H_2S sequestration into geothermal systems

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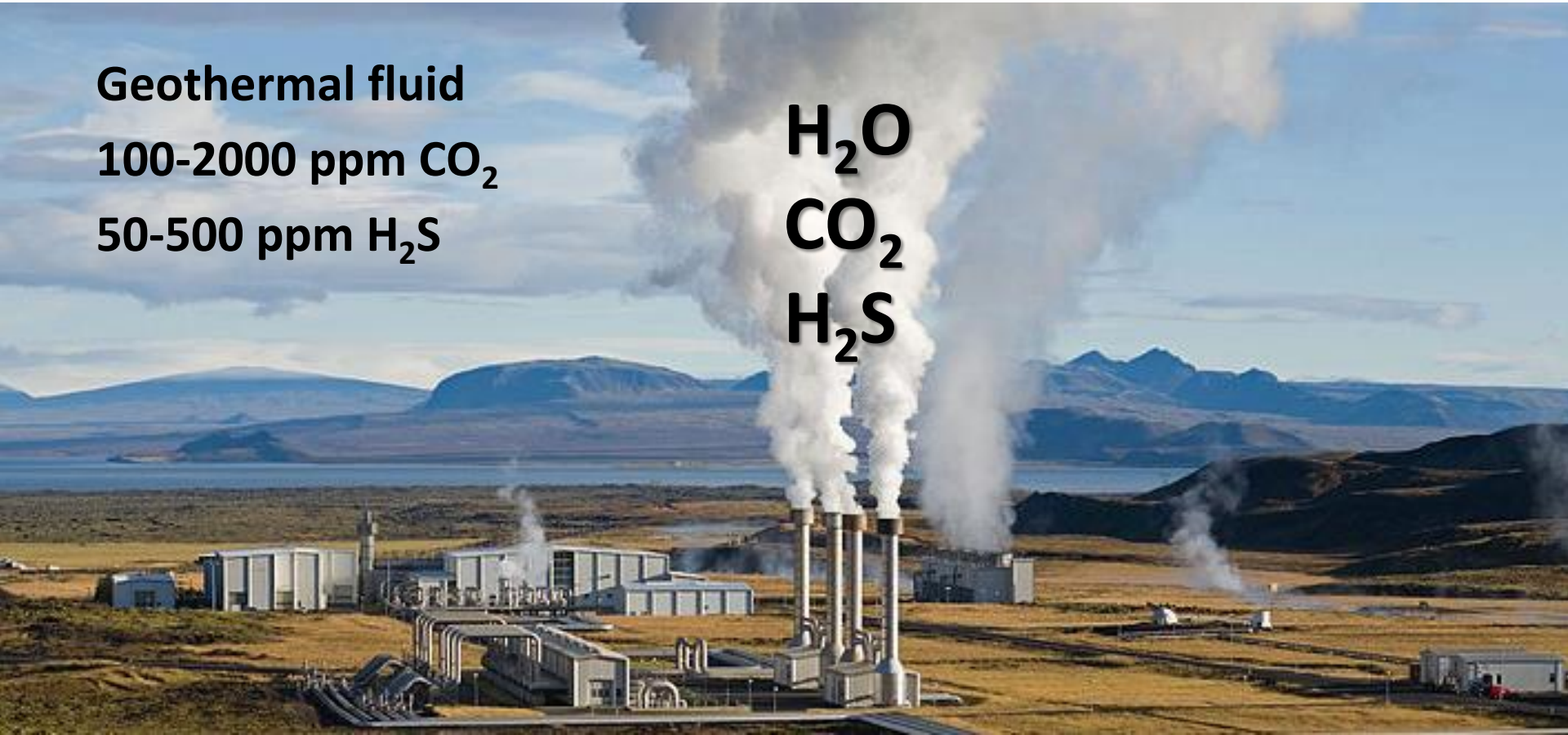
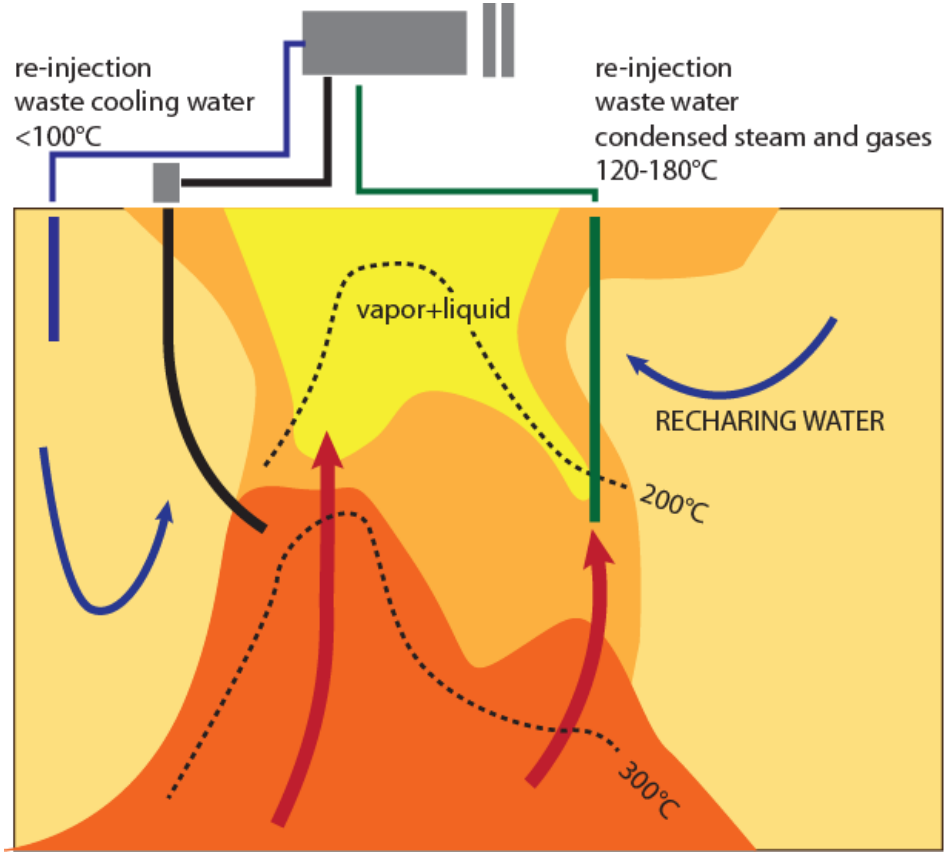
Motivation

- Sulfur is a major component in geothermal vapor and water
- Geothermal utilization results in considerable release of sulfur to is environment



Motivation

- One possible options of reducing H_2S is re-injection and mineralization into the geothermal systems



Motivation

- The H_2S is mineralized in the reservoir upon fluid-rock interaction and sulfide formation

basalt

+

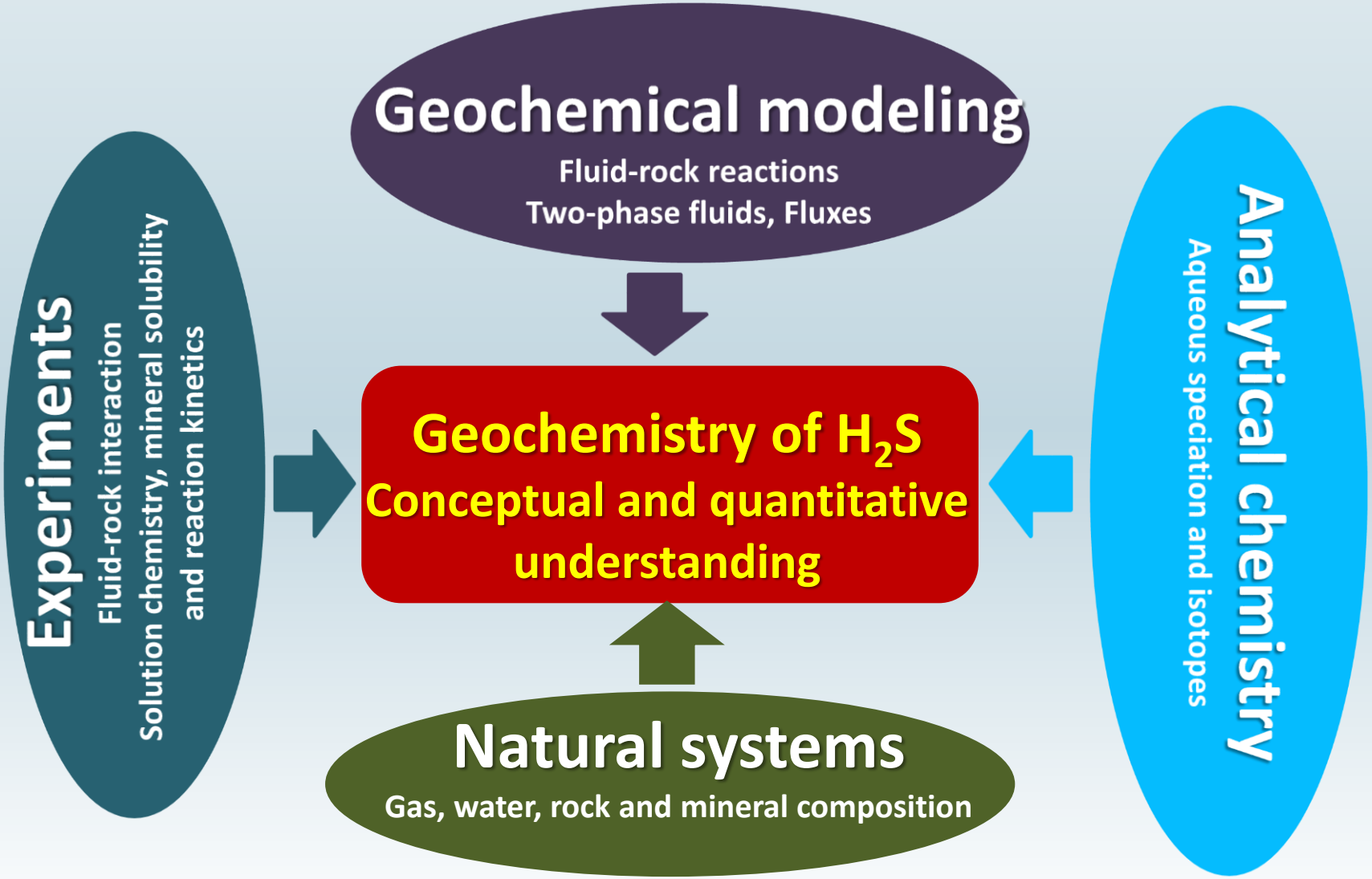
H_2S in water

=

sulfide

The project

- Study the geochemistry of H_2S in geothermal systems
- Study the mineralization of H_2S under geothermal conditions
- Assess the feasibility of H_2S sequestration


Geochemical modeling
Fluid-rock reactions
Two-phase fluids, Fluxes
Experiments
Fluid-rock interaction
Solution chemistry, mineral solubility
and reaction kinetics
Analytical chemistry
Aqueous speciation and isotopes
Geochemistry of H_2S
Conceptual and quantitative
understanding
Natural systems
Gas, water, rock and mineral composition

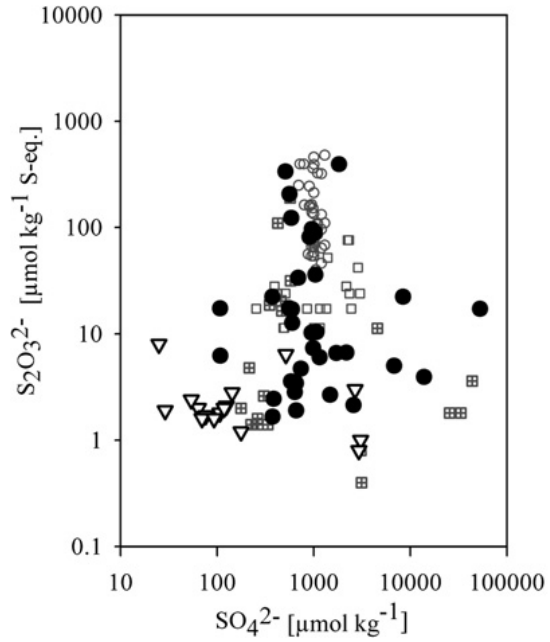
H_2S chemistry of natural geothermal systems

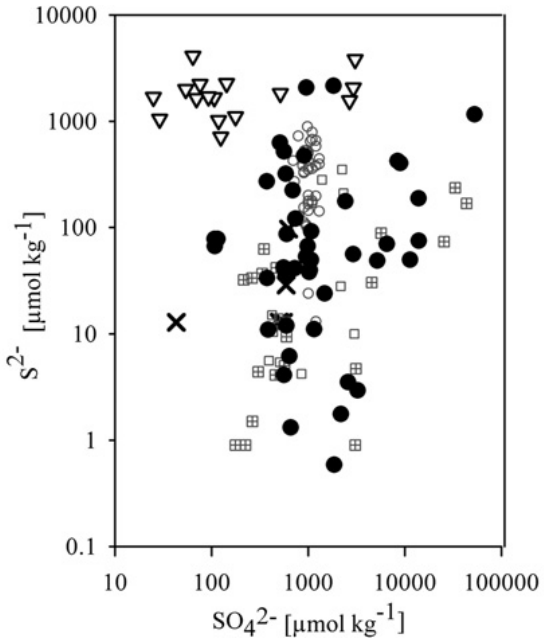
- The chemistry of sulfur is complex due to many oxidation states and possible reactions
- The chemistry of sulfur in geothermal systems is deviated into three sub-tasks
  - Sulfur speciation – The chemical form of sulfur in geothermal systems
  - The source of sulfur in geothermal systems
  - The reactions between sulfur species and rocks

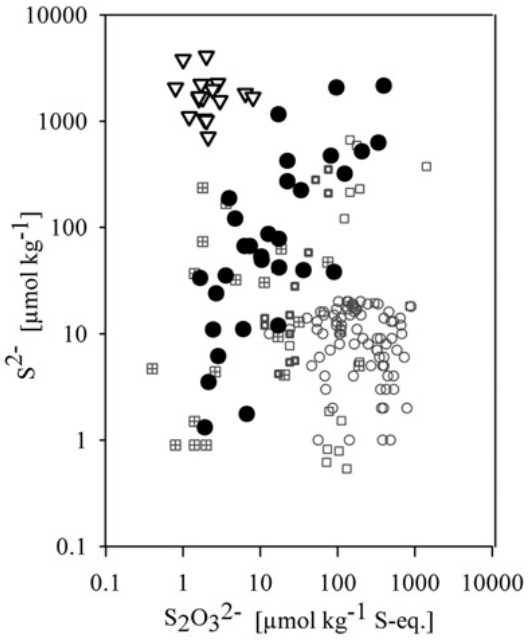
Sulfur speciation

- On-site sulfur species analysis
- H_2S, S_2O_3, SO_3, S_nO_6, S^0, S_n, SO_2 and SO_4
- In geothermal fluids in Iceland we have H_2S, SO_4 and S_2O_3
- H_2S both present in the water and steam phase

Sulfur speciation



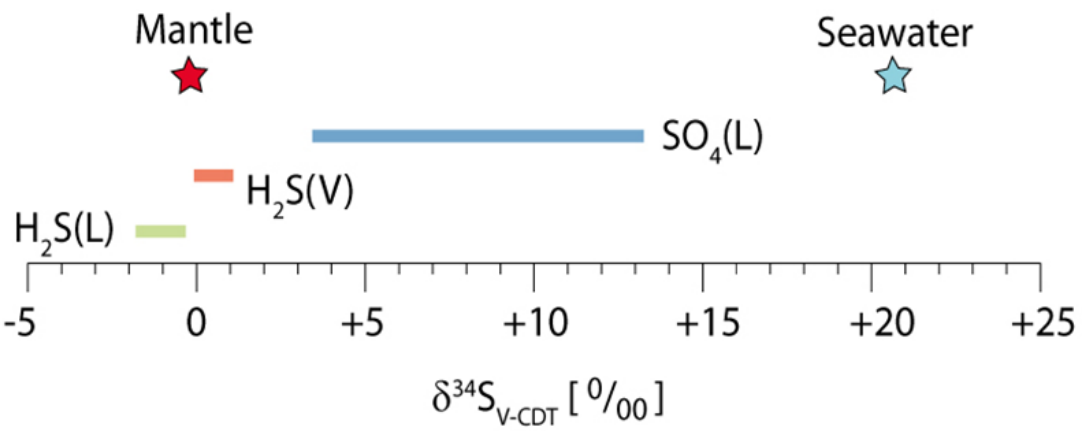




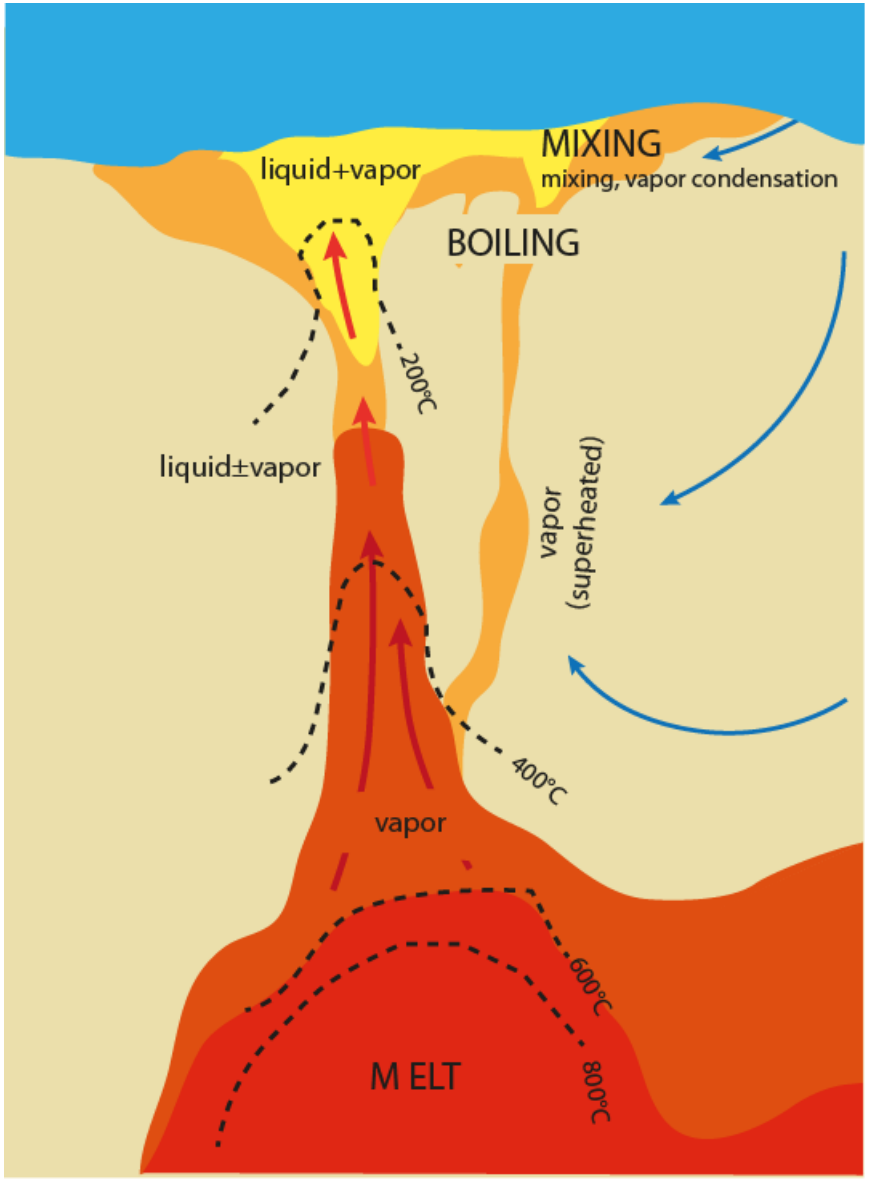
Sulfur source and isotopes

- The source of H_2S in steam and water and SO_4 in water was studied using sulfur isotopes
- H_2S (steam and water) originated from magma (mantle values)
- SO_4 originates by oxidation of H_2S and from marine S-source

Sulfur source and isotopes



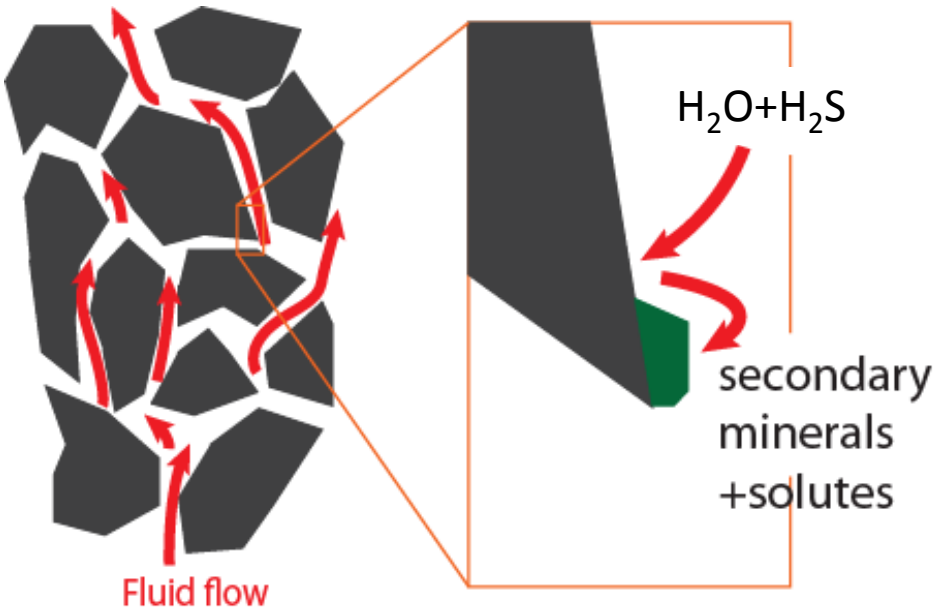
H_2S rock interaction



- H_2S concentration in geothermal systems are considered to be controlled by interaction between common alteration minerals and the geothermal fluids
- The H_2S concentration is effected by boiling and cooling

The process of H_2S mineralization - modeling

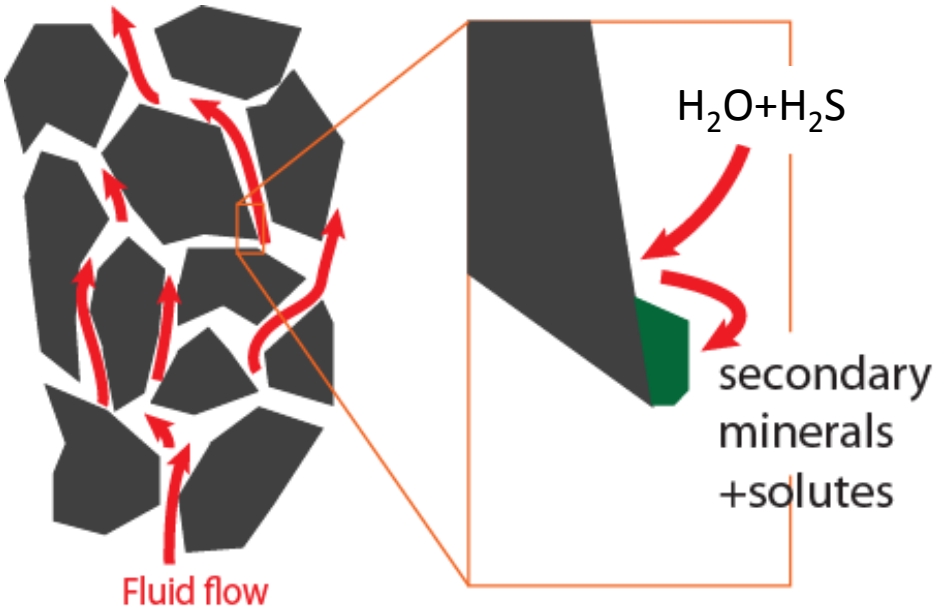
rocks + H_2O + H_2S = secondary minerals + solutes



- **Computer simulation of reactions between rocks, water and H_2S to form secondary minerals and elements in water**
- **Based on simulation many reactions using thermodynamics and kinetics**

The process of H_2S mineralization - modeling

rocks + H_2O + H_2S = secondary minerals + solutes



Reaction rates (TST)

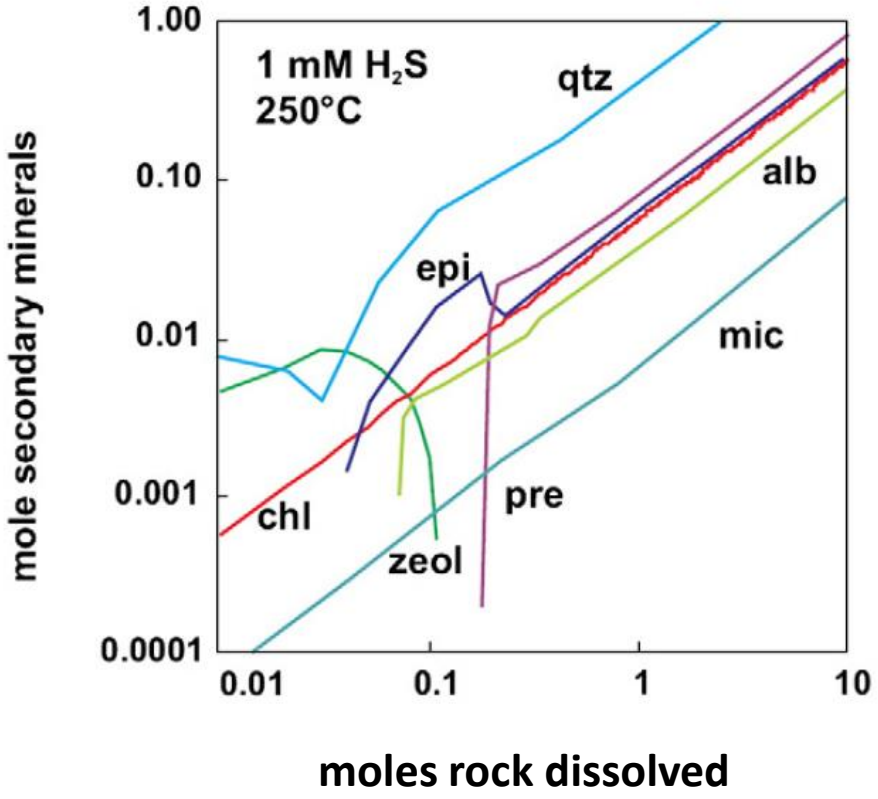
$$= \pm kAe^{-E_a/RT} \prod a_i^{\upsilon_i} \left(1 - (Q/K)^{\theta}\right)^{\eta}$$

Mineral solubilities

$$logK = \frac{\sum \nu_i \Delta G^0_{T,p,i}}{-RTln(10)}$$

H_2S mineralization

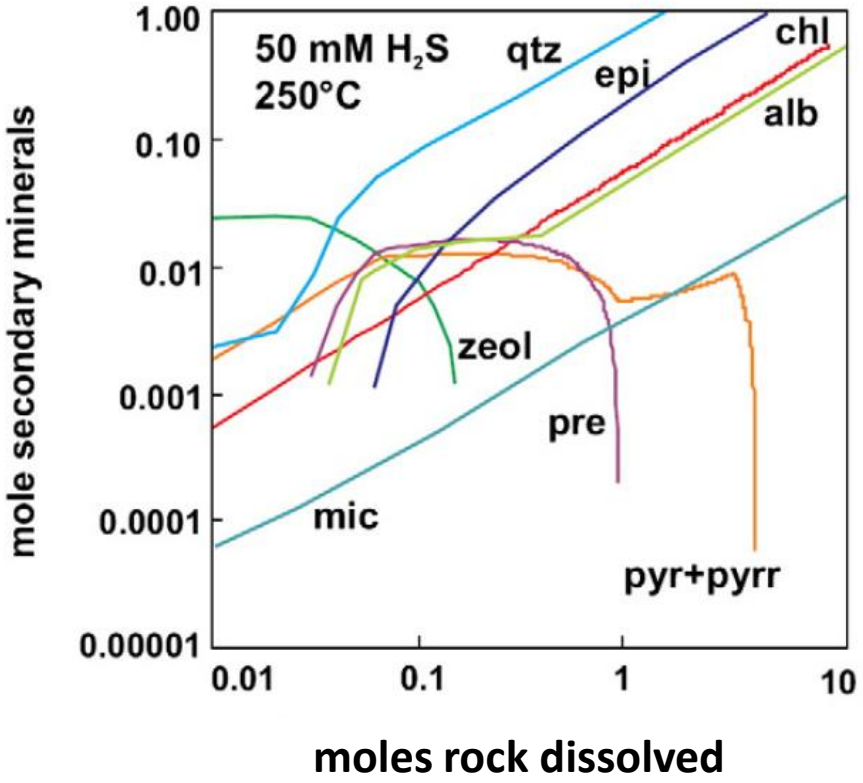
rocks + H_2O + H_2S = secondary minerals + solutes



At low H_2S concentration we have insignificant sulfide mineral formation

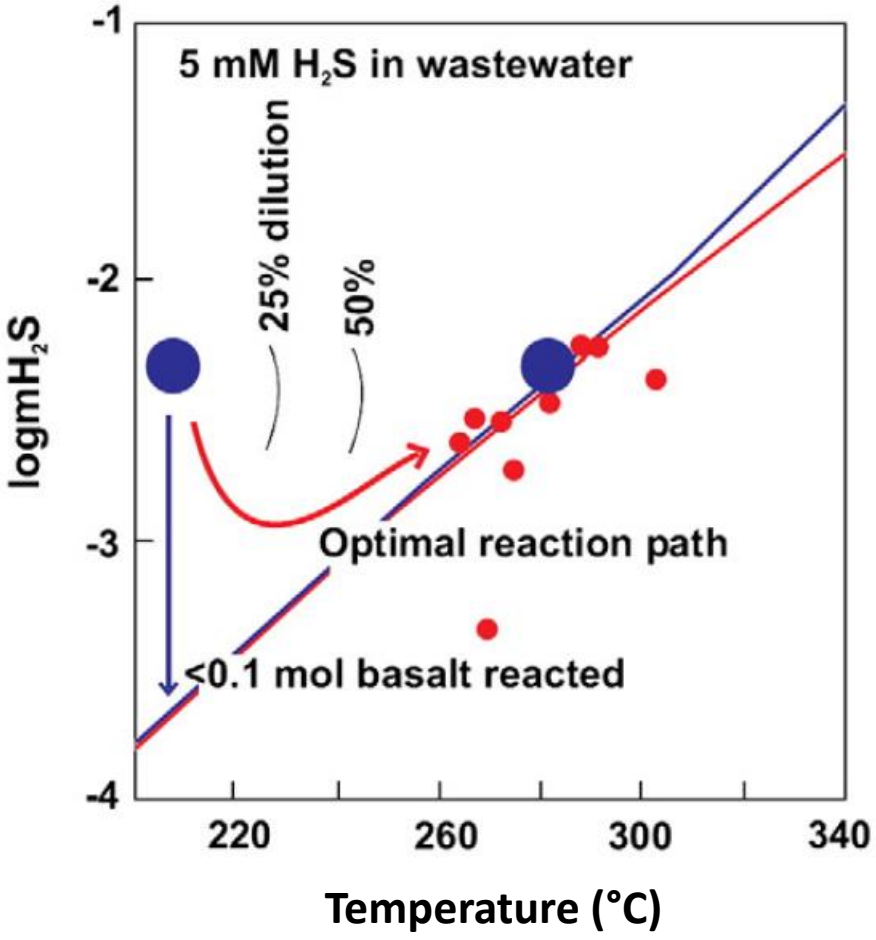
H_2S mineralization

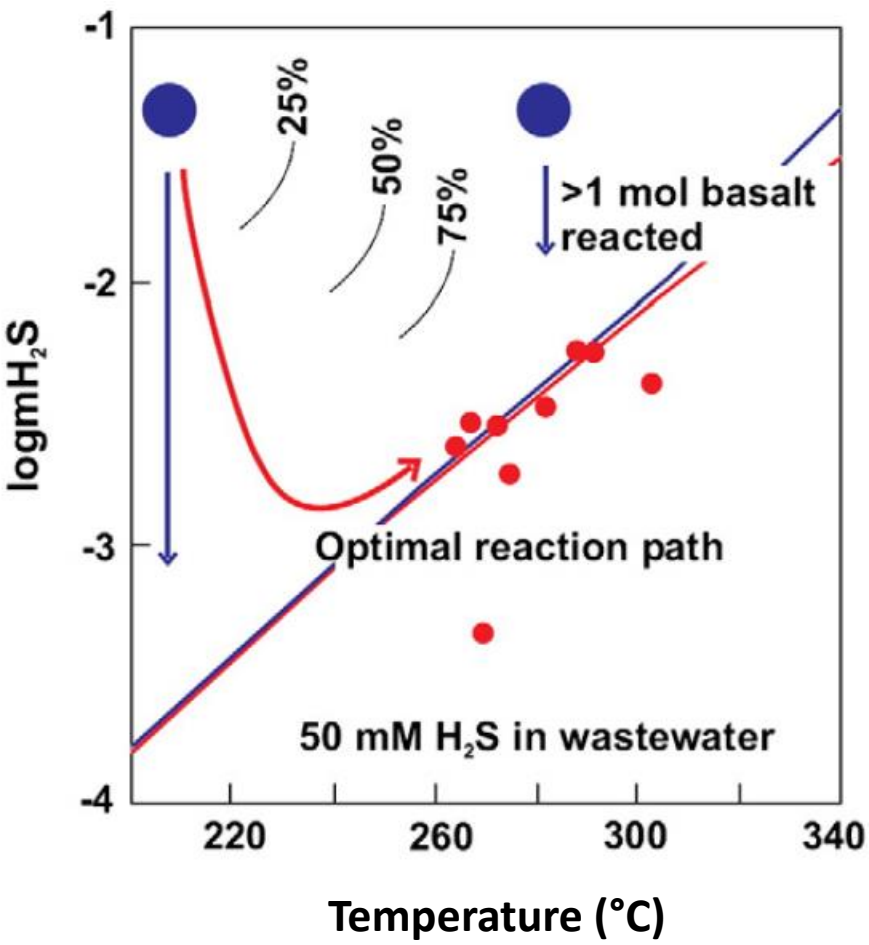
rocks + H_2O + H_2S = secondary minerals + solutes



At high H_2S concentration sulfide mineral formation is important

H_2S mineralization





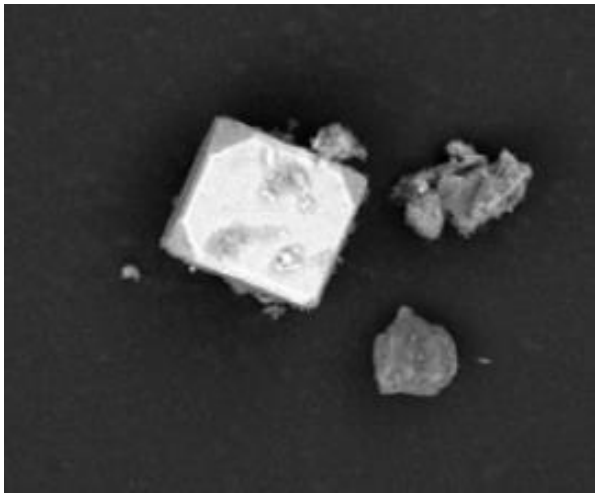
Experiments of H_2S mineralization

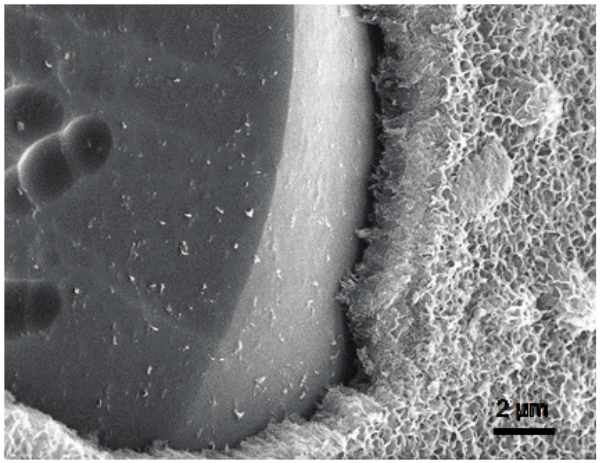
- The geochemical reaction modeling is being tested using laboratory scale fluid-rock experiments
- 70-300°C and 1-50 mM H_2S

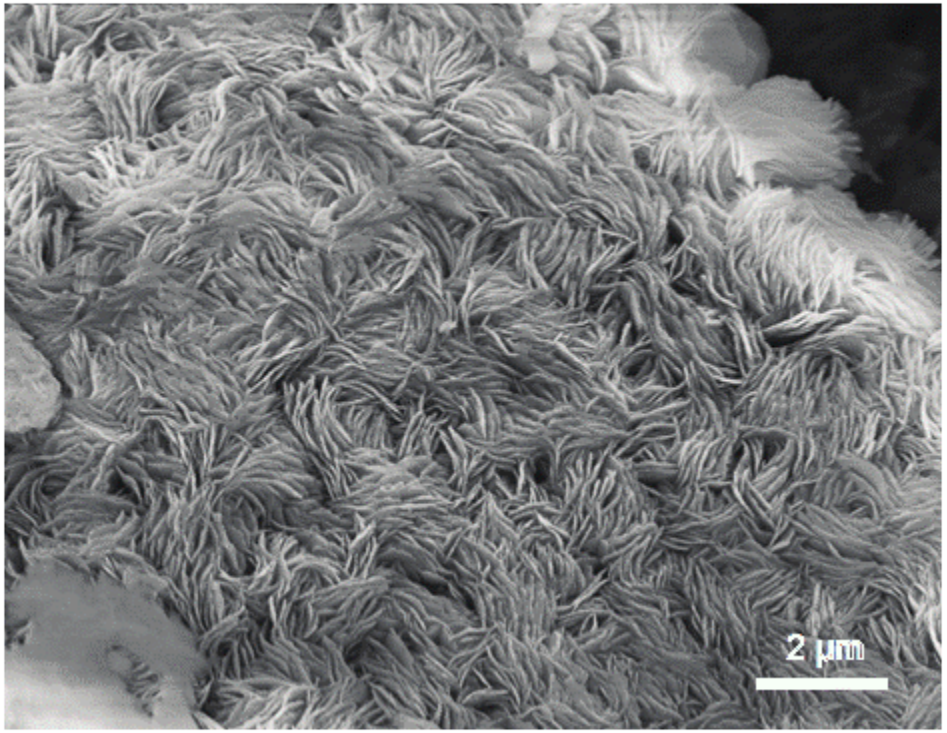
Batch type reactor

Experiments of H_2S mineralization

rocks + H_2O + H_2S = secondary minerals + solutes

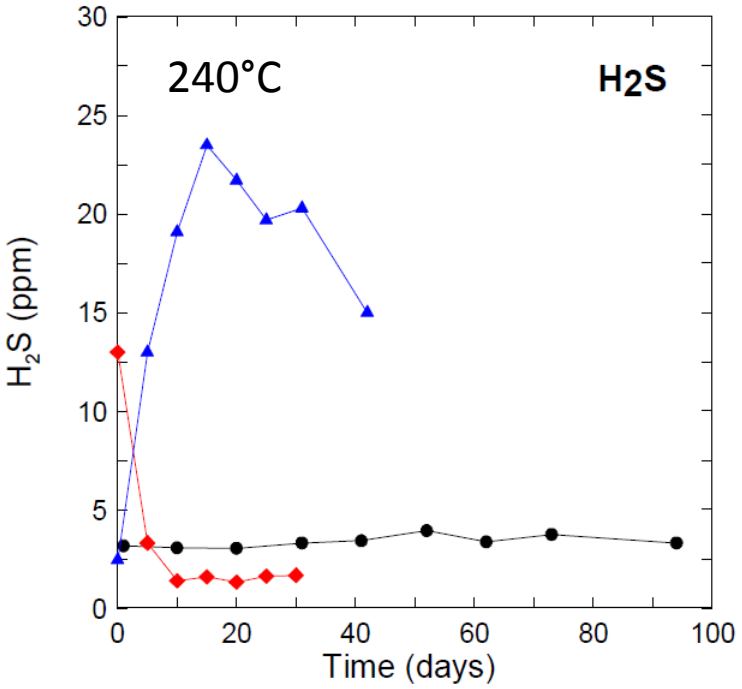


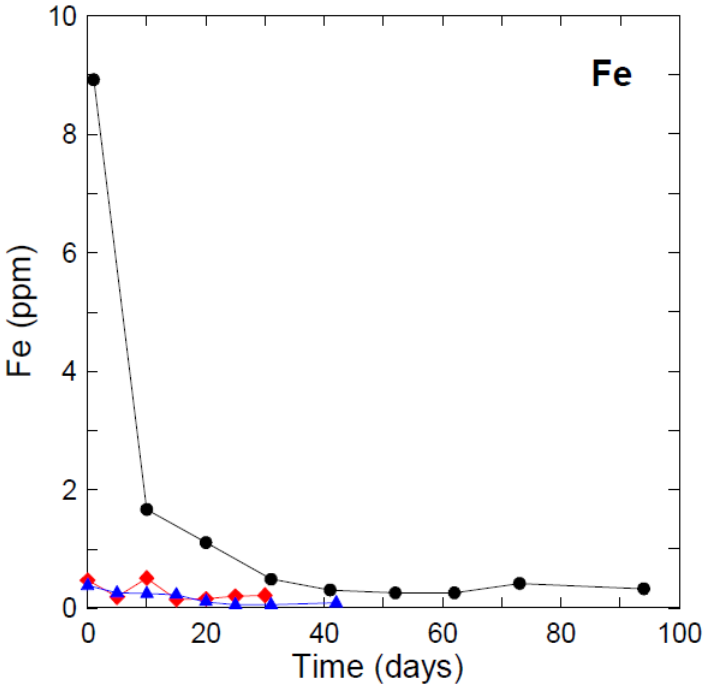




Experiments of H_2S mineralization

rocks + H_2O + H_2S = secondary minerals + solutes





Effective H_2S mineralization at high-temperatures

H_2S sequestration into geothermal systems

- H_2S emissions during geothermal utilization is of growing concern
- Possible way of reducing the emissions is re-injection of H_2S to depth whereas H_2S may mineralize to form sulfides
- The geochemistry and rate of such mineralization is being explored by studying natural systems, geochemical modeling and laboratory experiments
- So far the results are promising

People involved

Andri Stefánsson – UI
Experiments, isotopes and modeling

Hanna Kaasalainen – UI
Sulfur isotopes and chemical analysis

Shuhei Ono – MIT
Sulfur isotopes

Jóhann Gunnarsson Robin – UI
Sulfur chemistry and isotopes

Hanna Kaasalainen – UI
Sulfur chemistry and speciation

Snorri Guðbrandsson – UI
Experiments

THANK YOU

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rannís