

Preliminary Results of CO₂ Sequestration into Ogachi Geothermal Reservoir, Northeast Japan

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ABSTRACT

Reducing the amount of CO₂ emitted by fossil fuel combustion is imperative to curb global warming. A promising method is to sequester CO₂ into the earth's crust as carbonates. In geothermal fields, injected CO₂ may react with surrounding minerals, e.g., Ca feldspar and anhydrite, and may precipitate CaCO₃ at locations that are remote from the injection point, forming cap rocks.

We performed preliminary laboratory and field testing to investigate CO₂/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 CO₂ 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 (CaSO₄). 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 CO₂ injection. This result, together with our laboratory data, supports the feasibility of sequestering CO₂ as CaCO₃ in geothermal fields.

1. INTRODUCTION

Sequestering CO₂ 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 CO₂ may react with surrounding minerals, e.g., Ca feldspar and anhydrite, and may precipitate CaCO₃ 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.

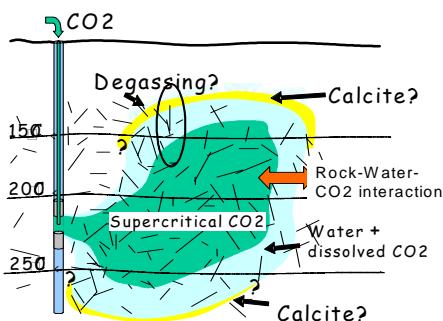


Figure 1: Concept of CO₂ sequestration in geothermal fields.

2. PRELIMINARY EXPERIMENT

Before the Ogachi field experiment a preliminary test was performed to examine how frozen CO₂ behaves in water.

A transparent acrylic pipe was set vertically and frozen CO₂ was injected from the top (Fig. 2). An important finding was that crushed (or powdered) CO₂ was not suitable because severe bubbling hampered the experiment, while platy CO₂ (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 CO₂ for the Ogachi experiment.

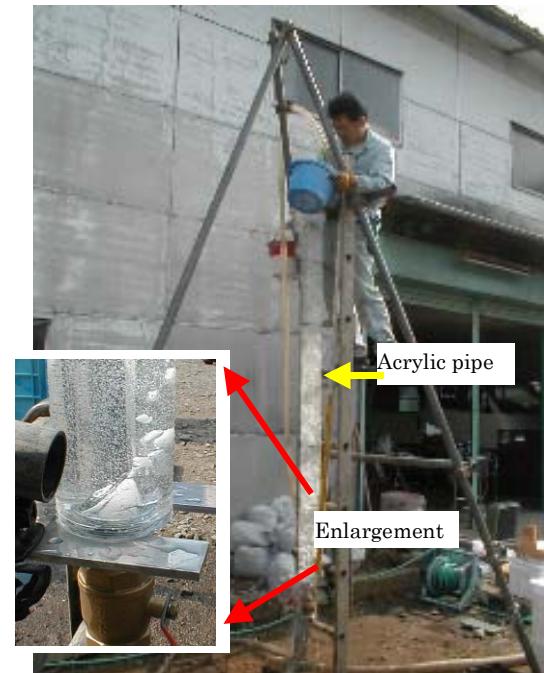


Figure 2: Preliminary frozen CO₂ injection test.

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 CO₂ with river water (i.e., river water was injected at a rate of 50 kg/min with frozen CO₂ at a rate of 0.5 kg/min)

Run-3) Injection of 3 wt% frozen CO₂ with river water

In Runs-2 and -3, frozen CO₂ 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, SiO₂, Na and SO₄ increased in all cases regardless of the CO₂ injection except for a decrease in Na and EC in Run-3 that was related to NaCl tracer injection and its subsequent diffusion. When CO₂ 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 SO₄ 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 HCO₃) (Fig. 4). The Ca increase was attributed to dissolution of thick anhydrite (CaSO₄) veins in the granodiorite (Kiho and Mambo, 1994, 1995; Ito, 2003).

In our experiments, the behavior of Ca and SO₄ is different from that of Kiho and Mambo (1994; 1995) in that Ca decreased while SO₄ increased after one day. As mentioned above, the SO₄ behavior was not influenced by CO₂ injection, and Ca is the only species affected by CO₂ 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 CO₂ 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 CO₂ injection experiments at Ogachi in 2003

Elapsed time	RUN-1 (River water)						RUN-2 (River water+1%CO ₂)						RUN-3 (River water+3%CO ₂)						
	*1	3h	22h	48h	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	207.6	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
SiO ₂ (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	6.32	6.34	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	113.2	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	180	270	254	4.33	403	464	310	231	277	268	119
K(mg/L)	1	3.6	5.3	8.3	13	24.8	9.1	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	1.68	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 ₄ (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 ¹⁸ 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

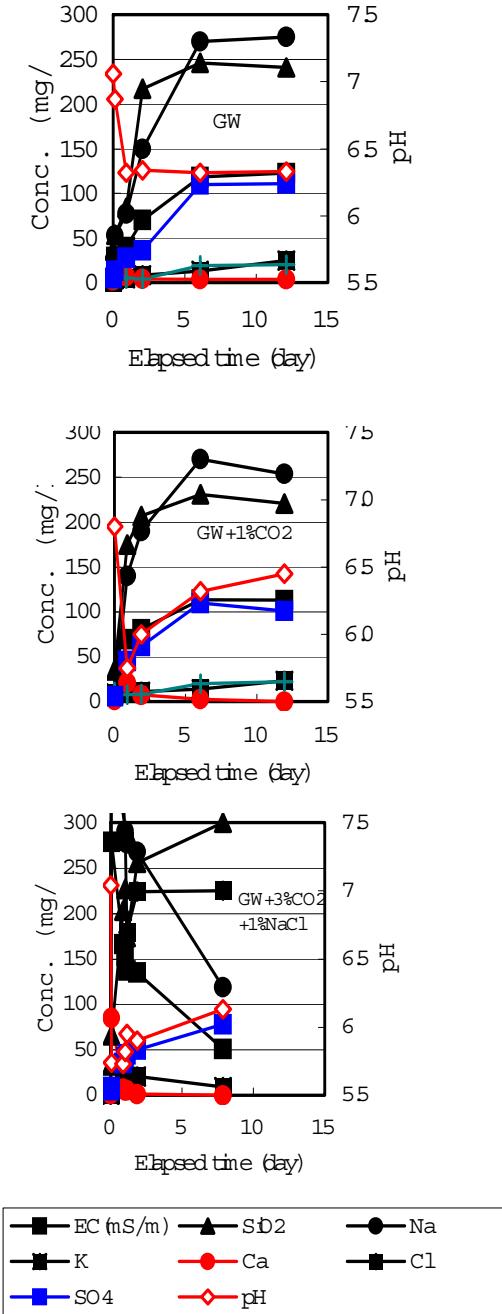


Figure 3: Behavior of EC, pH and major chemical species dissolved in water at 1030 m depth. The value of EC follows the left side scale. Data at origin is from river water for Runs-1 and -2, and river water +1% NaCl for Run-3. Data of 3 hr in Run-1 and 28 hr in Run-3 are sampled at 750 m and 850 m in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

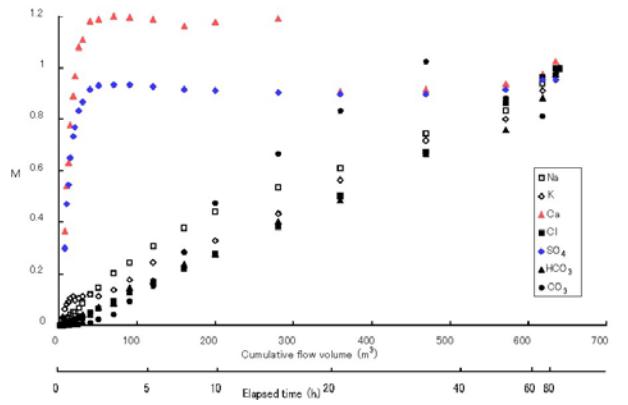


Figure 4: Behavior of major chemical species dissolved in the return water (modified from Kiho and Mambo (1995). M=(X-Xin)/(Xfo-Xin), where X: concentration in the return water, Xin: concentration in the injection water (river water), Xfo: concentration in the last sample of the return water.

5. CONCLUSIONS

We performed CO_2 injection tests into a geothermal wellbore at Ogachi, followed by laboratory rock- CO_2 -water interaction experiments which are described in Ueda et al, (2004). The main conclusion is that calcium dissolution was enhanced by adding CO_2 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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REFERENCES

- Ito, H.: Inferred role of natural fractures, veins, and breccias in development of the artificial geothermal reservoir at the Ogachi Hot Dry Rock site, Japan, *J. Geophys. Res.*, 108(B9), 2426, doi:10.1029/2001JB001671, 2003.
- Kiho, K. and Mambo, V.S.: Fluid geochemistry of hydraulic fracturing at the Ogachi HDR site, *Geoth. Resources Counc., Trans.*, 18, 453-456, 1994.
- Kiho, K. and Mambo, V.S.: Reservoir characterization by geochemical method at the Ogachi HDR site, Japan, *World Geotherm. Congress*, 2707-2711, 1995.
- Lackner, K.S.: A Guide to CO_2 Sequestration. *Science*, 300, 1677-1678, 2003.
- Ueda, A., Kato, K., Mizukami, M., Ohsumi, T., Yajima, T., Ito, H., and Kaieda, H.: Experimental studies of CO_2 -rock interaction at hydrothermal temperature, *Geochem. J.*, 2004 (submitted)