GEORG

GEOTHERMAL RESEARCH GROUP

ANNUAL REPORT
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H_2S sequestration into geothermal systems

Project ID: 11-04-003

Coordinator: Andri Stefansson

Start date: 2012

Duration: Three years

Partners: Reykjavik Energy, Landsvirkjun and MIT, USA

1 General status of the project

Hydrogen sulfide (H_2S) is among the major components in geothermal fluids, with concentrations ranging from a few ppb to levels of hundreds of ppm. Hydrogen sulfide is volatile and is commonly emitted into the atmosphere from geothermal power plants, causing potential environmental problems.

Several methods are employed in cleaning H_2S emissions including oxidation to form elemental sulfur or sulfuric acid. One proposed method includes injection of H_2S into geothermal systems where it may be mineralized into sulfides including pyrite. Reykjavík Energy is currently test such an injection into the geothermal system at Hellisheidi, where geothermal gas (CO_2, H_2S, N_2 and H_2) is being separated in a gas abatement station and the H_2S and CO_2 stream mixed at the surface with waste water and condensed steam prior to injection into the geothermal aquifer having temperatures >200°C.

In this project laboratory experiments are being conducted to study the interaction of H_2S-rich water with basaltic rocks and the geochemistry of sulfur in geothermal systems is being assessed. Using the data obtained from the experimental work together with geochemical modelling and data on the geochemistry of sulfur in geothermal system, the optimal conditions for H_2S sequestration into geothermal systems will be assessed.

The project is divided into three major tasks:

(i) H_2S oxidation under geothermal conditions
(ii) H_2S-water-rock interaction and H_2S mineralization rate
(iii) H_2S geochemistry and sequestration into geothermal systems.

During the second year of the project, we have focused on all three parts including experimental work on H_2S oxidation and H_2S-water-rock interaction under geothermal conditions and the geochemistry of H_2S in geothermal waters with a focus on tracing the source and quantifying reactions using multiple sulfur isotopes. The results of the experiments have been reported into a Science Institute UI Report and the results of the multiple sulfur isotope work have been submitted for publication in an international journal.

The work during 2013-14 was carried out by a M.Sc. student Jóhann Gunnarsson-Robin and the two postdoctoral researchers Nicole S. Keller and Snorri Guðbrandsson, all at the University of Iceland.

1.1 Project progress/time schedule

During the year 2013-14, the project progress was according to schedule.

During 2013-14 experimental work was carried out on the mineralization and oxidation of H_2S during water-rock interaction at 100-240°C as a function of pH and H_2S concentration. The work involved setting up high-temperature flow-through reactor systems and conducting experiments on H_2S-water-rock interaction. The work was reported in "Experimental study of H_2S sequestration in geothermal systems" (report available upon request). The main conclusion of this work was: (i) the interaction of H_2S-rich water with basaltic rocks (fresh, crystalline and altered) under geothermal

conditions results in sulfide mineralization as well as formation of other secondary phases including smectites and chlorites; (ii) equilibrium H_2S concentrations are rapidly attained under geothermal conditions at >200°C independent of the initial H_2S concentration. Such equilibrium concentrations were not attained at lower temperatures (100°C). This suggests that reservoir H_2S concentrations observed in geothermal systems like at Hellisheidi are likely to be rapidly attained upon injection of H_2S-rich fluids into the systems when temperatures exceed ~200°C; (iii) the fluid-rock interaction mechanism and H_2S-mineralization along a flow-path from high-H_2S source (H_2S injection source) occurs in certain ways. Next to the high-H_2S source (injection source) dissolution of primary rocks was observed to occur, followed by intensive sulfide and clay mineralization down-stream and eventually less intensive rock alteration and (iv) the rate and mass of H_2S mineralization was found to be controlled by the rate and mass of Fe release from the primary rocks. This shows that the geochemical behavior of Fe controls the H_2S mineralization, i.e. to understand the rate and mass of H_2S sequestration in geothermal reservoir one needs to understand and be able to quantify the geochemistry of Fe in these systems.

During 2013-14 extensive work was carried out related to development of models for tracing the source and reactions of H_2S including sequestration by mineralization of H_2S in geothermal systems using multiple sulfur isotopes or ^{32}S, ^{33}S, ^{34}S and ^{36}S. This work include sampling, extractions and isotope analysis carried out in 2012-14 and finished in 2014 as well as development of reaction isotope models involving fluid-rock interaction modeling together with isotope fractionation modeling, referred to by us as quantitative isotope reaction modeling. This work has resulted in a potential method for tracing H_2S sequestration upon injection into geothermal systems using the changes in the multiple sulfur isotope signatures from the injection fluids to the production fluids. This work will continue in 2014-15 including testes carried out associated with H_2S injections into the Hellisheidi geothermal system.

2 Project Management

The participating group in the project are University of Iceland (UI), MIT, USA (MIT), Reykjavik Energy (OR), and Landsvirkjun (LV). The role of the individual participants are: access to sampling and instrumental facilities (UI, MIT), data on fluid composition (UI, OR, LV) and access to geothermal power plants and sites (OR, LV). The Science Institute, University of Iceland (UI) head office is responsible for the financial management of the project.

The main leaders of the research project are: from UI: Andri Stefansson, professor in geothermal geochemistry; from MIT: Shuhei Ono, professor of isotope and sulphur geochemistry; from OR: Ingvi Gunnarsson, scientist; from LV: Sigurdur H. Markússon, project manager. The group will have access to other scientists and technical help within their institutions.

3 Student involvement

During the second year of the project the following students and postdoctoral researchers were involved:

Jóhann Gunnarsson-Robin – Master student at the University of Iceland. Project: Sulfur Geochemistry in the Krafla geothermal system. Expected date of finish fall 2014.

Snorri Guðbrandsson – Postdoctoral Researcher at the University of Iceland. Project: Experimental study of H_2S sequestration.

Nicole S. Keller – Postdoctoral Researcher at the University of Iceland. Project: Sulfur Isotopes in the Krafla Geothermal System.

4 Publications and disseminations

In 2013-14 the results of the work related to this project were reported in:

Gudbrandsson S. and Stefánsson A. (2014) Experimental study of H_2S sequestration in geothermal systems. Science Institute Univ. Iceland Report, RH-14-14.

Snorri Guðbrandsson, Andri Stefánsson, Prathap Moola og Jan Prikryl (2014) Útfellingar brennisteins í basalti. Vísindadagur OR og ON 2014.

Stefánsson A., Keller N.S., Gunnarsson-Robin J. and Ono S. (2014) Multiple sulfur isotope systematics of Icelandic geothermal fluids and the source and reactions of sulfur in volcanic geothermal systems on divergent plate boundaries. Geochim. Cosmochim. Acta (submitted).

5 Cost statement

An over view of the cost for 2013-14 together with explanations is shown in Table 1.

Table 1. Budget overview for 04.2013-04.2014[f]

Explanation	Georg	Other financing [e]	Total
Salaries [a]	3280	3463	6743
Operational expenses [b]		2833	2833
Travel expenses [c]		600	600
Overhead [d]		261	261
Total:	**3280**	**7158**	**10437**

[a] Salaries of students and postdoctoral researchers working as a part of this project. Salary cost of permanent staff (UI, LV, OR, MIT) are not included here.
[b] Operational expenses includes various consumables for reactors and sampling as well as chemical analysis.
[c] Travel expenses related sulphur isotopes analysis.
[d] Overhead of 2.5% (Science Institute, University of Iceland)
[e] Other financing includes: Orkurannsóknarsjóður Landsvirkjunar, Rannís and other financing.
[f] The budget overview was based on cost for 9m in 2013 and 3 m in 2014 for the relevant accounts according to Science Institute, University of Iceland (RH).