

## Practical Application of Directional Drilling at Takigami Geothermal Field

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**Keywords:** Takigami, MWD, directional drilling, steerable, reinjection well

### ABSTRACT

For the geothermal energy, directional drilling is an important method that needs to be explored and developed. In geothermal fields of Japan and in many wells of Takigami field, 90% of production and re-injection wells are completed by the directional drilling. Some directional wells of reinjection site No.2 are drilled for the same E-W fault from an early period of exploration to a developmental and an operational periods. In order to compare the conventional directional drilling with the advanced drilling system, this paper reports the optimization of these wells' trajectory, casing program, drilling progress and drilling cost.

At Takigami, starting from 1987, new directional survey system, Measurement While Drilling (MWD), was used for the production wells. After 1994, ten reinjection wells were drilled by the advanced drilling system ("The steerable drilling", MWD and High-torque Steerable Downhole motor). In the case studies of these wells, the steerable drilling system was an effective measure for drilling a pinpoint target where the well trajectory (drilling target) was required to be accurate. This made the process easy. Another benefit of the steerable drilling is that it allows to reduce the survey time, trip time and shorten drilling progress by many days. High-torque Steerable Downhole motor produce the penetration rate 2-3 times faster than the conventional directional drilling. The latest steerable directional well TR-7 can reduce drilling progress by half (or less) and drilling cost by 30% compared to that of TT-22.

Capacity of reinjection wells in Takigami was depleted by a silica scaling. The reasons for depletion are studied by silica scale and reservoir simulator. The steerable drilling contributed to a sidetrack of the existing well in order to rebirth reinjection capacity of the well. TR-3S (sidetrack well of TR-3) was drilled for 13 days. By steerable drilling, the cost was reduced by 20% of the new well.

### 1. INTRODUCTION

Takigami geothermal field is located in the northeast of Kyushu, Japan. This area, known as Hohi geothermal region, is one of the most active geothermal areas in Japan (Figure 1). Geothermal exploration in Takigami field started in 1979 with various surveys and drilling techniques. Starting from 1996, the 25MW Takigami electrical power plant is operated commercially.

Before 1990, in exploration stage, many directional wells were drilled by the conventional directional drilling technique (a combination of magnetic single shot survey and Low-torque Down Hole Motor). However, after 1993, the advanced directional drilling "Steerable drilling" technique (a combination of MWD and High-torque

Steerable Down Hole Motor) became widespread in some geothermal fields. At Takigami geothermal field, this advanced technique was applied for directional wells during developmental and operational periods.

The steerable drilling produces an accurate directional control of a well trajectory. Moreover, in comparison with the conventional directional drilling, the steerable drilling shortens drilling progress by reducing directional survey time and increasing the penetration rate. Finally, steerable drilling achieves the cost reduction of the drilling operation.

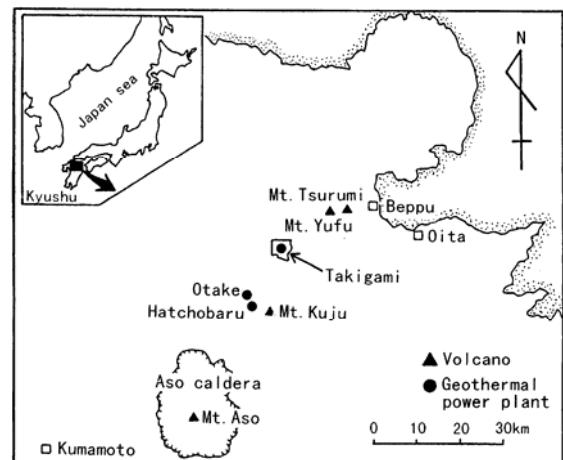


Figure 1: Location of Takigami Geothermal Field in the Northeastern Kyushu, Japan.

### 2. GEOLOGICAL STRUCTURE OF REINJECTION SITE NO.2

From an early stage of exploration in 1987 to a commercial production in 2000, eight directional wells were drilled for the same E-W fault well in reinjection site No.2. During this period, a conventional directional drilling technique was replaced by the steerable drilling method. In Takigami reinjection area, these two methods were compared for the same geological conditions.

Table 1: Drilling history of reinjection well at No.2 reinjection site.

Stage	Survey										Development				Operation				Remarks
	Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000				
Methods	Conventional										Steerable								
TT-18	■																		
TT-19	■																	E-W Fault Target	
TT-23	■																		
TT-22		■																E-W Fault Target	
TR-1										■									
TR-15										■									
TR-2										■								E-W Fault Target	
TR-3										■								E-W Fault Target	
TR-4										■									
TR-5										■								E-W Fault Target	
TR-6										■									
TR-3S										■								E-W Fault Target	
TR-6S										■								E-W Fault Target	
TR-7											■							E-W Fault Target	

Reinjection area was located in the north of Takigami field and reinjection wells were drilled for the same E-W fault in order to get the lost circulation of high permeable formations. Lost circulation zone was distributed on the E-W fault shown in Figure 2. We can see that in the N-S section, lost circulation zone lines up on the narrow vertical fault and is distributed in the third layer below smectite zone of the impermeable formation (Figure 3(a)). In the E-W section, lost circulation zone is distributed shallower from west to east with related geological basement structure (Figure 3(b)). Horizontal distribution of lost circulation zone is related to the E-W fault and vertical distribution of lost circulation zone is related to the third layer. This distribution is very important for the geological target. These geological targets are required to drill through correctly by advanced directional drilling.

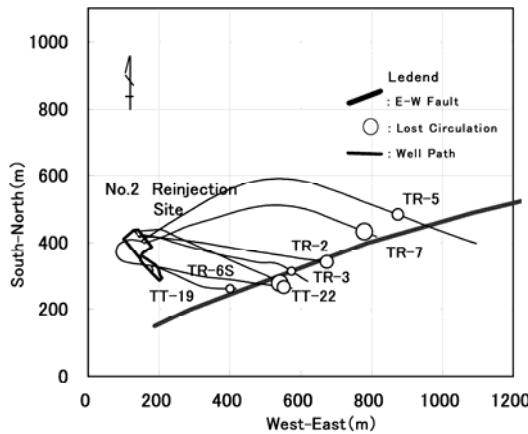


Figure 2 □ Distribution of lost circulation zone on the E-W fault and trajectory of reinjection well.

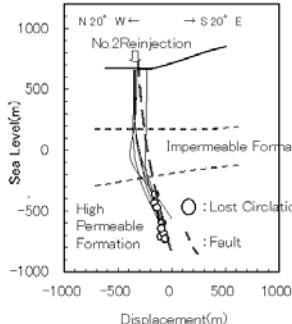


Figure 3(a): N-S section.

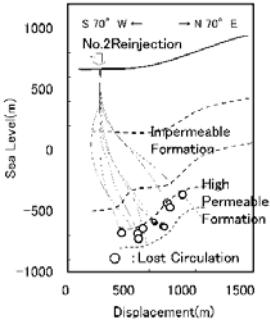


Figure 3(b): E-W section.

### 3. A COMPARISON BETWEEN THE STEERABLE DRILLING AND THE CONVENTIONAL DIRECTIONAL METHODS

It is helpful to compare the steerable drilling and the conventional directional drilling by actual drilling data. In Takigami field, the steerable drilling system was used from 1993 to 2000 and MWD with conventional down hole motor was used from 1987 to 1988 (Table 2). Before 1993, many directional wells were drilled by the conventional directional drilling.

Table 2: The Steerable drilling and MWD system application in Takigami geothermal field.

Well	Year	Depth	KOP	Max.Angle	Deviation	Steerable interval	Remarks
Production	TT-13	1987	2,707m	1,197m	26°	569m	1,197 ~ 1,344 m M-1 and DynaDrill
	TT-17	1988	2,654m	1189	39°	705m	1,189 ~ 1,330 m M-1 and DynaDrill
	TP-1	1993	2,151m	1,050m	40°	393m	1,050 ~ 1,711 m Slim-1 and PowerPak
Reinjection	TR-1	1994	1,914m	234m	41°	868m	234 ~ 909 m Slim-1 and PowerPak
	TR-1S	1995	1,505m	806m	34°	518m	806 ~ 1,450 m Slim-1 and PowerPak
	TR-2	1995	1,461m	275m	42°	557m	275 ~ 1,438 m Slim-1 and PowerPak
	TR-3	1996	1,550m	263m	38°	493m	263 ~ 1,550 m Slim-1 and PowerPak
	TR-3S	1998	1,540m	1,133m	63°	619m	1,133 ~ 1,408 m Slim-1 and PowerPak
	TR-4	1996	1,540m	248m	61°	481m	248 ~ 1,524 m Slim-1 and PowerPak
	TR-5	1996	1,700m	147m	56°	944m	147 ~ 1,417 m Slim-1 and PowerPak
	TR-6	1998	2,110m	160m	66°	436m	160 ~ 2,110 m Slim-1 and PowerPak
	TR-6S	1999	1,601m	327m	43°	439m	327 ~ 1,495 m Slim-1 and PowerPak
	TR-7	2000	1,415m	143m	44°	624m	143 ~ 1,390 m Slim-1 and PowerPak

### 3.1 CONVENTIONAL DIRECTIONAL DRILLING

The Conventional directional drilling system is a combination of a magnetic single shot survey equipment and a low-torque downhole motor. This method is long established and uses an inexpensive system.

(1) Drilling contractor can handle this survey equipment easily and estimate reactive torque of low torque downhole motor.

(2) However, it is difficult to estimate reactive torque in a deep well with a large diameter hole. Sometimes this method is unsuccessful when trajectory control and re-drilling is forced.

(3) Directional survey is required every 10m when using downhole motor and every 30-50m when performing rotary drilling. Survey takes 30-45min for 1500m of depth. These surveys postpone drilling progress of the well.

(4) Bottom Hole Assembly changes orienting and rotary sections. It takes time to trip BHA and to ream.

(5) Magnetic single shot survey equipment and low torque downhole motor are widely used and relatively inexpensive.

### 3.2 THE STEERABLE DIRECTIONAL DRILLING

The Steerable Drilling system is a combination of MWD system and a high-torque steerable downhole motor. Special service contractors supply these tools and specialists. This method was developed in the early 90's.

(1) Directional survey is transferred in real time by mud pulse of MWD. This system provides an accuracy of well trajectory and cuts the directional survey time.

(2) With the use of high-torque steerable downhole motor, it is easy to control tool face in deep depth and with a large hole diameter.

(3) Bottom Hole Assembly is the same for both orienting and rotary sections. Steerable motor produces larger penetration rate than a low-torque motor. This method reduces drilling progress of well.

(4) Tool costs and daily costs are relatively expensive.

### 3.3 COMPARE AN ACCURACY OF DRILLING TARGET BETWEEN STEERABLE DRILLING AND CONVENTIONAL DRILLING

The conventional directional drilling TT-22 had 50m target radius and was drilled through 30m distance from the center of drilling target (Figure 4).

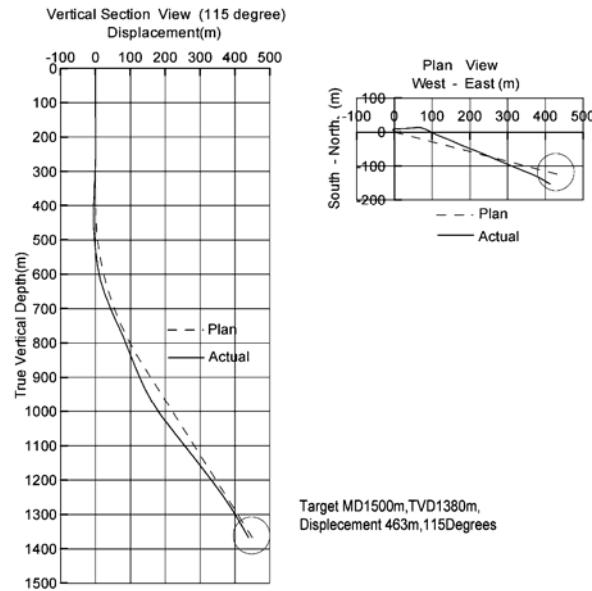


Figure 4: TT-22 Directional Survey plots.

The steerable drilling TR-7 had 5m target radius and was drilled through center of the drilling target (Figure 5). The plan and actual trajectory of the well TT-22 were away from each well. Though, these TR-7 overlapped each other, the steerable drilling was proved to be more accurate than the conventional drilling.

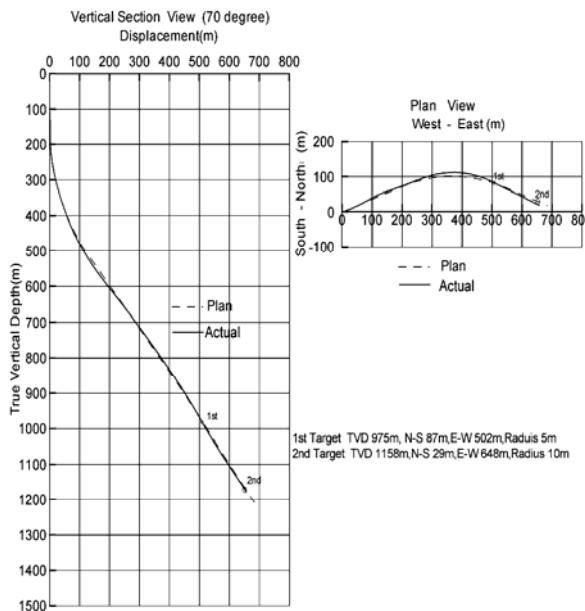


Figure 5: TR-7 Directional Survey plots.

### 4. INCREASING PENETRATION RATE AND SHORENTENING TOTAL DRILLING PROGRESS

To shorten drilling progress it is required to increase penetration rate of formation in order to reduce time and

daily drilling work (survey, change bit and BHA). For this, the steerable drilling is a very effective technology.

### 4.1 INCREASING PENETRATION RATE

Three different drilling methods, "Conventional Rotary", "Conventional Orienting with DynaDrill", "Steerable" were compared in order to analyze the increase of penetration rate. Penetration rate of seven wells in reinjection site No.2 was analyzed for different size holes. This comparison of penetration rate was performed for the same geological conditions (Table 3).

Penetration rate is related to WOB and bit rotation speed as general equation below suggests:

$$R_1 = K_1 W^{n^1} \quad R_1: \text{Penetration Rate (m/h)}, W: \text{WOB (ton/inch}^2\text{)}$$

$$R_2 = K_2 N^{n^2} \quad R_2: \text{Penetration Rate (m/h)}, N: \text{rotation (rpm)}$$

$K_1$  and  $K_2$ : fixed number on formation

$n^1$  and  $n^2$  : fixed number on formation

#### (1) 17-1/2" Drilling section

The Steerable drilling achieved at least twice penetration rate of the other drilling methods: twice WOB of the Conventional Orienting with DynaDrill and three times bit rotation of the Conventional Rotary.

#### (2) 12-1/4" Drilling section

The Steerable drilling achieved 2-3 times of penetration rate of the other drilling methods: 3-4 times WOB of Conventional Orienting with DynaDrill and three times bit rotation of the Conventional Rotary.

#### (3) 8-1/2" Drilling section

The Steerable drilling achieved twice penetration rate of the other drilling methods: 4-7 times bit rotation of the Conventional Rotary.

Table 3: Comparison of average penetration rates of different drilling methods and conditions.

Hole Diameter	Bit type Drilling condition ROP	Rotary	Orienting with DynaDrill	Steerable
17-1/2"	Bit type (IADC) WOB (t) 8~15	214·537	135·214	435·427
	Bit Rotation(rpm) ROP(m/h) 3.65	40~50 3.65	7 300 3.66	13~17 120~150 6.84
12-1/4"	Bit type (IADC) WOB (t) 13~18	437·537	135·214	435·437
	Bit Rotation(rpm) ROP(m/h) 3.86	50~80 3.86	5 310 5.85	12~20 195~250 11.71
8-1/2"	Bit type (IADC) WOB (t) 12~15	437·537	—	517·537
	Bit Rotation(rpm) ROP(m/h) 6.60	40~60 6.60		10~15 240~280 11.65

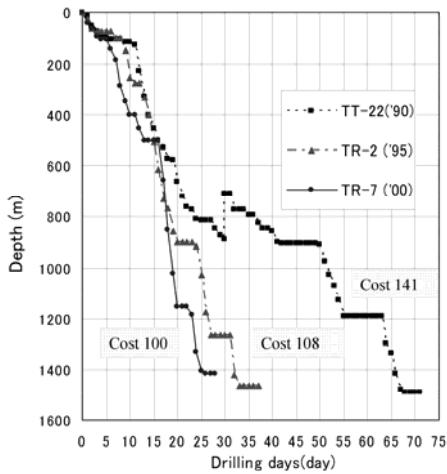
### 4.2 SHORTENING OF DRILLING PROGRESS

Actual drilling progresses of TT-22, TR-2 and TR-7 were compared. TT-22 was drilled by the conventional directional drilling. TR-2 and TR-7 were drilled by the steerable drilling.

#### (1) Effect of modification of directional drilling methods

For 17-1/2" section, well trajectory control of TT-22 took many days. It failed in estimation of a reactive torque. For

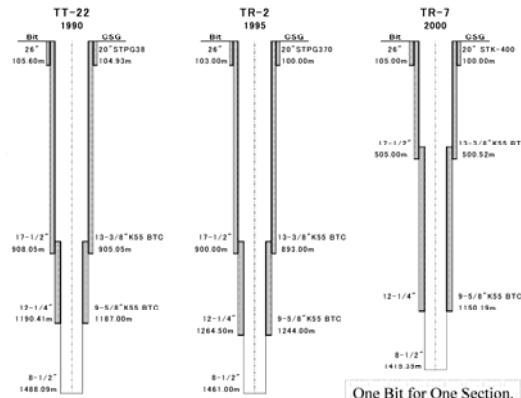
TR-2, new method of "Steerable" was applied to control trajectory of 17-1/2" section and to the smaller section. The progress of drilling was shortened by half (Figure 7).



**Figure 7: Comparison of actual drilling progress chart among TT-22, TR-2 and TR-7.**

#### (2) Effect of change of casing program

Furthermore, shortening progress was required. Casing program of TR-7 was modified and was extended to 12-1/4" section and shortened to 17-1/2" section, because 12-1/4" section had faster penetration rate than 17-1/2" section. The drilling progress of TR-7 was shortened by eight days compared to TR-2 (Figure 7, 8).



**Figure 8: Casing program of reinjection wells.**

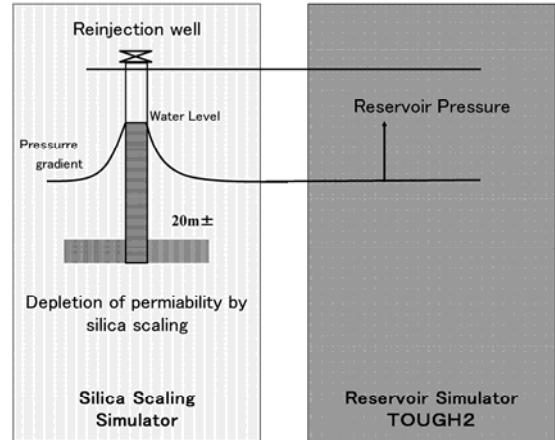
#### 4.3 REDUCTION OF DRILLING COST

Relative drilling costs of TT-22, TR-2 and TR-7 were compared. The cost was excepted to rig up and down for site preparation and for E-log. TR-7 drilling cost was set to 100, to which the other wells were compared. TR-2 relative cost was reduced from 141 to 108, and TR-7 relative cost was reduced from 108 to 100 compared to TT-22. The daily cost for the steerable drilling was larger than for the conventional directional drilling. The cost reduction was less effective than the actual shortening of the drilling progress (Figure 7).

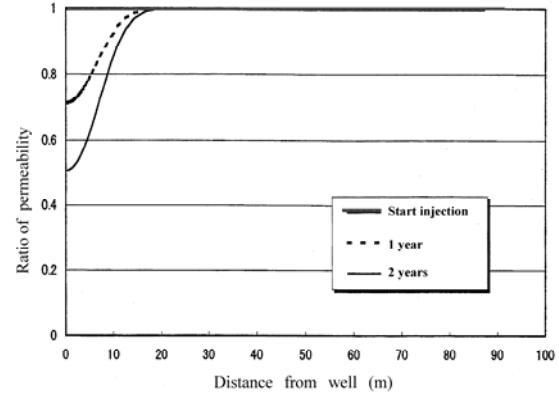
#### 5. REBIRTH OF REINJECTION WELL BY SIDETRACK DRILLING OPERATIONS

The 25MW Takigami Geothermal power plant produces 250t/h of steam and 1100t/h of hot water. All of the hot water is injected to north reinjection area by reinjection wells. For the first year (1996), the depletion of reinjection

capacity was 15-20% per year of the total capacity. Presently, it is 10% per year. In 1998, the study of depletion mechanism by Tough 2 and Silica Scaling simulator showed that the main reason for depletion was silica scaling around wellbore (Figure 9). This study was done on the area of 20m distance from wellbore. For area above 20m of wellbore, initial high permeability was sustained by simulation and calculation. Before reinjection, it had original capacity (Figure 10). At the same time, the silica scaling was detected at 1-4mm of thickness inside pipeline of reinjection. The depletion here was also caused by silica scaling.



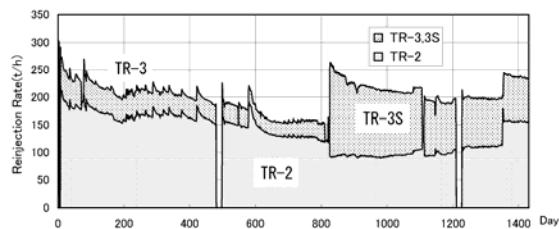
**Figure 9: Conceptual model of injectivity depletion.**



**Figure 10: Silica scaling area and permeability depletion ratio.**

#### 5.1 REBIRTH OF REINJECTION WELL

Initially, reinjection rate of TR-2 was 230t/h; for TR-3, it was 80t/h. However, after 800 days of the start of reinjection, reinjection capacities of TR-2 and TR-3 were depleted to 120t/h and 30t/h (Figure 11). It was decided to abandon TR-3 and to rebirth TR-3S by sidetrack of the target, which was located 20m of North-East distance from TR-2's lost circulation zone.



**Figure 11: Reinjection capacities of TR-2, 3 and TR-3S (1996.10<sup>th</sup> July-2000.10<sup>th</sup> June)**

## 5.2 TR-3S DRILLING OPERATION

Originally, TR-3 had 80t/hr reinjection capacity. However, it gradually decreased to 30t/h. Finally TR-3 was plugged by cement and KOP was set at 1133m. After that, TR-3 was drilled to a new target by the steerable drilling as TR-3S rebirth well (Figure 12).

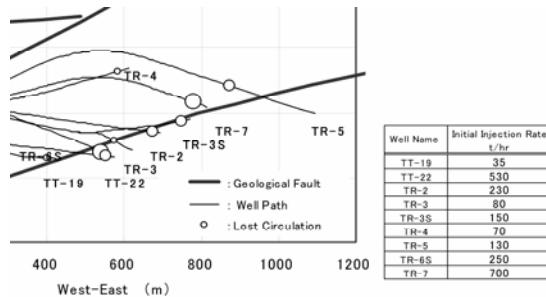


Figure 12: Well trajectory of TR-3S and others.

(1) Run 8-1/2" Slick BHA to the bottom. Small diameter section of silica scaling was not detected. The reason for TR-3 reinjection decrease was silica scaling of fracture in the high permeable formation.

(2) Pump first cement slurry into 8-1/2" open hole section. Note, cement slurry dropped to the lost circulation zone.

(3) Pump second cement slurry into 8-1/2" open hole section. Hard cement column was made at 1050-1200 meters.

(4) Drill out cement to 1133m and start sidetrack of TR-3, "TR-3S", from KOP of 1133m.

(5) The target radius of TR-3S was set to 5m and drilled by the steerable drilling.

BHA: Bit x 6-3/4"(A675PowerPak1.5°) x

6-1/2"SDC x Float sub x UBHO x

6-1/2"NMDC<sub>2</sub> x 6-1/2"DC<sub>3</sub> x X/sub x

5"HWDP<sub>5</sub> x 6-1/2"EQ-Jar x 5"HWDP<sub>15</sub>x 5"DP

(6) Maximum dog leg severity was at 7-8°/30m with appropriate azimuth and build up angle. Maximum inclination was reached at 63°.

(7) Lost circulation started at 1429m (the geological target depth). TR-3S encountered total lost circulation at 1500m and was finished at 1540mTD (Figure 13).

## 5.3 DRILLING RESULT OF TR-3S

TR-3S was given 150t/h of reinjection capacity and TR-2 reinjection capacity was reduced from 120t/h to 100t/h by interference of TR-3's reinjection. Total reinjection capacity was 250t/h. This capacity was equal to the original capacity of TR-2 (230t/h). This proved that the study of depletion mechanism was correct. In drilling operation, TR-3S was drilled without any trouble of high torque and drag. TR-3S was drilled accurately through the target.

Table 4: Reinjection capacities changes (ton/hr) before and after sidetrack operation

Condition	Well	TR-2	TR-3	TR-3S	Total
Initial capacity		230	80	—	310
Before TR-3 sidetrack		120	30	—	150
After TR-3 sidetrack		100	—	150	250

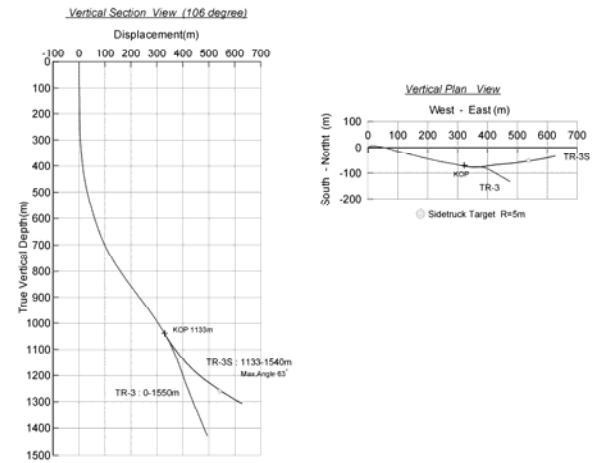


Figure 13: TR-3 and TR-3S Directional Survey plots.

## 5.4 SHORTENING OF DRILLING PROGRESS AND REDUCING DRILLING COST BY SIDETRACK

(1) Shortening of drilling progress

Sidetrack well TR-3S had a shorter drilling interval (407m) compared to drilling of the new well (500m). New wells like TR-2 and TR-3 took 33-37 days to complete a drilling operation. However, sidetrack wells like TR-3S took only 13 days to complete (Figure 14).

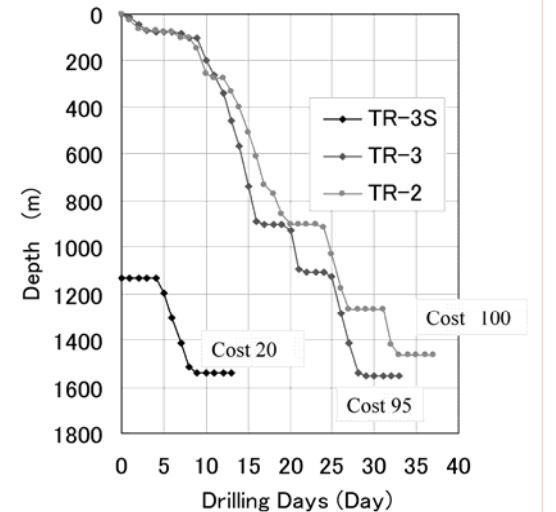


Figure 14: Drilling progress and cost between sidetrack well TR-3S and new well TR-2, TR-3.

(2) Reducing drilling cost

Relative drilling costs of TT-22, TR-2 and TR-7 were compared. The cost was excepted to rig up and down for site preparation and for E-log. TR-7 drilling cost was set to 100, to which the other wells were compared. TR-2 and TR-

3 relative costs were 95-100 due to the new well drilling. TR-3S cost was only 20 (20% of TR-2) due to the shortening of drilling progress and elimination of large diameter sections.

## CONCLUSIONS

An advanced directional drilling technique "The Steerable drilling" was applied to Takigami geothermal fields. The Steerable drilling drilled the geological target correctly, shortened drilling progress and reduced drilling cost by more compared to the conventional directional drilling.

The depletion of reinjection well was investigated by the study of silica scale and reservoir simulator. Silica scaling was determined to be the main reason for depletion. In silica scale simulator, silica damage area was 20 m around the well.

The existing well was re-borned by open hole sidetrack operation like TR-3S. TR-3S is one of the applications that shortens progress of drilling and reduces drilling cost.

From now on, these advanced techniques are the key technologies in the development of geothermal energy.

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