

## Preliminary Results of CO<sub>2</sub> Sequestration into Ogachi Geothermal Reservoir, Northeast Japan

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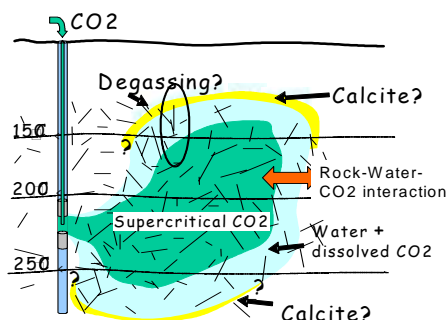
### ABSTRACT

Reducing the amount of CO<sub>2</sub> emitted by fossil fuel combustion is imperative to curb global warming. A promising method is to sequester CO<sub>2</sub> into the earth's crust as carbonates. In geothermal fields, injected CO<sub>2</sub> may react with surrounding minerals, e.g., Ca feldspar and anhydrite, and may precipitate CaCO<sub>3</sub> at locations that are remote from the injection point, forming cap rocks.

We performed preliminary laboratory and field testing to investigate CO<sub>2</sub>/rock water reaction. The field test site is located at Ogachi, northeast Japan, where Hot Dry Rock (HDR) geothermal power exploitation tests had been conducted previously. Frozen CO<sub>2</sub> was injected into an artificial reservoir with an initial temperature of 210°C using a 1100 m wellbore. The reservoir is mylonitized granodiorite with fractures mostly filled with anhydrite (CaSO<sub>4</sub>). Fluids at 1030 m depth were sampled in situ and then analyzed at the surface. It was found that dissolution of Ca was enhanced by CO<sub>2</sub> injection. This result, together with our laboratory data, supports the feasibility of sequestering CO<sub>2</sub> as CaCO<sub>3</sub> in geothermal fields.

### 1. INTRODUCTION

Sequestering CO<sub>2</sub> into the earth's crust is presently gaining much attention. Although the main targets for sequestration are oil and gas fields and saline aquifers (Lackner, 2003), geothermal fields may provide another option. In geothermal fields, injected CO<sub>2</sub> may react with surrounding minerals, e.g., Ca feldspar and anhydrite, and may precipitate CaCO<sub>3</sub> distally, thereby forming cap rocks (Fig. 1). In order to demonstrate the feasibility of this concept, we started both laboratory and field tests from 2002. This paper deals with a preliminary field test conducted at Ogachi site in 2003.



**Figure 1: Concept of CO<sub>2</sub> sequestration in geothermal fields.**

### 2. PRELIMINARY EXPERIMENT

Before the Ogachi field experiment a preliminary test was performed to examine how frozen CO<sub>2</sub> behaves in water.

A transparent acrylic pipe was set vertically and frozen CO<sub>2</sub> was injected from the top (Fig. 2). An important finding was that crushed (or powdered) CO<sub>2</sub> was not suitable because severe bubbling hampered the experiment, while platy CO<sub>2</sub> (2 cm in thickness) descended in the water successfully accompanied by only a small amount of bubbling (Fig. 2). As a consequence, we decided to use platy CO<sub>2</sub> for the Ogachi experiment.



**Figure 2: Preliminary frozen CO<sub>2</sub> injection test.**

### 3. OGACHI EXPERIMENT

A 1100 m wellbore, OGC-2, was used for this experiment. It has steel casing to a depth of 700 m and the remaining section is open hole. The geology is mylonitized granodiorite below 300 m depth (Ito, 2003). Its water level is 135 m deep, which is stable all year round under natural conditions.

Three series of experiments were conducted:

Run-1) Injection of river water

Run-2) Injection of 1 wt% frozen CO<sub>2</sub> with river water (i.e., river water was injected at a rate of 50 kg/min with frozen CO<sub>2</sub> at a rate of 0.5 kg/min)

Run-3) Injection of 3 wt% frozen CO<sub>2</sub> with river water

In Runs-2 and -3, frozen CO<sub>2</sub> was injected to a total of 50 kg and 150 kg, respectively. In Run-3, NaCl (1 wt%) was also injected as a tracer.

Water was sampled at 1030 m in depth for up to 12 days using a water sampler attached to a temperature-logging tool. The temperature at the sampling depth recovered to its original value of ~210°C within one day in all experiments.

Electric conductivity (EC), pH and some chemical species were analyzed either on site or back in the laboratory.

#### 4. RESULTS AND DISCUSSION

The results are shown in Table 1 and Fig. 3. In all experiments, pH decreased from 7 (river water value) to ~6. When the results from Runs-2 and -3 are viewed in more detail it can be seen that the pH decreased below 6 and then approached 6.4, which is probably the original formation water value. The EC, SiO<sub>2</sub>, Na and SO<sub>4</sub> increased in all cases regardless of the CO<sub>2</sub> injection except for a decrease in Na and EC in Run-3 that was related to NaCl tracer injection and its subsequent diffusion. When CO<sub>2</sub> was injected (Runs-2 and -3), the Ca concentrations increased very quickly (within one day) then quickly decreased to the original value.

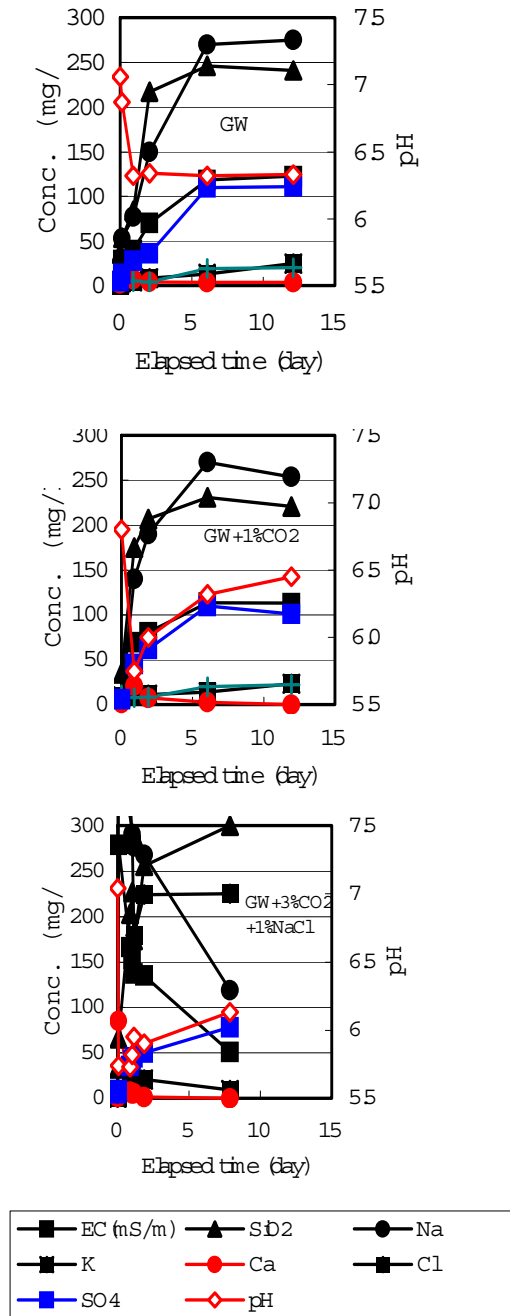
At Ogachi, a large volume of water injection (stimulation) was performed previously during HDR experiments using a nearby well, OGC-1 (Kiho and Mambo, 1994, 1995). For this experiment, an open hole section of 990-1000 m in depth was stimulated. Calcium and SO<sub>4</sub> contents in the return water increased quickly (within 3 hours) and stayed at high values for 4 days in contrast to other chemical species (such as, Na, K, Cl and HCO<sub>3</sub>) (Fig. 4). The Ca increase was attributed to dissolution of thick anhydrite (CaSO<sub>4</sub>) veins in the granodiorite (Kiho and Mambo, 1994, 1995; Ito, 2003).

In our experiments, the behavior of Ca and SO<sub>4</sub> is different from that of Kiho and Mambo (1994; 1995) in that Ca decreased while SO<sub>4</sub> increased after one day. As mentioned above, the SO<sub>4</sub> behavior was not influenced by CO<sub>2</sub> injection, and Ca is the only species affected by CO<sub>2</sub> injection. It may be possible that anhydrite had dissolved away at the time of our experiment and Ca may have been derived from other Ca-bearing minerals, such as Ca-feldspar in the host rock.

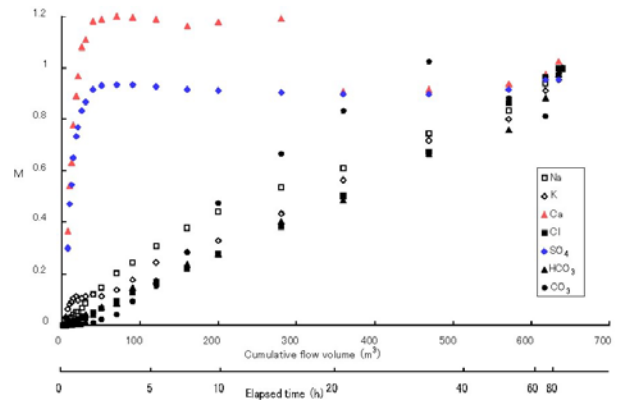
From these experiments, it is evident that Ca dissolution was enhanced by CO<sub>2</sub> injection and reacted very quickly. The following Ca decrease was possibly due to diffusion by water circulation in and around the wellbore, which also explains Na and Cl behavior in Run-3. Alternatively, the dissolved Ca may have precipitated as carbonate.

**Table 1: Summary of frozen CO<sub>2</sub> injection experiments at Ogachi in 2003**

	RUN-1 (River water)						RUN-2 (River water+1%CO <sub>2</sub> )					RUN-3 (River water+3%CO <sub>2</sub> )							
Elapsed time	*1	3h	22h	49h	145h	290h	*1	17h	40h	140h	282h	*1	+0.1%NaCl	1h	21h	24h	28h	45h	145h
Depth (m)	-	750	1030	1030	1030	1030	-	1030	1030	1030	1030	-	-	1030	1030	1030	850	1030	1030
Temperature (°C)	18	135.7	207.8	209.8	211.2	211.6	20	201	206.5	210	210.4	25	-	176.1	204.8	205.4	174.9	207.4	206.1
C-SiO <sub>2</sub> (mg/L)	34	55	84	217	247	241	35	175	207	231	221	33	34	66	203	227	174	256	300
pH	7.06	6.87	6.92	6.84	6.32	6.33	6.8	5.75	6	6.32	6.45	7.04	6.87	5.74	5.73	5.82	5.95	5.9	6.13
EC(mS/m)	5.3	28.7	39.8	70.1	118.3	122.4	7.6	69.4	80.6	113.6	118.2	4.74	220	279	166.3	153.3	137.4	135	50.9
Na(mg/L)	4.5	53	77	150	270	275	4.4	140	190	270	254	4.33	403	464	310	291	277	268	119
K(mg/L)	1	3.6	5.3	8.3	13	24.8	2.1	10	11	14	23.1	0.42	3.2	8.14	20.7	19.9	20.2	20.9	9.3
Ca(mg/L)	2.3	6.8	7.2	4.4	3.6	3.85	1.88	21	7.4	2.7	0.14	1.57	2.09	85.2	7.57	5.15	5.73	1.56	0.06
Mg(mg/L)	0.8	0.2	0.1	<0.1	0.1	0.1	1.06	0.2	0.1	<0.1	0.02	0.81	1.18	3.05	0.32	0.23	0.5	0.08	0.1
Al(mg/L)	<0.1	<0.1	<0.1	1	1	-	-	0.4	0.7	2.9	-	-	-	-	-	-	-	-	-
ΣFe(mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	<0.1	0.1	0.1	-	-	-	-	-	-	-	-	-
Cl(mg/L)	4	4	5	4	19	20	11	8	8.2	20	22.5	5.3	610	684	334	280	179	224	225
SO <sub>4</sub> (mg/L)	5	13	28	36	110	111	6.2	45	62	110	101	5.4	5.6	9.26	35.4	42	44.8	50	78
δD(‰)	-63.8	-63.7	-65	-71.1	-73.2	-70.6	-64	-65.7	-66.7	-70.1	-69.7	-65.2	-64.9	-62.6	-65.7	-62.7	-67.1	-66.4	-65.7
δ <sup>18</sup> O(‰)	-9.75	-9.86	-9.98	-10.4	-10.8	-10.8	-10.5	-10.3	-10.4	-10.7	-10.7	-10.1	-10.3	-10.4	-10.4	-10.5	-10.6	-10.6	-10.5
*1: River water																			



**Figure 3:** Behavior of EC, pH and major chemical species dissolved in water at 1030 m depth. The value of EC follows the left side scale. Data at origin is from river water for Runs-1 and -2, and river water +1% NaCl for Run-3. Data of 3 hr in Run-1 and 28 hr in Run-3 are sampled at 750 m and 850 m in depth, respectively. Top: Run-1, Middle: Run-2, Bottom: Run-3.



**Figure 4:** Behavior of major chemical species dissolved in the return water (modified from Kiho and Mambo (1995).  $M = (X - X_{in}) / (X_{fo} - X_{in})$ , where X: concentration in the return water,  $X_{in}$ : concentration in the injection water (river water),  $X_{fo}$ : concentration in the last sample of the return water.

## 5. CONCLUSIONS

We performed CO<sub>2</sub> injection tests into a geothermal wellbore at Ogachi, followed by laboratory rock-CO<sub>2</sub>-water interaction experiments which are described in Ueda et al, (2004). The main conclusion is that calcium dissolution was enhanced by adding CO<sub>2</sub> in water and this dissolution occurred very quickly. The content of dissolved Ca decreased quickly thereafter, which implies that Ca may have been removed as carbonate.

## 6. ACKNOWLEDGEMENTS

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