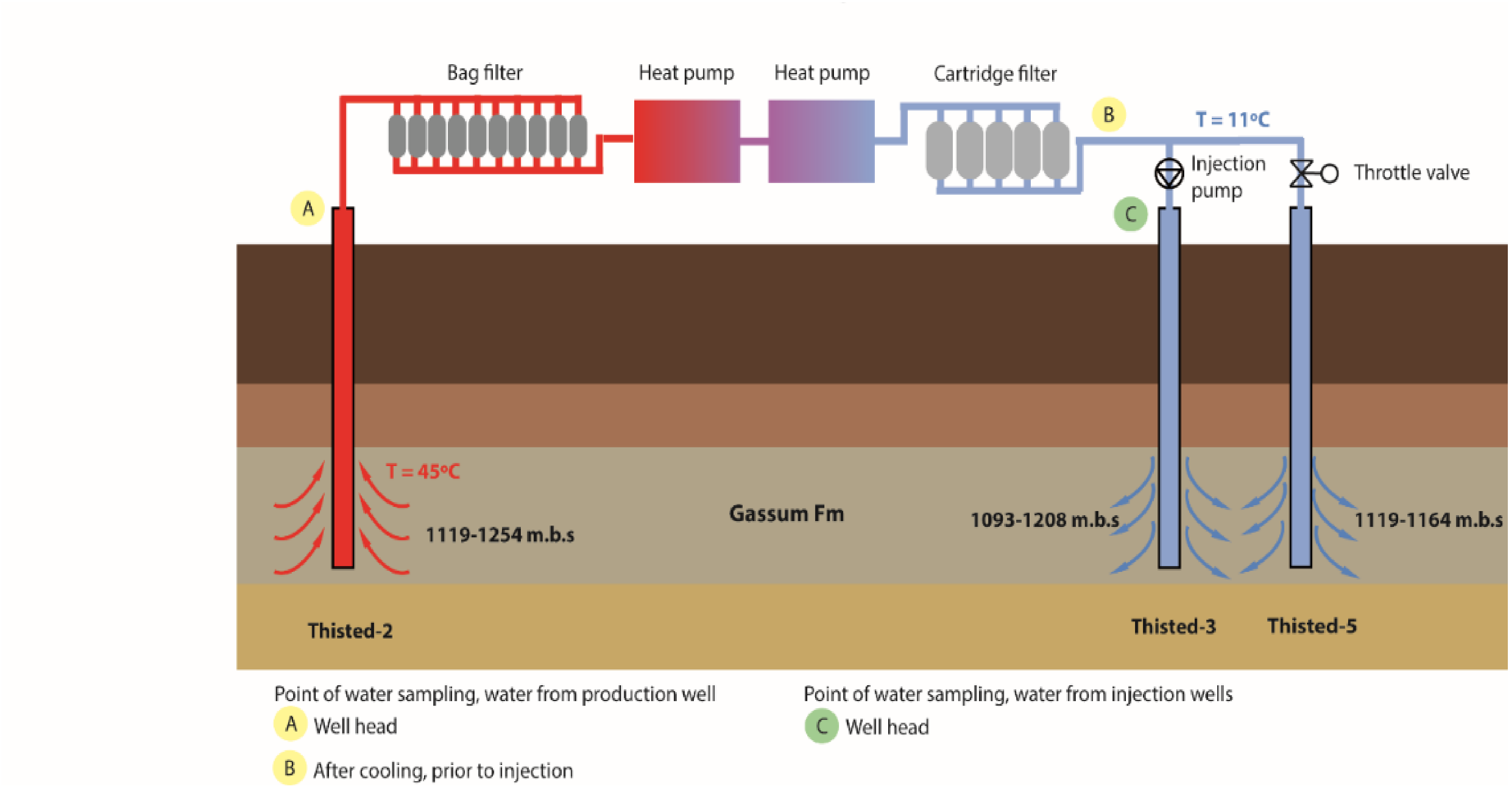
The data quality and the amount of data vary considerably

Six key plants with large amount of data:

- 2 plants from the Netherlands
- 1 plant from Germany
- 3 plants from Denmark

DK: Margretheholm
DK: Sønderborg
DK: Thisted
DE: Gross Schönebeck
NL: Honselersdijk
NL: Pijnacker-Nootdorp
DE: Insheim
SE: Lund
FR: Melleray
FR: Châteauroux, St Jean
DE: Neustadt-Glewe
DE: Neubrandenburg
DE: Waren/Müritz
DE: Neuruppin
DE: GeneSys Horstberg
PL: Pyrzyce

With respect to the six key plants:
A sketch of plant configuration is available from the PERFORM database/website
The figure below illustrates the position of wells, pumps and filters



Fact sheets – a fact sheet is prepared for each geothermal plant - Information about:

Number of production wells and injection wells.

Reservoir(s): Sedimentology of the producing reservoir. Average porosity.

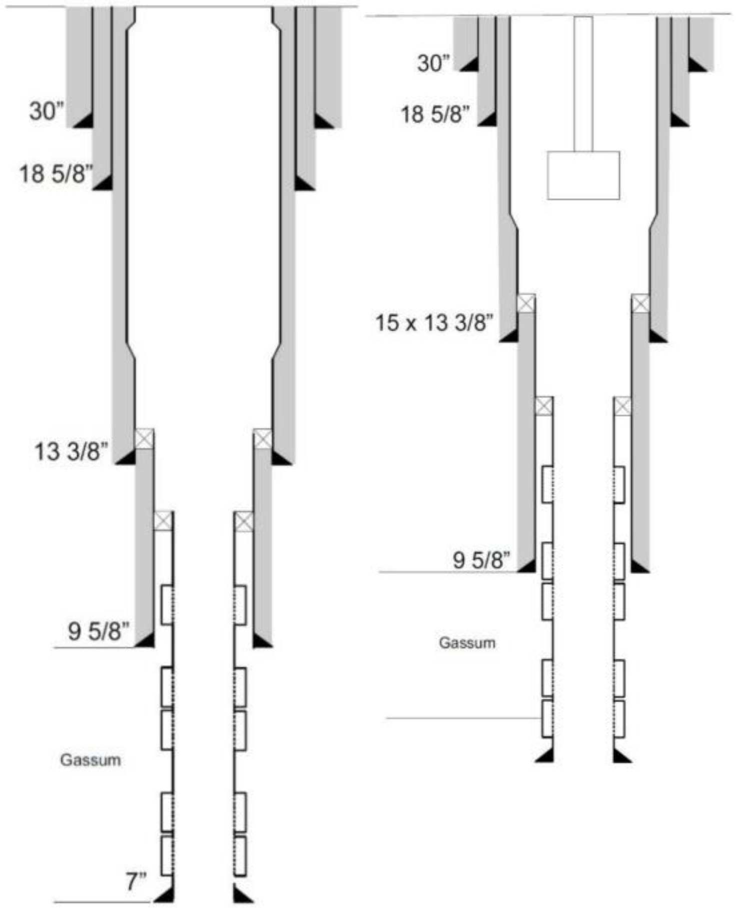
Reservoir depth

Reservoir temperature

Challenges: Problems observed – and actions taken

Geological model for the geothermal reservoir

Completion design, well completions and casing sizes



Analyses and raw data accessible from the website

Detailed datasets that can be ***down-loaded*** as Excel files (.xlsx)

brine analyses (xlsx)

brine particle analyses (xlsx)

mineral composition of reservoir rock (xlsx)

- **Brine analyses** i.e., chemical analyses of the composition of geothermal water. Including both formation and injection waters.
- **Brine particle analyses** i.e., chemical analyses of the composition of particles observed in the production and injection waters. Samples from downhole, filter bags, surface facilities and well head.
- **Mineralogical composition** of the reservoir rock. XRD etc.

Learnings from the data

(4 different topics are considered)

1. **Learnings from the water analysis data**
   Chemical analyses of the composition of geothermal water

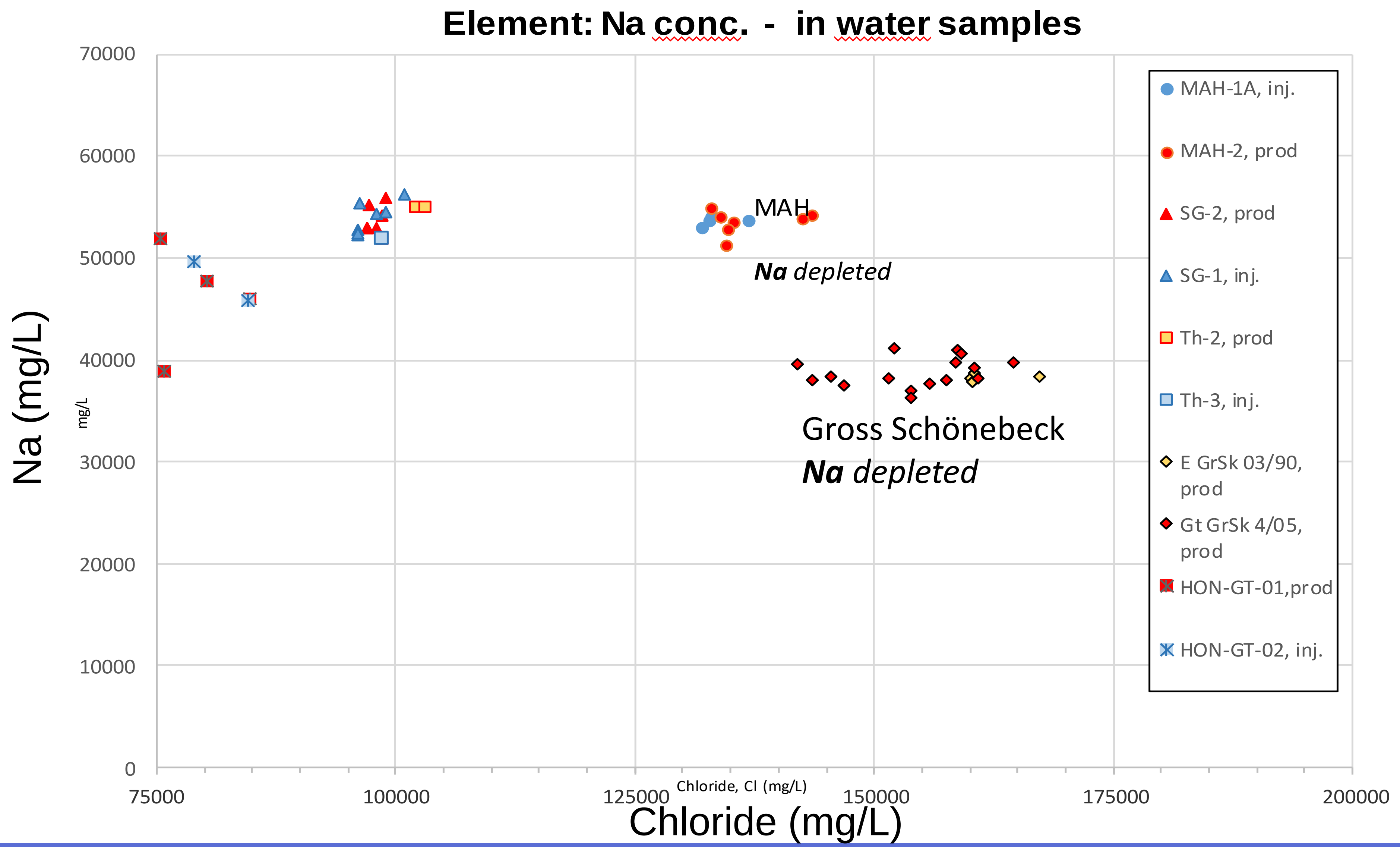
2. **Learnings from the particle analysis data**
   Chemical analyses of the composition of particles observed in the production and injection waters

3. **Learnings from challenges and actual problems observed the geothermal plants**

4. **Learnings from new methods developed in PERFORM**

Example of brine analyses (5 sites, 10 wells)

Chemical analyses of the composition of geothermal water. Sodium (Na) conc. in water samples



Na
(Sodium)

Low Na content in ***Margretheholm*** (MAH) and ***Gross Schönebeck***

The salinity varies considerably from site to site

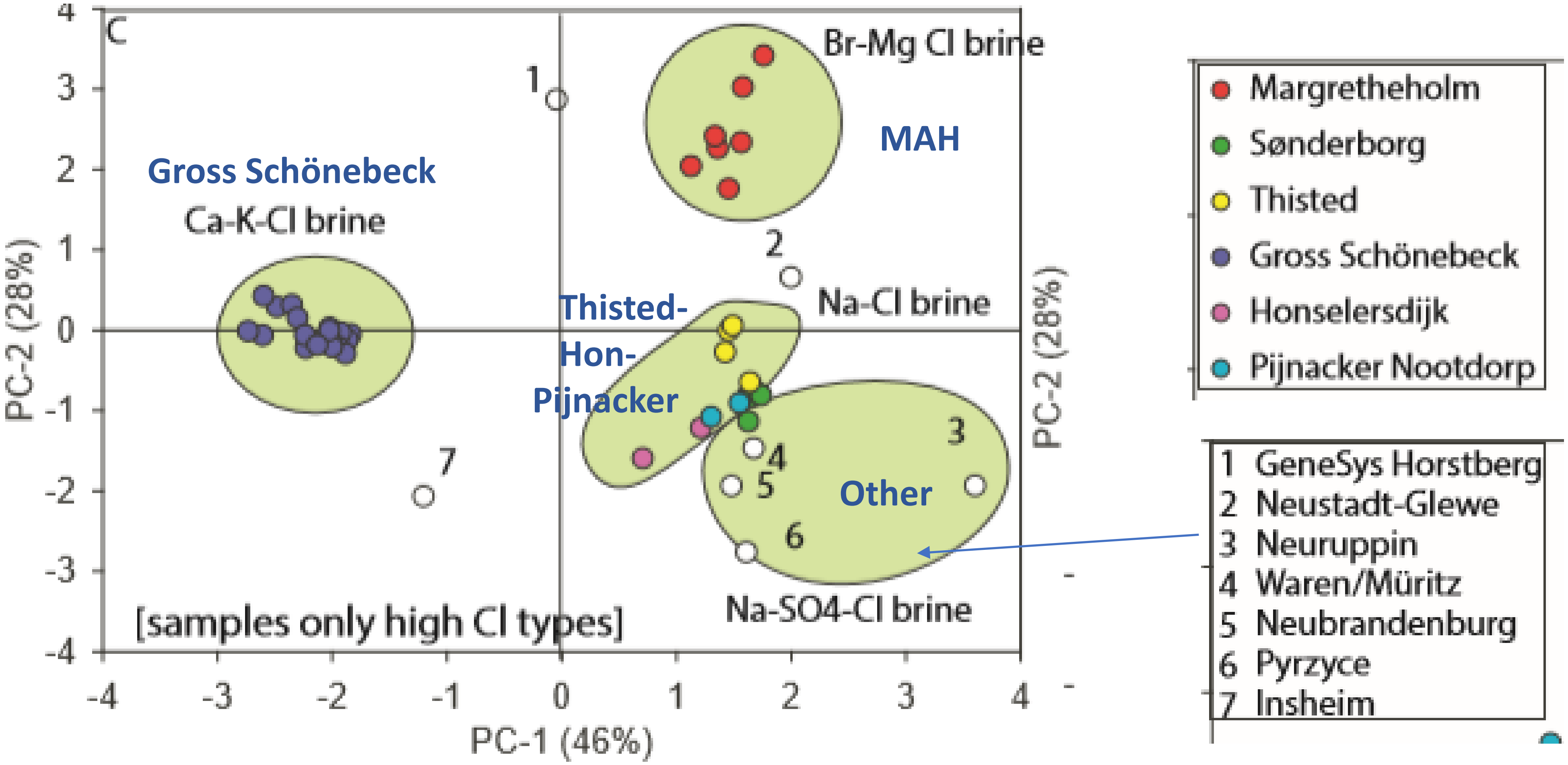
Not a linear correlation. The formation water is depleted w.r.t. ***Na*** in MAH and GrSk

Summary of water analyses: Subdivision into 4 brine types

Herein PCA is used to summarize the information content of several datasets. Data from 13 sites are included

Brine types:

- Gross Schönebeck type: Ca-K-Cl brine, Calcium-Potassium-Chloride rich brine
- Margretheholm (MAH) type: Br-Mg brine, Bromide-Magnesium rich brine
- Thisted-Hon-Pijnacker type: Na-Cl brine, Sodium-Chloride rich brine
- Other: Na-SO4-Cl brine Sodium-Sulphate-Chloride rich brine



Learnings from SI calculations

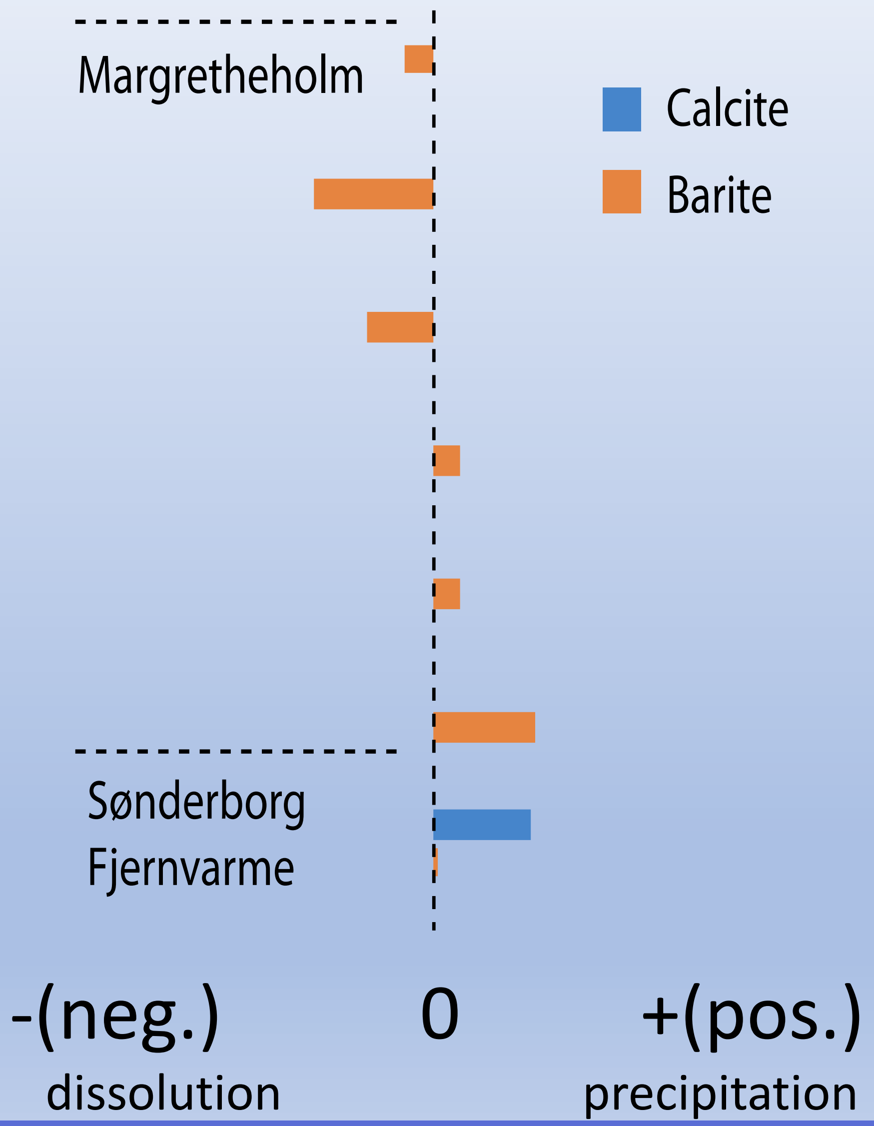
1. Another way to compile and compare water data from more sites is to calculate the **Saturation Index (SI)** based on the composition of the geothermal waters. ***Objective:*** *To point out sites with 'risk of scaling' (mineral precipitation).*

2. Mineral dissolution and precipitation depend on a positive or negative SI.
   Minerals, such as calcite and barite, will potentially precipitate, if SI > 0 (right of the vertical line) →

$$SI = \text{Log}\,\frac{IAP}{K_{sp}},$$

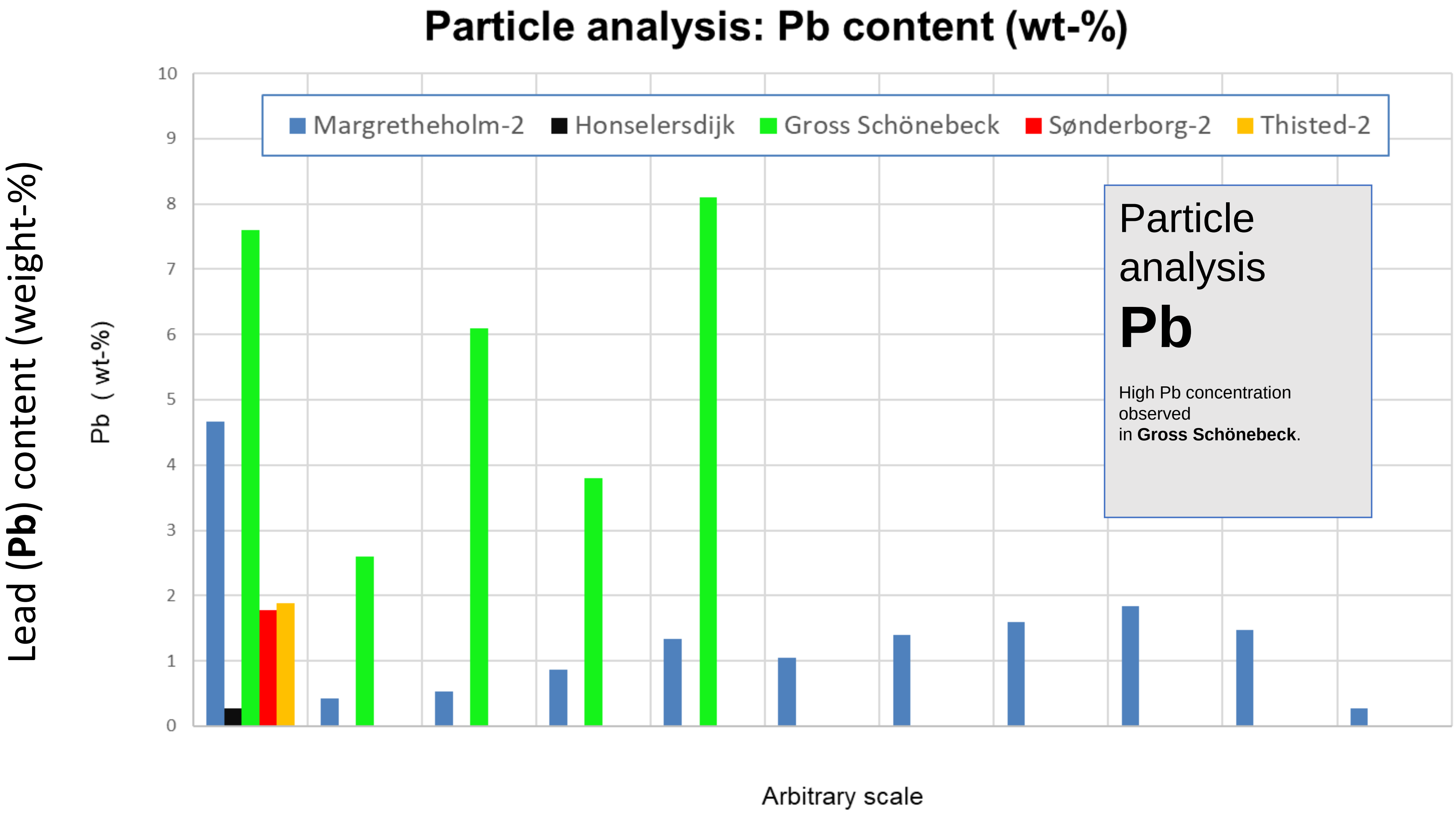
where K_{sp} refers to the solubility product.
and IAP refers to the product of the actual activities.

SI at downhole conditions



Example of brine particle analyses (5 sites)

Chemical analyses of the composition of particles observed in the production and injection waters

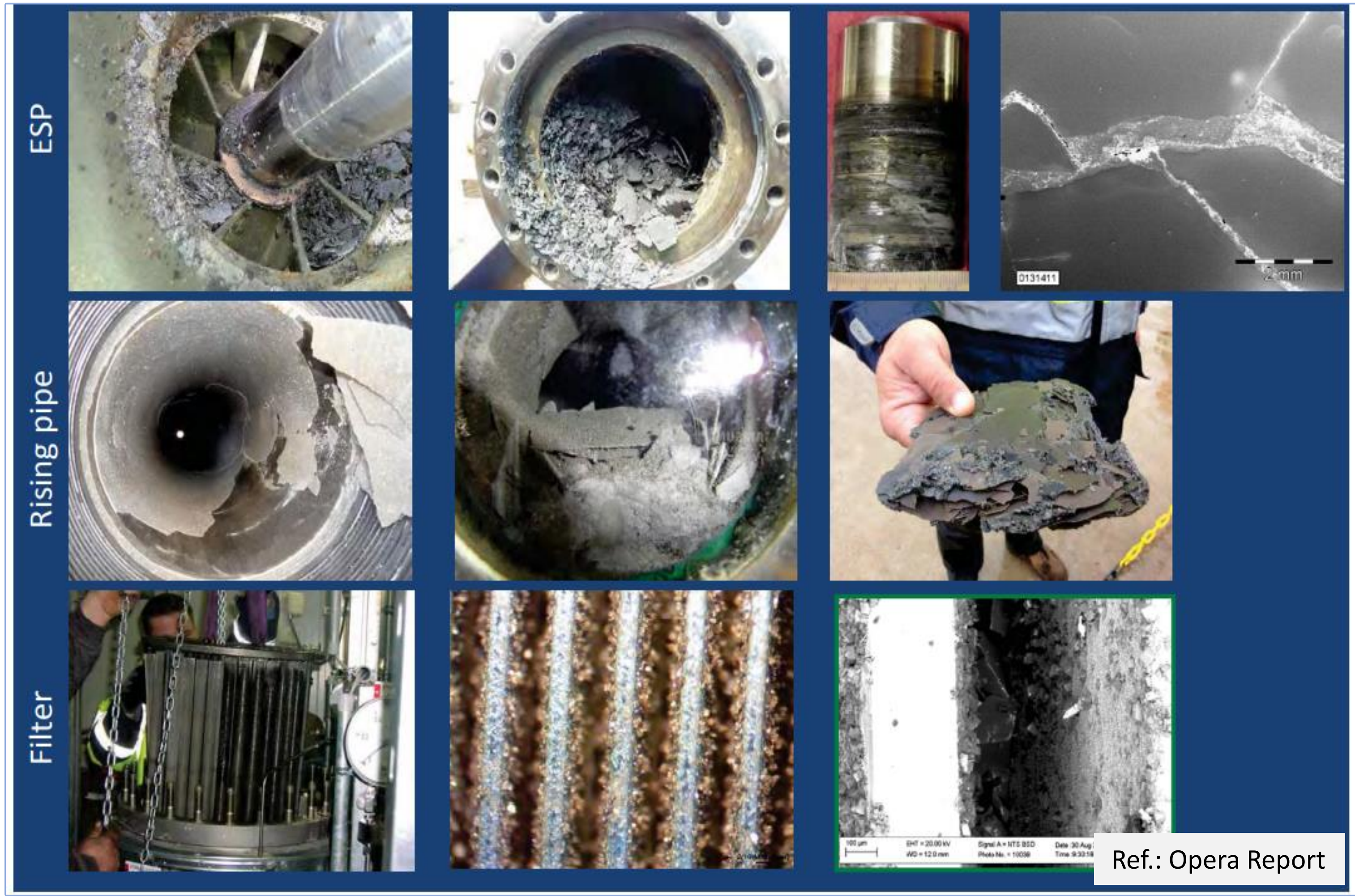


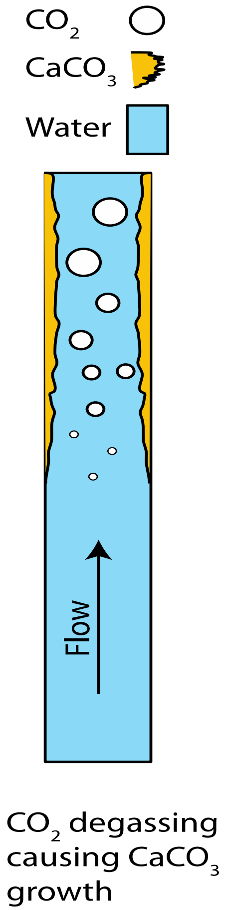
Problems and challenges – when operating a specific geothermal plant Learnings from actual problems observed the plants

- Clogging with particles – in the wellbore or in the reservoir itself.
- Precipitation of minerals (‘scaling’)
- Corrosion
- We have to face these challenges and come up with potential solutions for solving the problems
- Minimize problems *through*:
    - ❑ Knowledge building during the exploration and drilling phases. Samples while drilling.
    - ❑ Planning the plant design and installations based on the expected water chemistry.
    - ❑ Taking and analysing water samples in the operational phase.

Challenges – Scaling

Examples of scaling problems observed in installations of geothermal plants. Challenges related to calcite, barite and other scales are discussed in the website texts



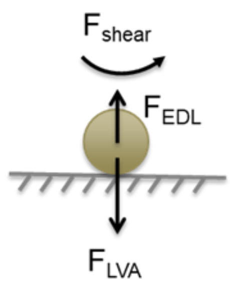


Challenges – Fines migration

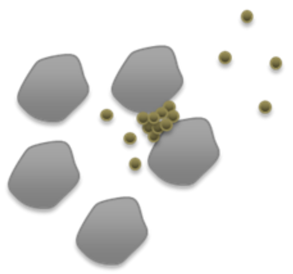
Below a critical salt concentration, there is a risk that fines may be released, leading to permeability reduction by pore plugging. The repulsive electrostatic forces exceed the attractive van der Waals forces and consequently, fines are *mobilized*. At "high" salt concentrations, the high content of ions in the formation water will to some degree shield this negative charge on the surface of the sandstone grains and the fines.

DLVO theory

The stability of colloidal systems is explained by the balance between attractive and repulsive forces



Permeability reduction by pore plugging



$F_{shear} + F_{EDL} > F_{LVA}$: Fines release

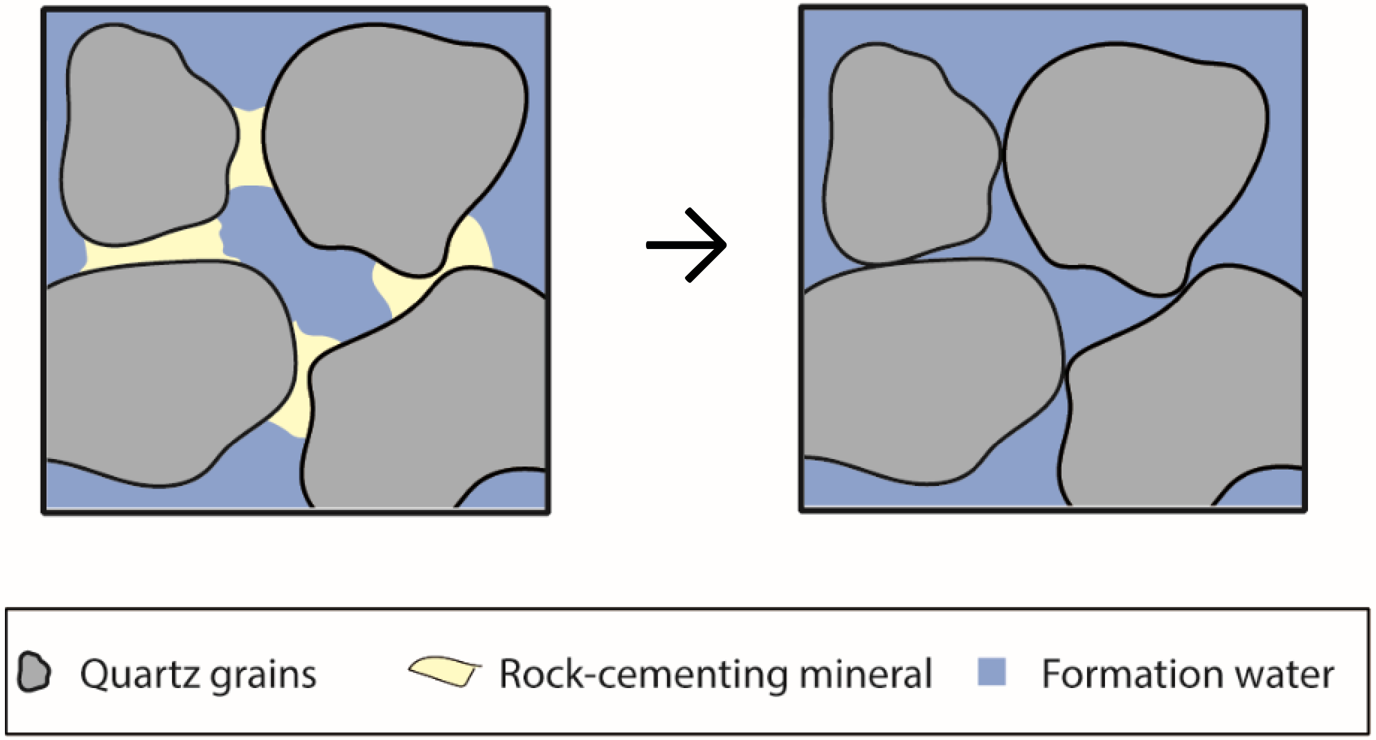
Intermolecular forces affect the fines

- Drag/shear forces (repulsive)
- Electric double layer forces (repulsive)
- Van der Waals forces (attractive)
- Repulsive > attractive: Fines release

Challenges – Mineral dissolution

Calcium (Ca) may be removed from the geothermal waters to avoid calcite ($CaCO_3$) scaling. This process changes solution chemistry:

The CO_3^{2-} activity is then lowered → pH decreases, initiating dissolution of calcite.



Identified challenges and problems	Table on 'Suggested Solutions' and methods developed for potential solutions through the PERFORM study work	Sites tested – and additional comments
Clogging of pores, perforations etc. by particles.	▪ **Use a self-cleaning particle filter** or another type of particle filter.	Grünwald, Oberlaa and Insheim.
Calcite scaling Precipitation of calcite is a common problem in geothermal plants	▪ **Avoid CO_2 de-gassing by maintaining a high operation (injection) pressure that exceeds the bubbling point.** ▪ **Use inhibitors to keep Ca in solution**. ▪ **Use cation filters to remove Ca^{2+}. Such filters could e.g., be based on seeded crystallization (FACT filter).** **The formed carbonate crystals are to be removed by filtration.** *FACT: Filtration Assisted Crystallization Technology*	Generally, a challenge in plants with high CO_2 and Ca^{2+} content, for example Pijnacker-Nootdorp, Insheim, and Ammerlaan.
Barite scaling Pronounced barite scaling is observed at sites producing from hot, saline brines.	▪ **Use scaling inhibitors.** ▪ **Use cation filters with adsorption materials for barium removal (e.g., chitosan or zeolite) prior to re-injecting cooled water.** ▪ **Avoid site-locations with Ba-rich brines in the system, if possible**.	Margretheholm, Insheim, Horstberg, Den Haag, and Groß Schönebeck.

Challenges – Corrosion

Operational challenges related to corrosion types are discussed in the text sections

Uniform corrosion

Pitting corrosion

Crevice corrosion

Galvanic Corrosion

CO_2 corrosion

Microbial induced corrosion

H_2S induced corrosion

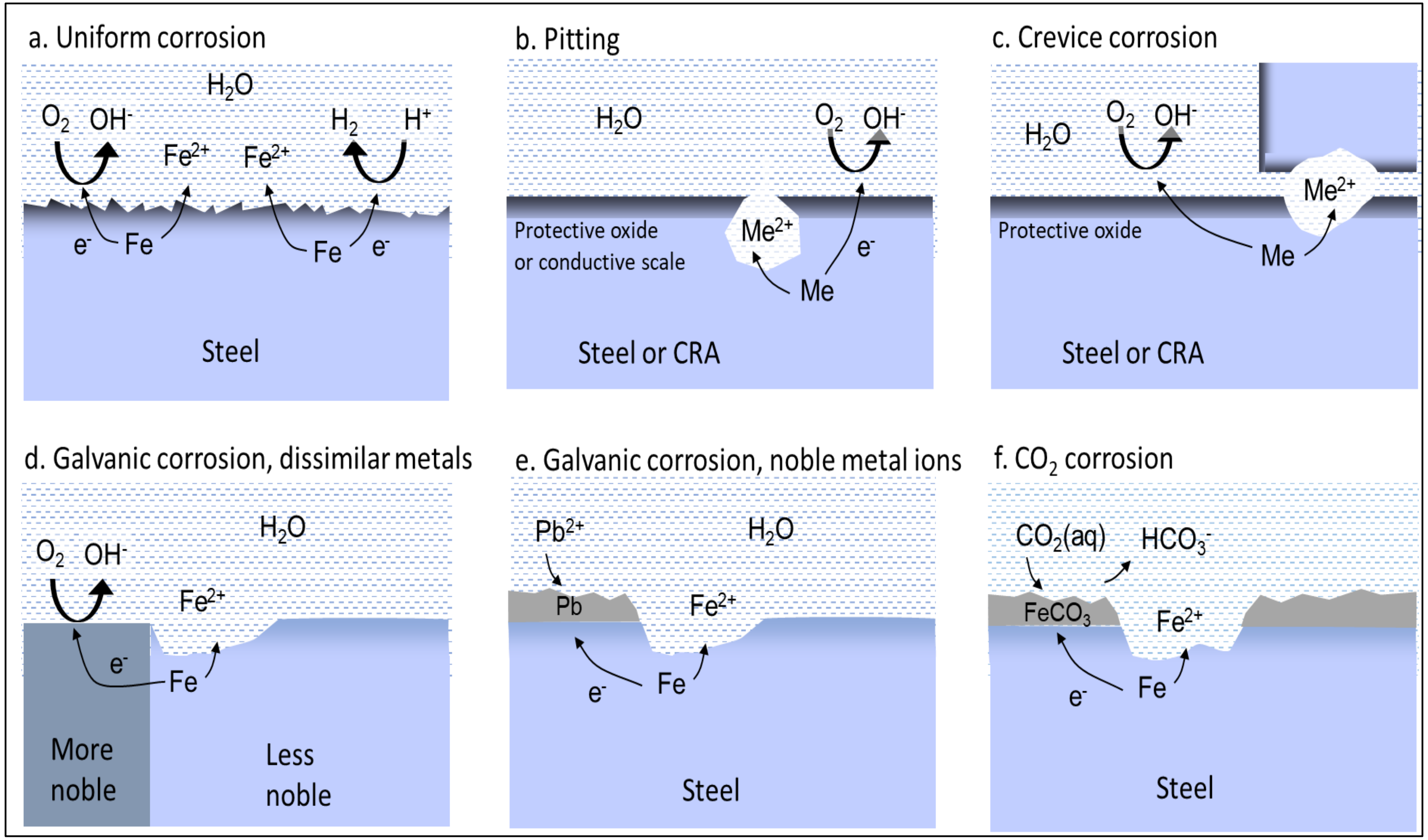


Figure provided by FORCE Technology (FT)

Identified challenges and problems	Table on 'Suggested Solutions' and methods developed for potential solutions through the PERFORM study work	Sites tested – and additional comments
Corrosion due to oxygen ingress.	▪ **Avoid (or limit) the amount of oxygen ingress, e.g., by maintaining a high operational pressure.** ▪ **Use casings of composite material.**	Corrosion due to oxygen ingress observed at Sønderborg, Lund and other plants.
H_2S-induced corrosion. Corrosion products such as sulphides (e.g., FeS).	▪ **Remove H_2S by adding iron-based additives** like iron hydroxide or $FeCl_3$. A PERFORM publ. describes this process in detail ▪. **The generated particles can then be removed by filtering**	Sønderborg, Pyrzyce and Oberlaa. ▪ Especially a problem at strongly reducing conditions.
Galvanic corrosion due to dissolved Pb^{2+} and Cu^{2+} in the formation brine. Especially pronounced if the chloride concentration > 100,000 mg/L. May lead to generation of metallic lead (Pb(0)) and copper (Cu(0)) in the geothermal wells.	▪ **Use particle filters for removal of metallic Pb and Cu.** ▪ **Use cation filters with adsorption materials for removing Pb^{2+} and Cu^{2+}** (materials could be chitosan, Fe-oxide, and zeolite). ▪ **Use corrosion inhibitors.** ▪ **Use tubings and casings made of corrosion-resistant material, e.g. casings of composite material.** ▪ **Use corrosion-resistant alloys, e.g. stainless steels.**	Margretheholm (Pb), Sønderborg (Pb) and Gross Schönebeck (Cu). ▪ Cation filters have been successfully tested in the laboratory – a field test is still needed. ▪ Carbon steel and several higher alloyed steels were tested in the lab. in order to examine/control the corrosion processes.

Summary and take home messages

The database and website contain:

- Site-specific data and material published by the PERFORM study group.
- Geochemical analyses (water chemistry, particles in the brines).
- Information about operational challenges, learnings and potential solutions to problems.

- ***We recommend to*:**
  - **Consult the PERFORM database and website** in order to (i) *get a better understanding* of the technical risks associated with geothermal operations, and (ii) *gain knowledge of* how to minimize these risks.
  - **Implement the solutions to problems/challenges** described in the tables on 'suggested solutions'
  - Conduct feasibility studies to get information on **the water chemistry prior to drilling**.
  - **Use the knowledge on the expected water chemistry in planning and designing installations** (both surface and downhole installations).
  - **Set up a monitoring program** – because frequent monitoring of the composition of produced water is essential in order to mitigate problems.
  - **Consider the materials to be used in the installations**. Use composite material or corrosion-resistant alloys to prevent corrosion etc.
  - **Utilize the new methods** developed through the PERFORM study work (filters etc.).