Geothermal Relief Well at the Onikobe Geothermal Power Station

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ABSTRACT

The Onikobe single-flash steam turbine geothermal power plant in Japan has been supplying electricity to the grid for 36 years. Power station output has increased over the years and reached 15 MWe (gross) in February 2010. Numerous natural geothermal manifestations were present in the field prior to development. New fumaroles accompanied by hot liquid discharges spontaneously appeared near Well 128 on 8 September 2010. Such spontaneous features had frequently appeared in the past. The new features were monitored carefully – the manifestations intensified abruptly on 8 October, and engulfed Well 128 the same day. The fumaroles continued to grow until a large scale steam explosion occurred on 17 October 2010. A crater-lake formed and the Well 128 wellhead became submerged in hot water.

After the steam explosion, steam and water continued flowing from the crater-lake. Fluid sampling was performed using a radio-controlled helicopter, and results of the chemical analysis of the fluid showed that the fluid in the crater was identical to production well 128 fluid. This suggests that Well 128 was damaged by the steam explosion incident, and that the residual flow from the crater-lake afterwards could be due to a casing failure in Well 128. This paper describes the sequence of crater-lake events and relief well drilling which finally succeeded in killing and plugging Well 128.

Introduction

The Onikobe geothermal field is located in the Backbone Range of northern Honshu Island, Japan within the Onikobe caldera (2.7-1.7Ma), which measures roughly 9 km (north-south) by 7 km (east-west) (Yamada, 1988); see Figure 1. The Katayama depression, a triangular topographic depression (1.5 km by 0.5 km) which has formed on top of the Katayama structural dome (3 km by 2 km) in the Onikobe caldera, is interpreted to be a downfaulted block resulting from extensional stress across the dome. The faults are believed to provide the vertical fluid conduits which charge the Onikobe geothermal reservoir.

When plant operations first began, a series of shallow production wells withdrew steam-enriched fluids from the shallow part of the reservoir. Steam production however declined over time. So plant output was maintained by drilling deeper make-up wells over a period of years. Two fluid populations are encountered in the deep part of the Onikobe geothermal reservoir, one neutral (pH=6.7-7.8) and the other acidic (pH=3). Deviation drilling was employed to increase steam production while avoiding acidic fluids just beyond the power plant site.

Well 128 was completed as the second deviated production well at Onikobe in 1980. It was drilled to 1255 m total depth and

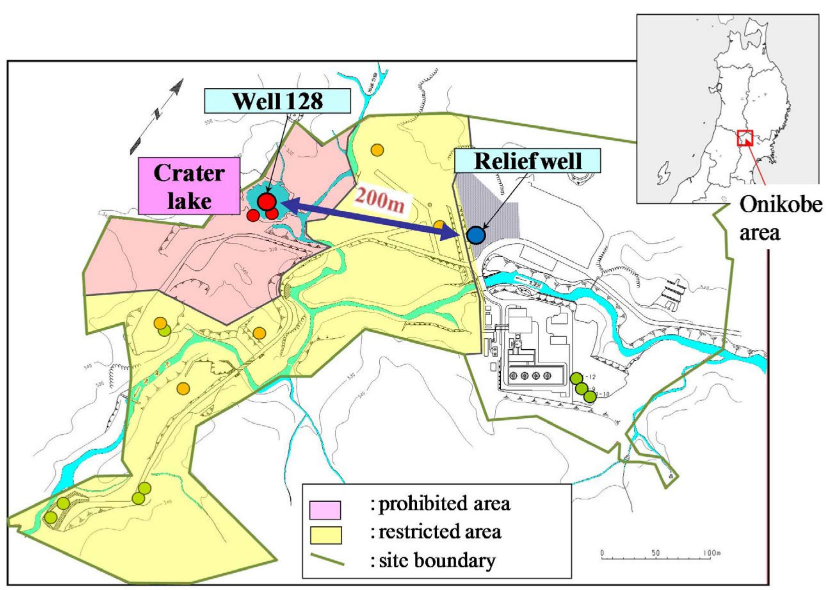

Figure 1. Map of the Onikobe geothermal power plant and wellfield.

encountered neutral fluids below the shallow acidic alteration zone. Well 128 produced neutral fluids at first, but over time the discharge became more acidic. The well has multiple feedpoints.

New fumaroles discharging acidic hot water spontaneously appeared near Well 128 on 8 September 2010 (Akasaka et al., 2011). Such spontaneous features had frequently appeared in the past at Onikobe. The new features were monitored carefully – the manifestations intensified abruptly on 8 October, and the fumaroles engulfed Well 128 on the same day. The fumaroles continued to grow until a large scale steam explosion occurred on 17 October 2010. A crater formed and the wellhead entirely became submerged in hot water. One project worker was killed and another was severely burned by steam explosion.

Relief Well Decision

After the large-scale steam explosion, intermittent hydrothermal eruptions about 20 m high were observed for a prolonged period. Hot water eruptions from 5 to 15 m in height were still occurring intermittently in February 2012. Samples taken of the erupting fluids were analyzed chemically, and these analyses reveal fluid compositions that are very similar to those of fluids that had been produced from Well 128 prior to the disaster (see Table 1). We therefore tentatively concluded that the uncontrolled discharges were blowing out from the damaged Well 128 wellhead.

Table 1. Fluid compositions of well 128 and crater-lake.

		Erupted water	Well 128 water	Ratio
Sampling date		30/3/2012	Average conc. (2007-2009)	
		(a)	(b)	(a)/(b)
pH (temp)	-	3.0 (18.0℃)	3.2	
Electrical conductivity	μS/cm	8400	11473	0.73
TDS	mg/L	5320	7810	0.68
Na	mg/L	1190	1717	0.69
K	mg/L	204	309	0.66
Ca	mg/L	303	515	0.59
Mg	mg/L	22	32	0.69
Cl	mg/L	2590	3953	0.66
SO_4	mg/L	124	46	2.70
SiO_2	mg/L	572	688	0.83

Post-disaster, "restricted" and "prohibited" areas were designated within the site for safety reasons (Figure 1) but the Onikobe project continued to operate and generate electricity at a reduced capacity. Vibration monitoring equipment including a seismometer were installed at Onikobe to monitor continuing subsurface activity. But the first step to returning project operations to normal was clearly to regain control over Well 128 and to shut it in permanently.

Drilling a relief well was determined to be the most suitable solution to the problem based on the following considerations:

a) This approach would not involve the exposure of personnel to hazards from proximity to the discharging wellhead.

b) Direct intercept and re-entry is considered feasible with the available technology.

c) Probability of failure is acceptably low.

Relief Well Plan

1. Well Location

Since the Onikobe geothermal power plant is located within the Kurikoma Quasi-National Park, relief well drilling operations could only take place within the plant yard, and the "restricted" and "prohibited" safety zones within the site must also be respected. So, the relief well was spudded near the power station outside the controlled area approximately 200 meters to the east of the Well 128 wellhead (see Figure 1).

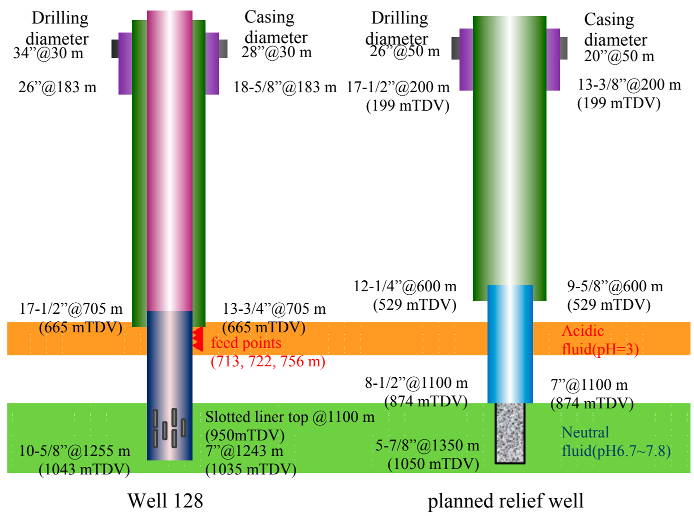

Figure 2. Casing designs of Well 128 and planned relief well.

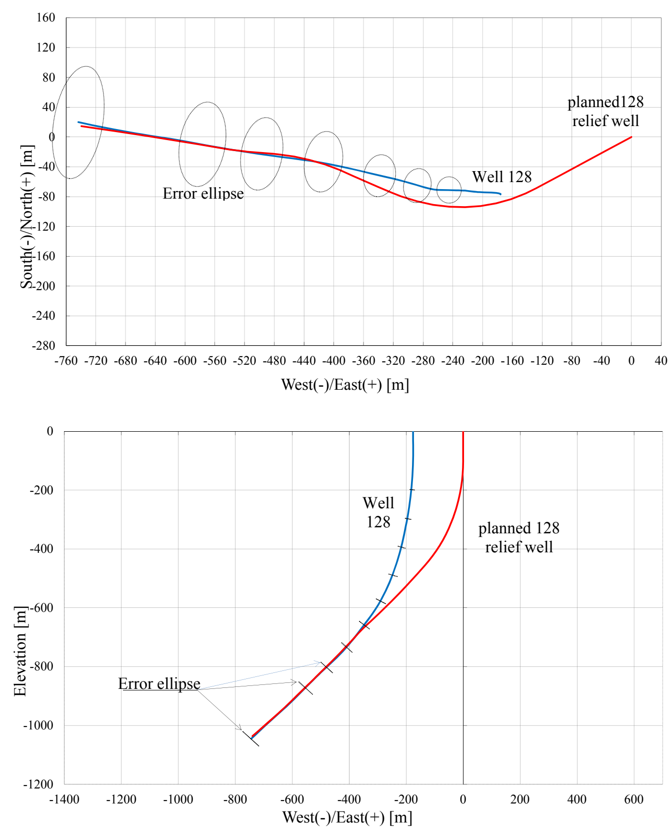

Figure 3. Floor map and cross section map of well tracks around Well 128 and the error ellipses.

2. Well Track

Casing designs of Well 128 and planned relief well are showed in Figure 2. The original well design program was to kick-off at 70 m (dogleg rate 5°/30 m). Maximum inclination was planned to be 55° at 660 m. Since Well 128 is deviated to the west, the relief well was deviated westward even more strongly. In addition, because there are other production wells located between Well 128 and the relief well, well track to avoid these production wells was planned. The Well 128 trace had been measured using single shots at 30 m intervals. Accordingly, the error ellipse increases with depth. The Well 128 trace was estimated to have about 50 m uncertainty at 1,000 m (Figure 3). In consideration of these uncertainties, it was essential that the relief well intercept Well 128 above this level.

3. Directional Control

In order to carry out the drilling in accordance with the well-track plan, Measurement-While-Drilling (MWD) was used below the kick-off point. Ranging to detect magnetic interference was also used to ascertain well location. Considering the possibility of drilling under lost circulation conditions, we used the E-field Gyro MWD. Ranging is generally considered to be about 15 m in a magnetic Casing and we couldn't ascertain the degree of corrosion by acid geothermal fluids at first.

4. Rig Equipment

The relief well is relatively shallow, but with the high-inclination and high-dogleg-rate constraints. Maximum drilling efficiency and precise positioning were essential. We therefore adopted the following:

a) 3000 m class drilling machine

b) Top Drive System (TDS)

c) E-field Gyro MWD

Relief Well Program

Relief well drilling went according to plan until the 13-3/8" Casing installation. During 12-1/4" drilling, however, the relief well encountered a large fracture zone at 600 m which had never been encountered at Onikobe before. As a result, directional control was lost for about 40 meters. Since the total loss of circulation could not be cured and the drilling direction had deviated from the planned track, it was decided to plug back the hole with cement at 462 meters and to perform a sidetrack.

Relief well sidetracking using an 8-1/2" bit was carried out six times (D-0, D-1, ..., D-5) as shown in Figure 4. Sidetrack drilling was generally directed westward towards intersection targets shallower than 896 meters total depth in Well 128, where substantial lost circulation had occurred during drilling of Well 128. During the D-0 drilling, the intermittent hydrothermal blowout from Well 128 ceased in the crater-lake due to fracture connection with Well 128.

Based on the results of D-0, sidetracks D-1 and D-2 targeted intersections near 700 m depth. But many magnetites in the fresh andesite encountered near 700 m depth made it difficult for ranging to effectively located Well 128 such that Well 128 was not been encountered. It was then decided to try to sidetrack through a region with less magnetite interference. Since sidetrack D-3 reached within 0.9 m of Well 128 at 735 m, we next tried milling and scraping. Although scraping was carried out between 760 and 830 meters, we could not confirm contact and/or pressure continuity with Well 128. We abandoned sidetrack D-3 at that stage. Next, aiming at 810 m, we drilled sidetrack D-4 to 840 m and tried scraping at 800 m. This time, pressure continuity with Well 128 was achieved, so we attempted the suppression and plugging of Well 128 with cement. However, because the pump pressure was not rising during cementing (Figure 5), we could not confirm that the cement was actually plugging Well 128. Moreover, the water level of the crater-lake dropped for several days after the first plugging operation as described below. Accordingly, it was decided to perform sidetrack D-5.

Sidetrack D-5 passed within 0.5 m of Well 128 and lost circulation increased at 890 meters. Therefore, plugging Well 128 was again attempted. This time, the injection pressure increased and a cement plug formed at 774 m in the relief well (Figure 6). We concluded that the cement plug also occupied the shallow part of Well 128.

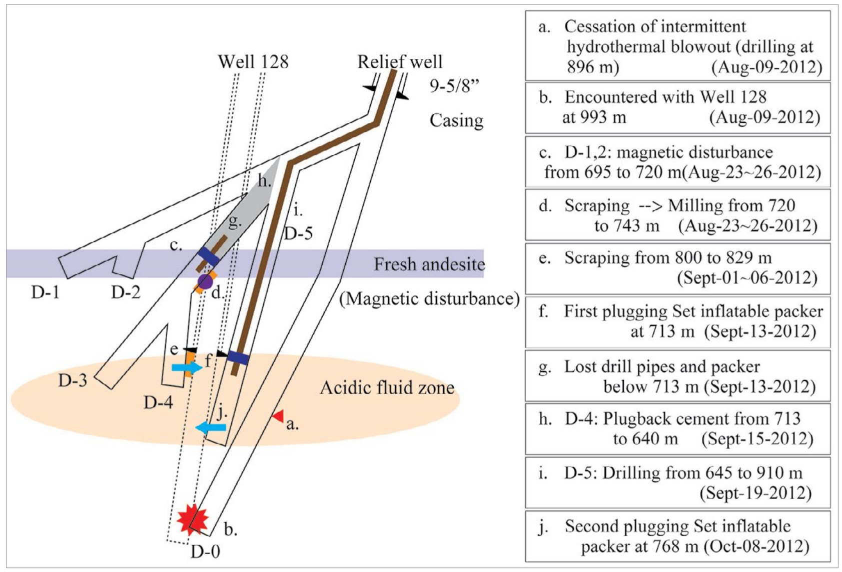

Figure 4. Schmatic of sidetracks D-0 to D-5.

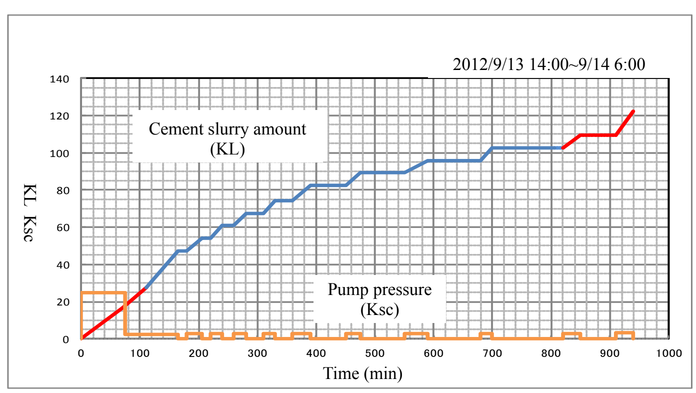

Figure 5. Sequence of cement slurry and pump pressure during first plugging operation using sidetrack D-4.

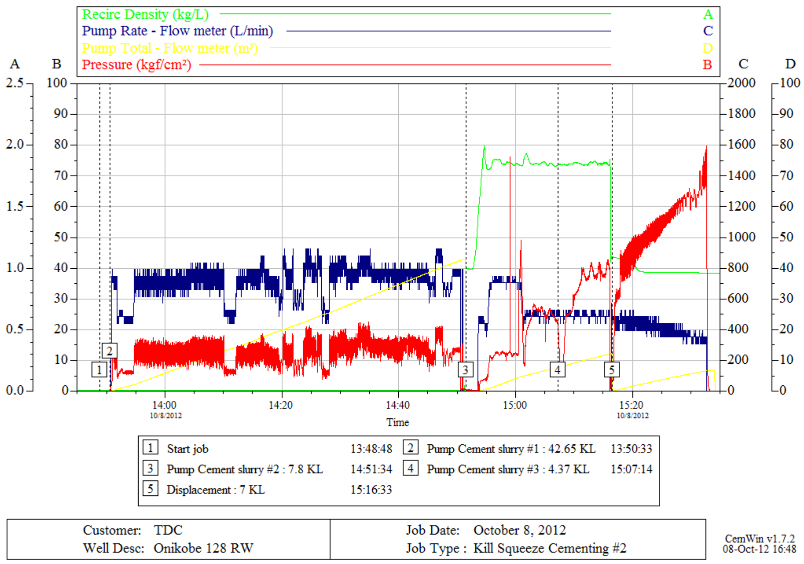

Figure 6. Sequence of cement slurry and pump pressure during second plugging operation using sidetrack D-5.

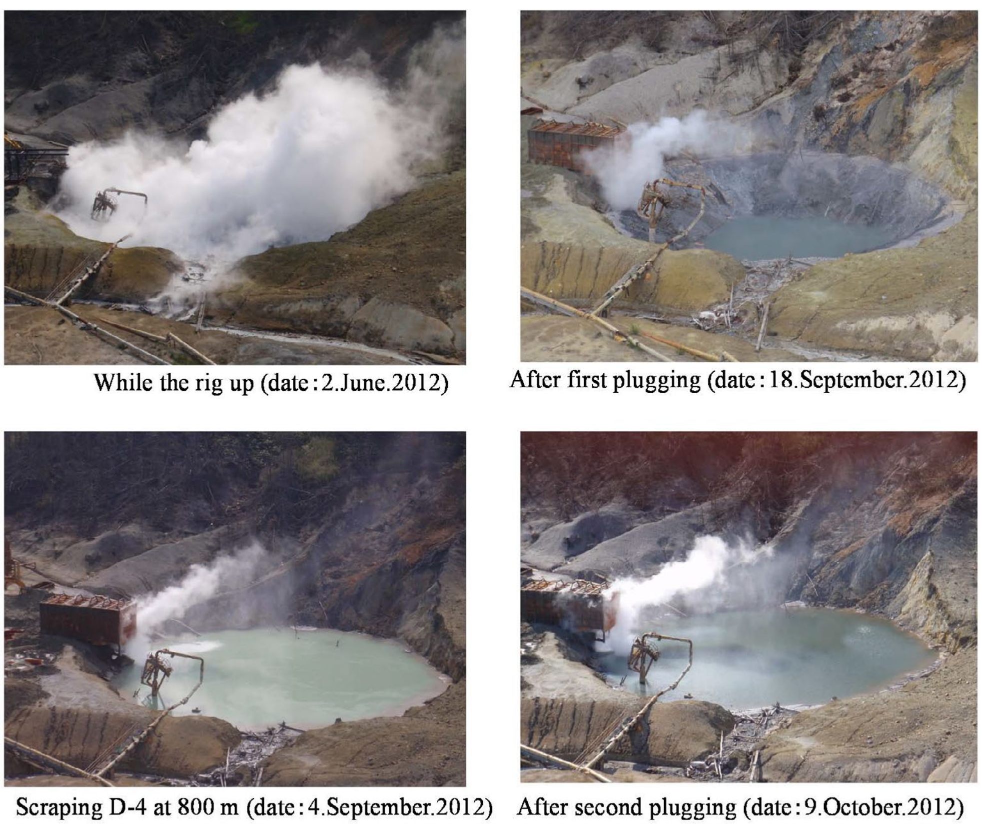

Figure 7. Photographs of the crater-lake during relief well drilling.

Sequence of Crater-Lake Events During Drilling

As soon as the total loss of circulation occurred at 896 m depth during drilling sidetrack D-0, the intermittent hydrothermal eruptions at the surface ceased (Figure 7). After that, there were a number of changes in the water level in the crater-lake, masked to some extent by varying amounts of rainfall. When Well 128 was occluded by sidetrack D-4 (after cementation), the crater-lake water level fell to 4.5 m below maximum. This was a major factor that convinced us to drill sidetrack D-5. Since Well 128 was plugged by sidetrack D-5, the water level in the crater-lake has risen due to the inflow by stream water. At present, we think that outflow and inflow are roughly in balance based on monitoring results.

Conclusions

Relief well drilling was performed successfully after many obstacles were overcome. This relief well effort was a first for Onikobe. There is only a few similar recorded cases in other geothermal fields in the world.

After Well 128 was successfully plugged by the second cement injection through the relief well, we continued to monitor conditions in and around the crater. At present, anomalously high temperatures are no longer observed in the crater-lake. Accordingly, J-POWER is now considering relaxing the "restricted" and "prohibited" access restrictions on the grounds that there is no continuing anomaly. Next, it is expected that similar relief well operations will be undertaken to perform "plug and abandon" operations on the two other wells that remain submerged in the crater-lake. The intent is to deal with Wells 136 and 138 as soon as possible.

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