

# EVALUATION OF POTENTIAL GEOCHEMICAL RESPONSES TO INJECTION IN THE FORGE GEOTHERMAL RESERVOIR, UTAH

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## **Executive Summary**

Plugging of fracture porosity from mineral precipitation due to injecting cold water into a geothermal reservoir can impact the overall permeability of the fracture network in the reservoir. This can have serious ramifications on the efficiency of the geothermal resource. Geochemical modeling can be useful in providing a first-hand evaluation of potential of mineral precipitation along the different reaction paths. We developed geochemical models for injecting four different relevant water compositions in the FORGE Utah geothermal reservoir through well 58-32. Results and discussions related to this work are presented in this technical report.

## **Conclusions and Recommendations**

- Quartz, calcite and clays were predicted to possibly precipitate over the reaction path.
- Anhydrite was not predicted in this model, but has been predicted in the RHS reaction models (that I presented in the EGI seminar), especially with acidified 45-3 water. Thus, possibility of anhydrite precipitation CANNOT be ruled out at the FORGE site.
- Low-TDS groundwater is the best option for avoiding mineral deposition in the stimulated fractures. Even a mixture of this groundwater with 45-3 water would make a difference in the quantity of possible precipitation in fractures.
- Also, acidified 45-3 water may cause overall lower mineral precipitation compared to untreated 45-3 water (especially calcite), however it is still predicted to cause some quartz precipitation.
- A reactive transport model with full thermal-chemical-hydro coupling is essential to significantly improve our understanding and predictive ability of porosity alternation in fractures. Such a model will also likely help resolve the anhydrite prediction issue. The geochemical models developed in this project will serve as effective constraining tools for the reactive transport model.

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## **Introduction**

Geothermal resources are increasingly being used as a source of energy [1]. To extract the heat for use, a cool fluid is injected into the geothermal reservoir, where it typically flows through a network of natural or induced fractures, gains thermal energy from its contact with the reservoir rock, and is produced as heated fluid from which thermal energy is extracted at the earth's surface. The difference in temperatures and chemistry between the reservoir fluid-rock and the injected water set up a polythermal kinetic reaction path that can lead to precipitation or dissolution of minerals and effectively alter the fracture porosity. This is one of the main challenges in sustaining the efficiency of the geothermal energy extraction process. The goal of this project was to evaluate the chemical potential of mineral precipitation/dissolution upon injection of cold fluid of varied compositions into the FORGE Utah geothermal reservoir, located near Milford, Utah.

The geological details of the site are described in detail by Stuart Simmons and others [2–4]. The Roosevelt Hot Springs geothermal reservoir is located ~2 miles southeast from the FORGE site. Both the geothermal reservoir are liquid-dominated reservoirs hosted in the same granitic rock formation and thus have similar geochemical characteristics. The Roosevelt Hot Springs geothermal reservoir is an old and active site where the Blundell Power Plant has been operational since 1984. Conversely, the FORGE Utah site has been chosen to build a new 'geothermal laboratory' that will be funded by DOE. A new well (Well 58-32) has been drilled and will be used to inject cold fluid into the FORGE Utah reservoir.

## **Model Development**

The polythermal kinetic reaction path models for the fluid-rock interactions were developed using The Geochemists' Workbench (GWB v.9) software [5].

### **Conceptual model:**

Upon drilling of the 58-32 well and stimulating fractures in the host rock, relatively cool water will be injected into the dry rock. The model simulates kinetic reactions between 1kg water with proportionate mass of minerals from the host rock assuming fracture porosity of 10%. The water kinetically reacts with the rock over 10 days. The water temperature is set to uniformly rise from 60°C to 200°C over 10 days (Figure 1). In order to mimic production and subsequent cooling, the heated and reacted water composition is separated from the rock minerals and cooled down to 50°C in a closed system.

### **Geochemical parameters:**

Mineralogical composition of almost equal portions of quartz, plagioclase feldspar and K-feldspar is assumed, based on XRD data provided by Clay Jones. Secondary minerals allowed to precipitate were Calcite, Illite, Kaolinite, Saponite (Na and Ca) and Anhydrite. Kinetic parameters were assigned to each mineral according to the database published by the USGS [6]. Precipitation kinetic data for most minerals is not studied, and thus dissolution parameters were applied to precipitation. This simplification assumes that the principle of reversibility holds true [7]. Mineralogical parameters set in the model are presented in Table 1.

Four different water compositions, presented in Table 2, were tested with the model. Water 1 is the composition of water from well 45-3 (Roosevelt Hot Springs) at 60°C with silica aqueous concentration set to amorphous silica saturation ( $\Omega_{Amrph-Silica} = 1$ ). Water 2 is the composition of water 1 acidified (to pH~5) with sulphuric acid in order to avoid amorphous silica formation in the

pipelines. Water 3 is a typical low-TDS, low residence time groundwater composition. Water 4 is a 1:1 mass mixture of Water 1 and 3 calculated by GWB.

### **Results & Discussion**

Figure 2 presents the key results of the 10-day polythermal and kinetic reaction path of the four fluid compositions with the primary minerals of the FORGE Utah geothermal reservoir host rock. The top row presents the evolution of pH along the reaction path, the middle row presents the expected mass in grams of secondary minerals to precipitate, and the bottom row presents the overall mass in grams of minerals gained from 1kg of water over a period of 10 days.

The pH of the reaction remained near-neutral in all cases, except in case of Water 2 wherein it was acidic. The minerals of interest in all the cases were quartz, calcite, illite and kaolinite. Quartz and calcite were predominant in the case of Water 1 (well 45-3). However, the supersaturation of calcite is pH sensitive, as it remains under saturated in case of Water 2 (acidified 45-3 water). Quartz supersaturation is directly dependent on  $\text{SiO}_{2(\text{aq})}$  concentration. Thus, Water 3 which is a low TDS groundwater (also low in  $\text{SiO}_{2(\text{aq})}$ ) leads almost no quartz deposition. Water 4, being a mixture of the low TDS groundwater and well 45-3 water, predicts an intermediate effect of the two independent compositions. Clays, represented in the model by illite and kaolinite, are predicted to form in all the cases. More precision and amount of kinetic data is required to make an accurate prediction on the exact clay phases likely to precipitate. Figure 2 also presents the overall gain or loss in mineral mass over the reaction path.

Another point of interest would be the scaling potential of the produced fluids as they cool down near the earth's surface. This aspect has economic ramifications for the entire process, as scaling of minerals in pipes and heat exchangers can reduce the life and efficiency of the equipment. Figure 3 demonstrates that, while calcite and amorphous silica may remain undersaturated below 100°C, quartz becomes supersaturated in all the water cases, predicting a high propensity of scaling with quartz.

Since the driving motivation of this project is to evaluate the potential of porosity drop caused by different injectate water compositions in the reservoir fractures, it is imperative to estimate the total mass or volume of mineral gained and the porosity dropped for each case. Therefore, estimated porosity reduction per kg of water are calculated (by assuming a rock density of 2.5 g/cm<sup>3</sup>) for each water types, as presented in Table 3. These values of change in porosity are given per kg of water. From this result, it can be estimated that, for an injection rate of 4 kg/s (arbitrary value for the sake of providing an example), the porosity drop per day could be 207% for Water 1 (45-3). While the actual value may be lower when a fracture flow system is considered, it indicates that the possibility of fracture sealing is high, especially with unacidified well 45-3 water.

Anhydrite was a mineral of concern that was not predicted to precipitate in any of the cases. Anhydrite precipitation in geothermal fields that can be relatively fast and lead to rapid loss of fracture porosity. Our hypothesis was that anhydrite would be expected to form when acidified 45-3 water is injected in the FORGE reservoir. The reasons for this hypothesis were (1) acidifying the water with sulphuric acid adds substantial amount of sulphate ions, and (2) such an effect was predicted in the models for the Roosevelt Hot Springs, as presented by Vivek Patil in an EGI seminar on March 25, 2019 [8]. On the contrary, none of the cases for the FORGE model promoted anhydrite precipitation. This is because all the four water compositions are under saturated with respect to anhydrite. Even if the same is true in case of our RHS models [8], the 'flush' configuration of the RHS model, in addition to the presence of a equilibrated reservoir fluid, can be speculated to have made the difference.

As demonstrated in this study, geochemical reaction path modeling can provide a valuable first-hand estimate of the likelihood and quantity of mineral deposition in the fracture network of a geothermal reservoir. The efficiency of an EGS can be greatly hampered by plugging of fracture porosity. However, the reactive system is highly dynamic and a dual-porosity or dual-permeability based coupled reactive transport model is necessary in making more informed predictions of the impact the above mineral reactions would have on the fracture porosity and the overall permeability through the reservoir.

### **References**

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## Figures

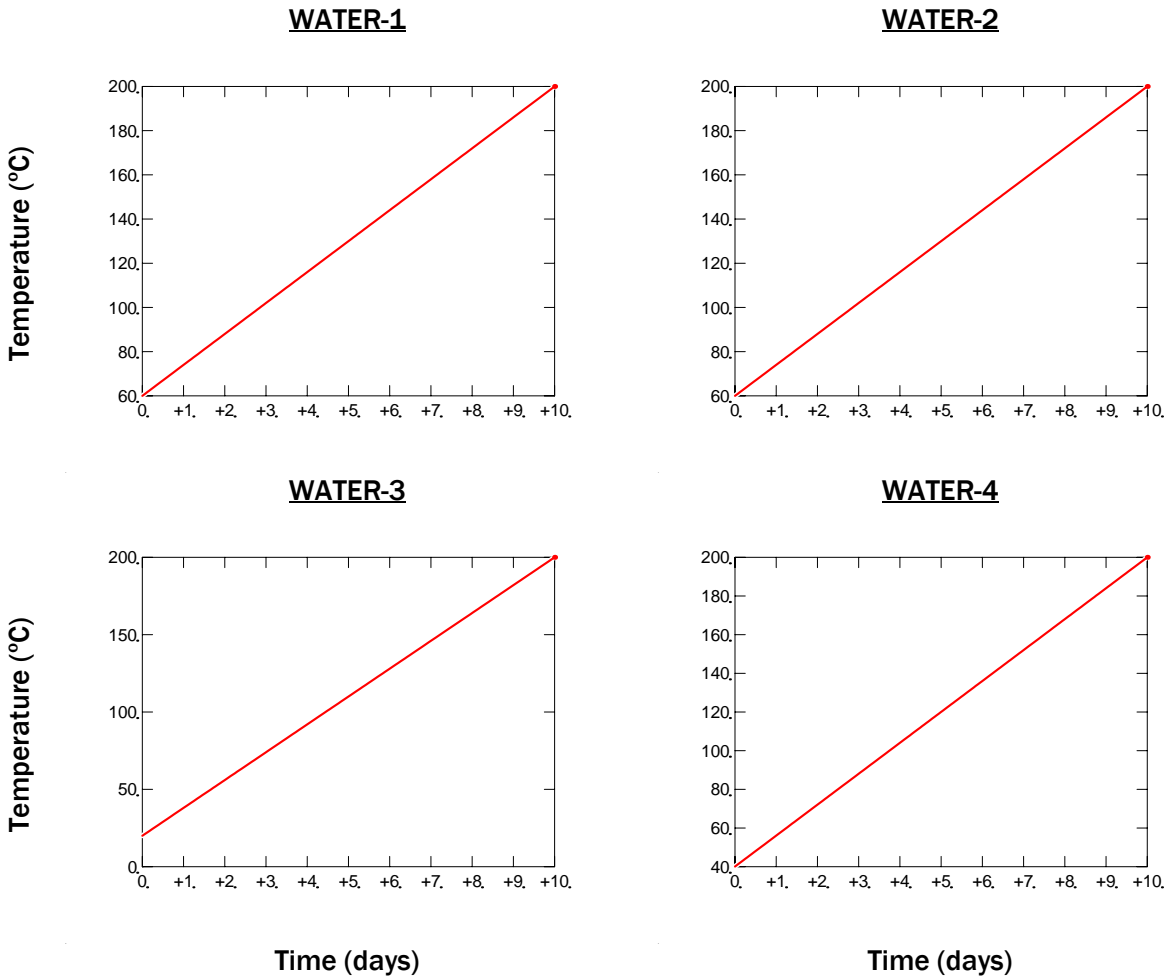


Figure 1: Temperature profile along the heating reaction path. The temperature of the fluid phase is set to rise from to 60°C to 200°C steadily over a period of 10 days

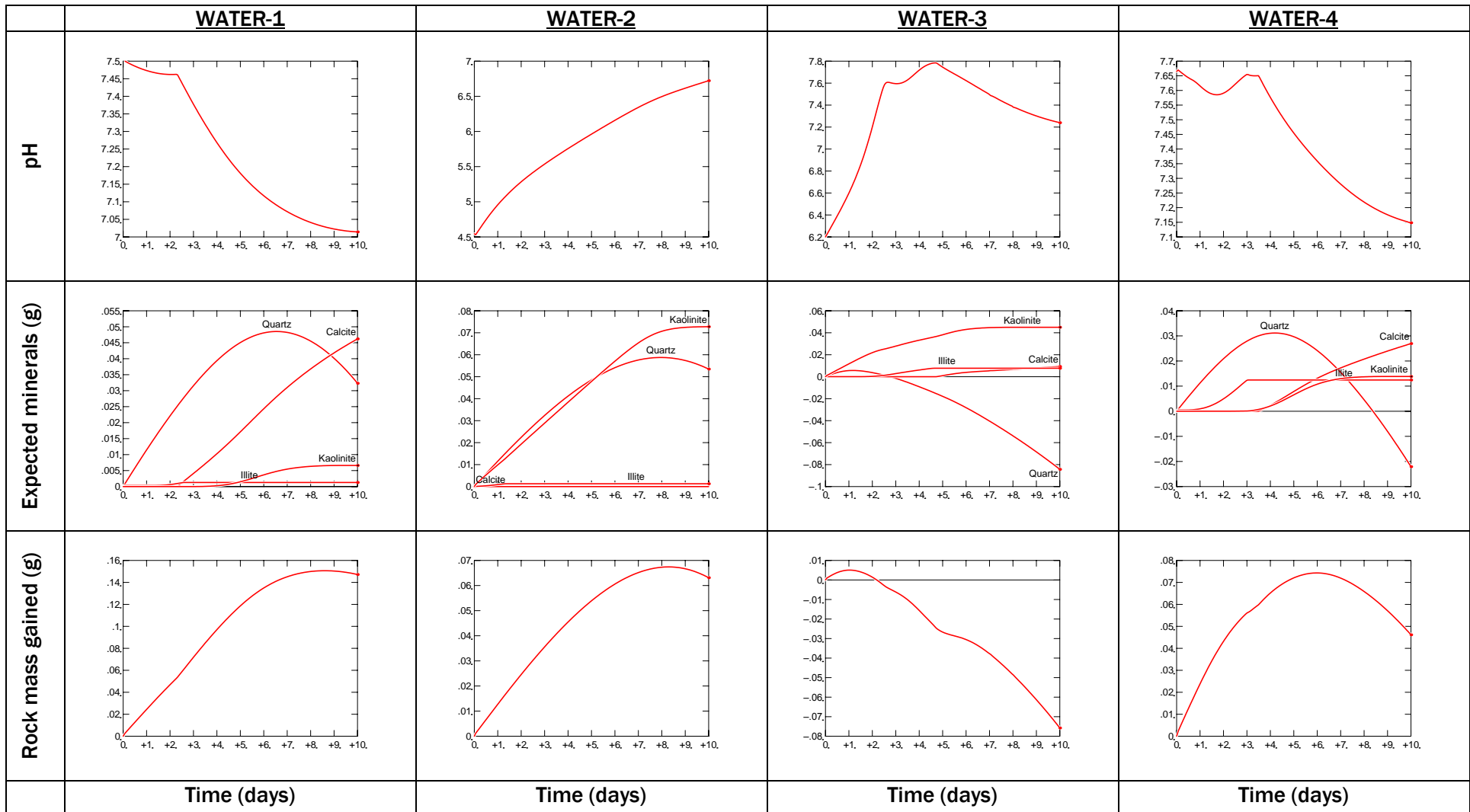


Figure 2: Reaction path modeling results of injecting four water compositions into the FORGE Utah reservoir rock. Abscissa in all plots denotes time in days. Top row – pH evolution; middle row – expected secondary precipitation; bottom row – total rock mass gained (or lost if negative)

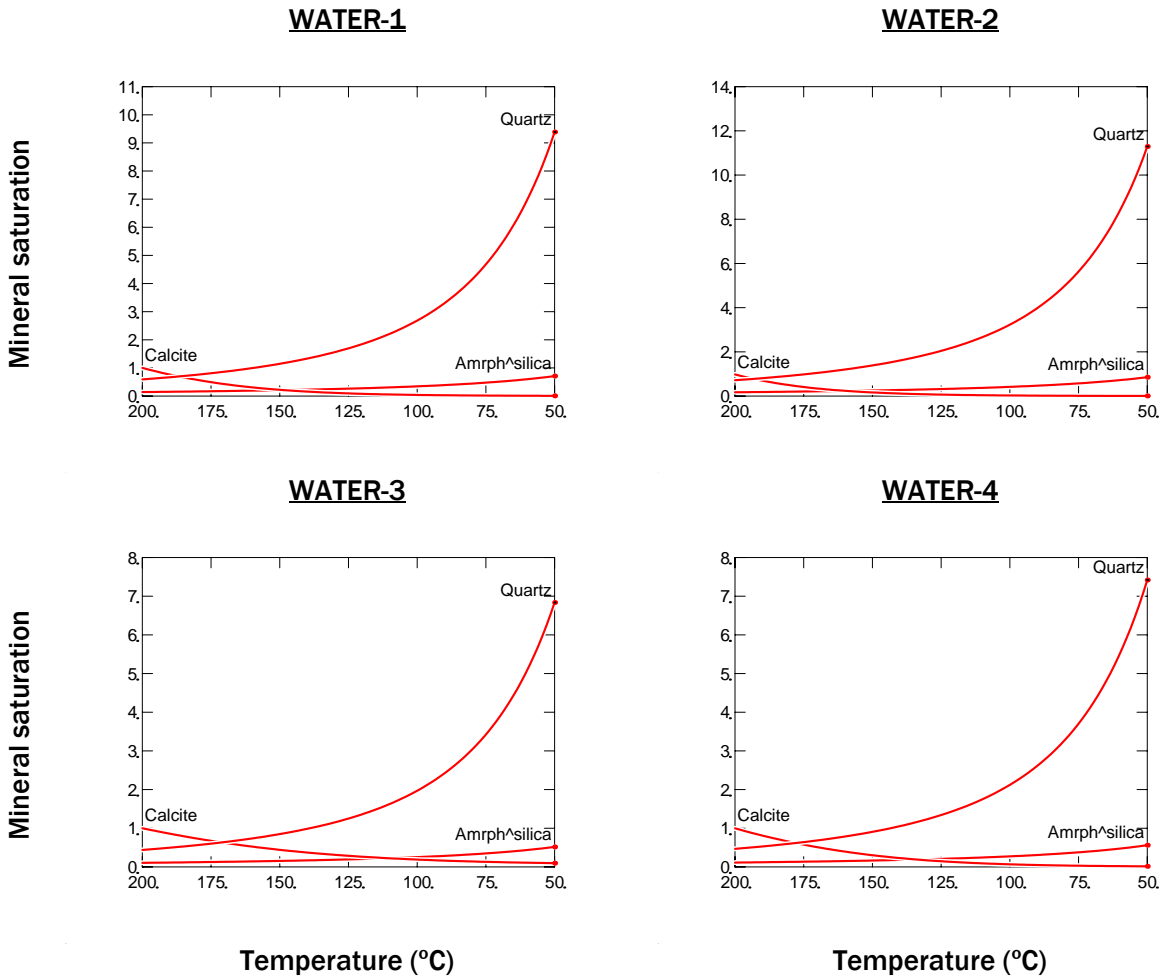


Figure 3: Post-production cooling of fluid in a closed system (no gas escape or mineral precipitate). Mineral saturations show that quartz becomes supersaturated while amorphous silica and calcite remain undersaturated below 100°C.

## Tables

Table 1: Mineralogical parameters set in the FORGE Utah geochemical model.  $K_{25}$ ,  $E_a$  and  $A$  are kinetic parameters for the water-rock reactions. The associated kinetic rate equations are described in Appendix B: .

<b>MINERAL</b>	<b>VOLUME (cm<sup>3</sup>)</b>	<b><math>K_{25}</math> (mol/cm<sup>2</sup>.s)</b>	<b><math>E_a</math> (kJ/mol)</b>	<b>A (cm<sup>2</sup>/g)</b>
<b>Albite</b>	2268	2.75E-17	69.8	10
<b>Anorthite</b>	243	7.59E-14	17.8	10
<b>K-feldspar</b>	2754	3.89E-17	38	10
<b>Quartz (diss)</b>	2511	4.90E-18	76	10
<b>Quartz (prec)</b>		3.80E-14	49.8	10
<b>Calcite</b>		1.55E-10	23.5	10
<b>Illite</b>		1.66E-17	35	150
<b>Kaolinite</b>		6.61E-18	22.2	150
<b>Anhydrite</b>		6.46E-08	14.3	10
<b>Saponite-Ca</b>		1.66E-17	35	150
<b>Saponite-Na</b>		1.66E-17	35	150

Table 2: Different water compositions used in the FORGE Utah geochemical model. Water-1 represents the composition of produced water from well 45-3 (Roosevelt Hot Springs) and cooled down to 60°C. Water-2 represents the well 45-3 water acidified with sulphuric acid. Water-3 represents a typical low-TDS groundwater composition [9]. Water-4 is a 1:1 mixture of Water-1 and Water-3

<b>FLUID CHEMISTRY (mg/kg)</b>				
	<b>Water 1</b>	<b>Water 2</b>	<b>Water 3</b>	<b>Water 4</b>
<b>Temperature</b>	60°C	60°C	20°C	40°C
<b>pH</b>	7.5	4.5	6.2	7.66
<b>Na</b>	2710	2695	3.03	1359
<b>K</b>	612	608.6	1.09	307.2
<b>Ca</b>	27	22.83	3.11	13.34
<b>Mg</b>	0.02	0.018	0.7	0.3434
<b>SiO<sub>2(aq)</sub></b>	220	220	16.4	116.3
<b>Al</b>	0.1	0.027	0.1	0.1
<b>Cl</b>	4935	4671	0.5	2351
<b>SO<sub>4</sub></b>	53	97.35	1	23.27
<b>HCO<sub>3</sub></b>	87	1.835	20	49.49

Table 3: Estimated porosity drop or gain from reaction of FORGE reservoir rock with different injectate compositions. A density of 2.5 cm<sup>3</sup>/g is assumed for the secondary precipitation.

<b>Precipitation per kg of injected water</b>
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<b>Water</b>	<b>Mass gained (g)</b>	<b>Volume gained (cm3)</b>	<b>Porosity dropped</b>
<b>1</b>	<b>0.15</b>	<b>0.06</b>	<b>0.000006</b>
<b>2</b>	<b>0.06</b>	<b>0.024</b>	<b>0.0000024</b>
<b>3</b>	<b>-0.08</b>	<b>-0.032</b>	<b>-0.0000032</b>
<b>4</b>	<b>0.045</b>	<b>0.018</b>	<b>0.0000018</b>

## **Appendix A: GWB React Script for Water-1**

temperature initial = 60 C final = 200 C  
time end = 10 days

H2O = 1 free kg  
Cl- = 4935 mg/kg  
HCO3- = 87 mg/kg  
SO4-- = 53 mg/kg  
Na+ = 2710 mg/kg  
K+ = 612 mg/kg  
Ca++ = 27 mg/kg  
Mg++ = .02 mg/kg  
Al+++ = .1 mg/kg  
pH = 7.5  
SiO2(aq) = 220 mg/kg

react 2268 cm3 "Albite low"  
react 2754 cm3 K-feldspar  
react 2511 cm3 Quartz  
react 243 cm3 Anorthite

suppress ALL  
unsuppress Quartz K-feldspar "Albite low" Anorthite Calcite Illite  
unsuppress Kaolinite Saponite-Na Saponite-Ca Anhydrite

kinetic Quartz dissolution pre-exp = 4.898e-18 act\_eng = 76 surface = 10  
kinetic Quartz precipitation pre-exp = 3.8e-14 act\_eng = 49.8 surface = 10  
kinetic K-feldspar dissolution pre-exp = 3.89e-17 act\_eng = 38 surface = 10  
kinetic "Albite low" dissolution pre-exp = 2.754e-17 act\_eng = 69.8 surface = 10  
kinetic Anorthite dissolution pre-exp = 7.586e-14 act\_eng = 17.8 surface = 10  
kinetic Calcite pre-exp = 1.549e-10 act\_eng = 23.5 surface = 10 nucleus = 1000  
kinetic Illite pre-exp = 1.66e-17 act\_eng = 35 surface = 150 nucleus = 1000  
kinetic Saponite-Na pre-exp = 1.66e-17 act\_eng = 35 surface = 150 nucleus = 1000  
kinetic Saponite-Ca pre-exp = 1.66e-17 act\_eng = 35 surface = 150 nucleus = 1000  
kinetic Kaolinite pre-exp = 6.607e-18 act\_eng = 22.2 surface = 150 nucleus = 1000  
kinetic Anhydrite pre-exp = 6.457e-8 act\_eng = 14.3 surface = 10 nucleus = 1000

porosity  
epsilon = 1e-5  
suffix \_Water1  
go

pickup fluids  
precip off  
temperature final = 50 C  
suffix \_Water1\_cooling

**Appendix B: Kinetic rate law for mineral precipitation/dissolution**