Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Deep Drilling Experience for Pohang Enhanced Geothermal Project in Korea

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Keywords: Korea, EGS, Geothermal, Electricity, Granodiorite, Drilling

ABSTRACT

Pohang EGS Project is a research, development and demonstration project for the generation of MW scale electricity from a doublet system of wells deeper than TVD 4 km in Korea. The geothermal resource is Granodiorites below around 2,400 m from the surface under the Tertiary and Cretaceous sedimentary basin. The project duration is 2010 to 2015.

This paper introduces the deep drilling experience from the first well, which has been drilled 4,127 m at present and is waiting for well logging. The second well is planning to start to drill in 2014. The drill rig, casing, cementation, mud, bit, bottom hole assemble, drilling performance and the problems experienced have been presented.

1. INTRODUCTION

Pohang Enhanced Geothermal System (EGS) Project is located on Pohang city; South Korea. Well coordinates are 129°22'46.08" E and 36°06'23.34" N. The five- year Pohang EGS project started in Dec. 2010 with the goal of producing MW scale electricity using a geothermal resource from boreholes greater than 4 km deep.

The project has two stages; in the first stage the project involves the planning and drilling of around 2 km deep borehole and analysis of the geothermal resources at that depth, with the aim of achieving in excess of 100 degree Celsius. Since the goal of the Stage I achieved 103 degree Celsius at 170 m, the Project moved into the Stage II (2013-2015) that involves a drilling of the second well including a directional drilling and construction of a geothermal power plant, accessing geothermal resources from around 4 km in depth.

The Stage 1 well at Pohang, named PX-1, was drilled in 2012 to a depth of 2,250 m.

Well PX-1 is currently being extended to a depth around 4,127 m. Assuming PX-1 reaches the temperature of 180 Celsius degree and that subsequent hydraulic stimulation is successful, the second well will be designed to deviate to match reservoir geometry.

The Project is managed by NEXGEO as principal research organization operating under the Prime Research Contract entitled "Technology Development of Geothermal Commercial Plant for MW Class". The Korean Government is represented by the Korea Institute of Energy Technology Evaluation and Planning ("KETEP") through the Ministry of Trade, Industry and Energy of Korea. The project team consists of NEXGEO, the Korea Institute of Geosciences and Mineral Resources; Seoul National University; the Korean Institute of Construction Technology; POSCO and Innogeo Technologies Inc.

The drilling operation and plan of Stage I was supervised by BESTEC Drilling GmbH., Germany and Nexgeo Inc. has supervised the extension drilling to 4,127 m. The mud engineering service has been performed by AMC Oil & Gas, Germany. Fangmann Inc, Germany carried out the cementing job for 13 3/8" casing.

Further information on the Pohang EGS project can be found from Song & et el., (2015) in this Congress.

2. SITE GEOLOGY AND GROUNDWATER

The Pohang EGS site is located north of Pohang City in Southeast Korea. The site belongs to the Tertiary Pohang Basin overlying Cretaceous sedimentary rocks, Eocene volcanic rocks such as tuff and Permian Grano-diorite basement. The Pohang Basin consists of Miocene marine sediments and a bottommost clastic sediments layer (Song et al., 2010). The Sedimentary rocks are almost horizontally dipping, the outcrops of rocks under this formation can not be seen around the site.

From lithological observation of the cuttings as shown in Table 1, about 206 m of Semi-unconsolidated Mudstones and lapilli Tuffs and alternative rocks of Sedimentary rocks and Crystal Tuffs are identified. The Sedimentary rocks consist of Shale, Sandstone and Mudstone, which are metamorphosed thermally. The Shale became Hornfelsic Slate. The Crystal Tuff of 330 to 652 m has very strong in hardness that it showed the ROP of 0.3 -1.5 m/day. Andesite and Andesitic Tuff are present from 1250 to 2356 m before the Granodiorite occurs.

The Granodiorite has been determined by age-dating, sampled from 3970 to 4000 m, and shows around 280 Ma by Shrimp age dating method. Amphibolic dikes are present in the depth of 3556-3726m, 3792-3824 m and 4040-4062m.

About 3.5 m^3/hr of Lost Circulation at 3434 m occurred and gouges were recognized from the cuttings. And the lost circulation of about 1 m^3/hr was continued up to 3500 m. But the gouge was not found up to 4127 m until the drill is stopped now.

The water for the drilling operation is supplied by two small wells from an aquifer below 160-180 m depth from the.

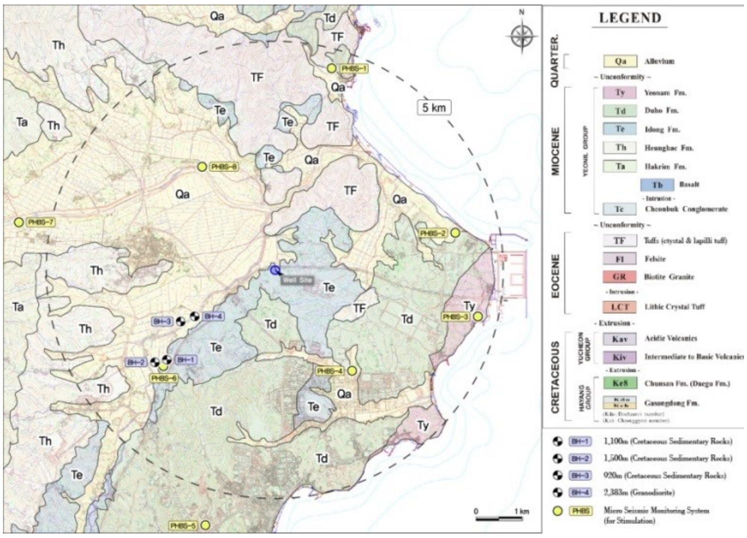


Figure 1. Surface geology in the vicinity of the well site

Table 1. Lithostratigraphic classification of PX-1 well

Depth(m)	Rock type	Geological age
0 ~ 206	Mudstone	TERTIARY
206 ~ 330	Lapilli tuff	
330 ~ 652	Crystal tuff	CRETACEOUS
652 ~ 744	Mudstone/Sandstone/Shale etc.	
744 ~ 860	Crystal tuff	
860 ~ 944	Mudstone/Sandstone/Shale etc.	
944 ~ 1040	Crystal tuff	
1040 ~ 1169	Mudstone/Sandstone/Shale etc.	
1169 ~ 1250	Crystal tuff	
1250 ~ 1418	Andesitic Tuff	
1418 ~ 1567	Andesite	
1567 ~ 1996	Andesitic Tuff	
1996 ~ 2128	Andesite	
2128 ~ 2198	Andesitic Tuff	
2198 ~ 2250	Andesite	
2250 ~ 2356	Andesitic Tuff	
2356 ~ 3356	Granodiorite	PERMIAN
3356 ~ 3726	Amphibolitic dyke	
3726 ~ 3792	Granodiorite	
3792 ~ 3824	Amphibolitic dyke	
3824 ~ 4040	Granodiorite	
4040 ~ 4062	Amphibolitic dyke	
4062 ~ 4127	Granodiorite	

3. DRILLING RIG

Since there was not any deep drilling in South Korea, a drilling rig utilized on the project well was purchased by NEXGEO Inc. from the Chinese company, GUANGHAN JINCHENG PETROLEUM MACHINERY CO., LTD (SJPE), who also contracted all the crews to operate the drilling rig under the company SJPE.

The GDE 15A rig is rated for drilling to 5,000 meters with 5” DPs and should be sufficient for drilling the wells in Pohang. Also, a top drive of rated capacity 3500 KN is equipped. The major part of equipment has shown in Figure 2.

Item	Spec.
Nominal drilling depth	3,500~5,000 m
Max. hook load	3,150 kN
Nominal class	1,500 HP
Drawworks max. input power	1,500 HP
Substructure height	7.62 m
Rotary/setback loading	3,150/1,800 kN
Mast height	45 m
Sheave dia. of crown block	1,270 mm
Wireline diameter	35 mm
Rotary table drive	800 kW
Open dia. of rotary table	37 1/2"
Max. pressure of mud pump	5,000 psi
Total volume of mud tank	250 m^3
Annular BOP(boresize/pressure)	13-5/8"/ 5,000 psi

Figure 2 Specification of main parts of the rig

4. DRILLING PLAN

2012: Drilled 2,250 m and got 103 degrees Celsius at the bottom of well.

- 0-30 m: 24” hole, 20” conductor,
- 0-330 m: 17 1/2” hole, casing 13 3/8” (completed)
- 0-330 m: 13 3/8” casing cementing (completed)
- 330-2,250 m: 12 1/4” hole (completed)

2013: Started to drill from 2,250 m to 4,500 m which is an extension of the 2012 m

- 2,250 m-2,400 m: 12 1/4” hole (completed)
- 0-2,400 m: 9 5/8” casing & cementing (completed)
- 2,400-4,127m: 8 1/2” hole, open hole (completed)

2014: Start to drill new well to 4,500m

- 0-4,127 m: well logging (incompleted)

Hydrofracturing stimulation (incompleted)

- 0-30 m: 24” hole, 20” conductor (incomplete)

2015: Complete drill new well to 4,500m

- 30-330 m: 17 1/2” hole, casing 13 3/8”
- 0-330 m: 13 3/8” casing cementing
- 330-2,400 m: 12 1/4” hole, casing 9 5/8”
- 0-2,400 m: 9 5/8” cementing
- 2,400- 4,500 m Directional drilling 8 1/2” hole

5. WELL AND WELLHEAD CONFIGURATION

5.1 Well profile

The vertical well profile of PX-1 is shown in Figure 3. The Well profile comprised drilling the 17 1/2” section to a depth of 330 m and setting 13 3/8” casing. Then drilling the 12 1/4” section to a depth of 2,400m, set the 9 5/8” casing and finally drill 8 1/2” section to a depth of 4,127m at present.

5.2 Configuration of Wellhead

As shown 13 3/8” casing head houseing in Figure 4, 5000 psi of 13 3/8” drilling spool, 13 3/8” double ram BOP and 13 3/8” annular BOP.

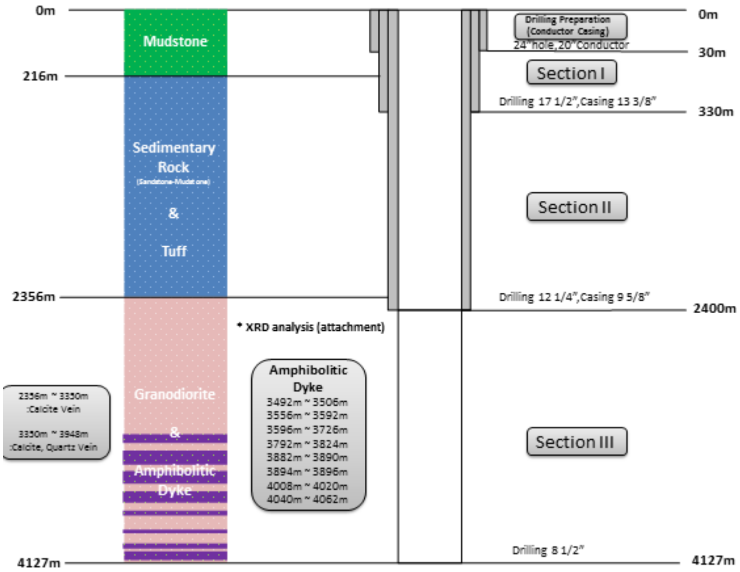


Figure 3. PX-1 Well profile and Lithology

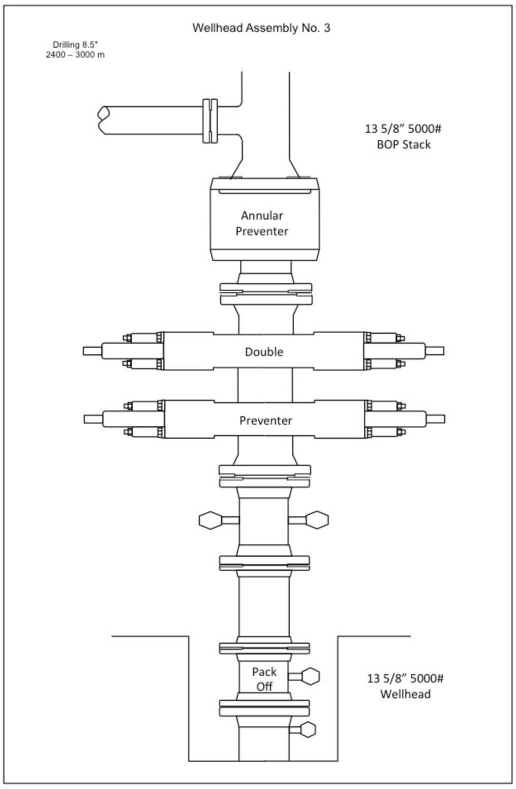


Figure 4. Configuration of Wellhead

6.1 13 3/8" Casing Design

Based on following assumptions, the 13 3/8" casing were design;

- Collapse 1: The annulus is filled with 1.08 g/cm^3 fluid and the casing is evacuated
- Collapse 2: Assumes 0.226-bar/meter external frac gradient with 1.0 g/cm^3 internal fluid Density
- Burst: The burst load assumes 207 bar surface bullhead pressure with same internal and external hydrostatic gradients.
- Joint: The joint strength is the tension load while running assuming buoyancy for 1.0 g/cm^3 density fluid.

Table 2. 61 lbs# L-80

61 lbs# L-80 0-500m	Comment	Demand	Rating	Safety Factor
Collapse 1	Evacuated	53bar	115.1bar	2.17
Collapse 2	Trapped Water	67.2bar	115.1bar	1.17
Burst	N/A	206.8bar	310.3bar	1.50
Joint	Top Joint	39.6ton	630tons	15.91

Table 3. Design of Casing

Section	EA	Description	Length
13 3/8” Surface casing 0~330m	1	13 3/8” Float Shoe BT&C	0.60 m
	2	13 3/8” 61# N80 BT&C	22.28 m
	1	13 3/8” Float collar BT&C	0.71 m
	28	13 3/8” 61# N80 BT&C	306.50 m
	Total Length		330.09 m

6.2 9 5/8” Casing Design

6.2.1 Design criteria

Based on following assumptions, the 9 3/8” casing were design;

- Collapse 1: The annulus is filled with 1.08 g/cm^3 fluid and the casing is evacuated
- Collapse 2: Assumes 0.226-bar/meter external frac gradient with 1.0 g/cm^3 internal fluid Density
- Burst: The burst load assumes 207 bar surface bullhead pressure with same internal and external hydrostatic gradients.
- Joint: The joint strength is the tension load while running assuming buoyancy for 1.0 g/cm^3 density fluid.

47 lbs#. L-80

Table 4. 47 lbs# L-80

47 lbs#. L-80 330-2406m	Comment	Demand	Rafting	Safety Factor
Collapse 1	Evacuated	254.1	313.0	1.23
Collapse 2	Trapped Water	249.5	313.0	1.25
Burst	N/A	275.8	473.7	1.72
Joint	Top Joint	18.3ton	508.9ton	26.92

Table 5. 43.5 lbs# L-80

43.5 lbs# L-80 330-2406m	Comment	Demand	Rafting	Safety Factor
Collapse 1	Evacuated	222.4	252.3	1.13
Collapse 2	Trapped Water	216.6	252.3	1.16
Burst	N/A	275.8	436.4	1.58
Joint	Top Joint	46.6 ton	470.08 ton	9.78

Table 6. 40 lbs# L-80

40 lbs# L-80 330-2406m	Comment	Demand	Rafting	Safety Factor
Collapse 1	Evacuated	169.4	197.9	1.17
Collapse 2	Trapped Water	163.8	197.9	1.21
Burst	N/A	275.8	396.4	1.44
Joint	Top Joint	129.8 ton	444.1	3.20

Table 7. Design criteria

Section	EA	Description	Length
9 5/8" Intermediate casing 0~2,400m	1	9 5/8" Float Shoe BT&C	0.45 m
	2	9 5/8" 47# N80 BT&C	22.18 m
	1	9 5/8" Float collar BT&C	0.40 m
	208	9 5/8" 47#, 43.5#, 40# N80 BT&C	2,379.97 m
	Total Length		2,400.00 m

7. CEMENTING

7.1 Cementation 13 3/8" Surface Casing 0-330m

13 3/8" section drilled until 330.09 m. The cementing operation was performed by Fangmann, Germany. Mixing equipment was built on site using local available parts and pumps. A Gardner-Denver duplex pump (Model 3FXX172) was used forpumping the entire cement job. 10 m^3 of water spacer was pumped. Following the water spacer, 34 m^3 of lead cement(density 1.60 g/cm^3) was pumped, followed by 10 m^3 of tail cement with a density of 1.77 g/cm^3. The drill pipe was displaced `with 0.3 m^3 of fresh water and 2.8 m^3 of 1.05g/cm^3 density mud. During the whole job good returns were observed. Approximately 17 to 18 m^3 of cement were circulated to surface. The cement fell back to 2.1 meters below the cellar floor and the annulus had to be filled up with cement manually to surface. The tail cement should have normally been at 1.9 g/cm^3 density however the mixing tank used for the cement didn't have an agitator so 1.77 g/cm^3 was as high as could be mixed. The Cement Type is Class G Buildchem and the Bentonite Type is Bentonil GTC4 Süd-Chemie Korea Co., Ltd.

7.2 Cementation 9 5/8" Intermediate Casing 330-2400m

12 ¼" section drilled until 2406, 8 m. 9 5/8" casing running depth drilled to 2400 m. (Float Shoe @ 2400m). Circulation head nippled up on casing, during site preparation for cementing circulation done. After preparation, circulation head replaced by double plug cementing head. Cementing pump, batch mixer and cement surface lined checked and tested. Cementing operation performed by Nexgeo. HT-400 cementing pumps were used for the operation. Cement slurry mixed in locally built 2 ea. 24 m3 batch mixers. Other lines and valves supported by locally.

The procedure of the cementing job was as follow; Pre-job safety meeting with supervisor and drilling crew. Test cementing line @ 500 psi and @ 3000 psi. 2.4m3 water pumped as spacer. Dropped bottom plug and displaced by 0.8 m3 water. Cement slurry prepared as lead and tail. Lead slurry was 24 m3, 1.6 g/cm3, pumped at 0.95 m3/min rate. Tail slurry was 71.5 m3, 1.8 g/cm3, pumped at 0.5 m3/min rate. Dropped top plug, displaced top plug and clean surface with 1.6 m3 water. Start displacement by using rig pumps and displaced with 94.3 m3 drilling mud. (Last 2.4 m3 pumped by cement pump). Set top plug and hold pressure at 2800 psi for 5 min. Bleed off pressure. No flow back. 1.22 g/cm3 cement slurry contaminated with drilling mud reached the surface. Wait on the cement slurry.

The main agent used was G- Class cement and 35% Silica Flour. Diacel HTR-100 used as retarder. Diacel RPM powder used as friction reducer. Defoamer added cement slurry to reduce foam in the slurry.

7.3 Cement Laboratory Tests

Laboratory tests for the cement and additives was carried out by Turkish Petroleum.

The environment of the well was assumed as follow; Bottom Hole Static Temperature (BHST) is 90 C0. Bottom Hole Circulating Temperature (BHCT) is 60C0.Bottom Hole Pressure (BHP) is 5072 psi and Mud Weight is 1.14 g/cm^3.The cement type was G class and Specific Gravity was 3.15. The composition of the cement slurry was Cement + 59.7 % Water (BWOC) + 35 % Silica Flour (BWOC) + 0.15 % HTR (BWOC) + 0.3 % LWL (BWOC) + 0.3 % RPM (BWOC).

The slurry Properties was as follow; Cement slurry density was 1.84 g/cm3. Yield was 1.85 ft3/ sack (50 kg). Thickening Time (70 Bc) was 04 hrs 40 min. @ 60 C & 5072 psi. Compressive Strength was 1972 psi @ 24 hr, 90 C & 3000 psi

8. DRILLING FLUID PROGRAM

8.1 17 ½" Section

A viscous fluid was used in this section of the well to adequately transport drill cuttings to the surface. A flocculated bentonite drilling fluid was environmentally safe and adequate to do the job.

8.2 12 ¼" Section

Water based KCL-polymer mud used for 12 ¼" section to prevent some formation swell and stuck pipe. Caustic soda used for pH, CMC-LV used for fluid loss. Mud weight: 1.10-1.15 g/cm^3, Funnel Viscosity: 50-70 sec/qt, pH: 8.5-9.5, API Fluid Loss: ≤ 8, PV: ALAP, YP: 10-30 lb-100ft^2, MBT: ≤ 30 lb/bbl

8.3 8 ½" Section

Water based polymer mud used for 8 1/2" section. Xanthan Gum used as main viscosifier. Caustic soda used for pH, PAC-LV (Poly anionic cellulose) used as fluid loss agent, for high temperature Driscal-D used for HT fluid loss agent. Hi-Vis pill prepared and pumped the well when needed.

Mud weight: 1.20-1.25 g/cm³, Funnel Viscosity: 60-90 sec/qt, pH: 8.5-10, API Fluid Loss: ≤ 10, PV: ALAP, YP: 10-30 lb-100ft², MBT: ≤ 20 lb/bbl

9. BIT PROGRAM

Ten bits were required to drill PX-1. With the exception of the first 200 meters, the formations were much harder than anticipated however the formation was not abrasive.

9.1 17 ½" Section

The 17 ½" section was drilled with 2 bits (IADC code 115 and 435X) to 330 meters in 260.5 hours. The average rate of penetration for the 17 ½" section was 1.27 meters per hour. The 17 ½" section was drilled with the following bit parameters: 8 - 12 tons bit weight, 50 - 80 RPM according to bounce and 2,200 – 2,800 liters per minute flow rate.

9.2 12 ¼" Section

The 12 ¼" hole section was drilled with a total of 8 bits. The bits were as follows: 3 – IADC code 447X, 3 – IADC code 517X and 2 - IADC code 547 (X and Y). The 1,920 meters of hole was drilled in 1,001.5 hours with an average penetration rate of 1.92 meters per hour and 240 meters per bit.

The 12 ¼" hole section was drilled with the following bit parameters 8 - 16 tons bit weight 50 - 70 RPM and 2,100 liters per minute flow rate. The parameters on the bit were controlled by the bouncing of the drill string and the inability to get the damaged drill collars repaired for more weight on bit once the shock tool was run in the hole.

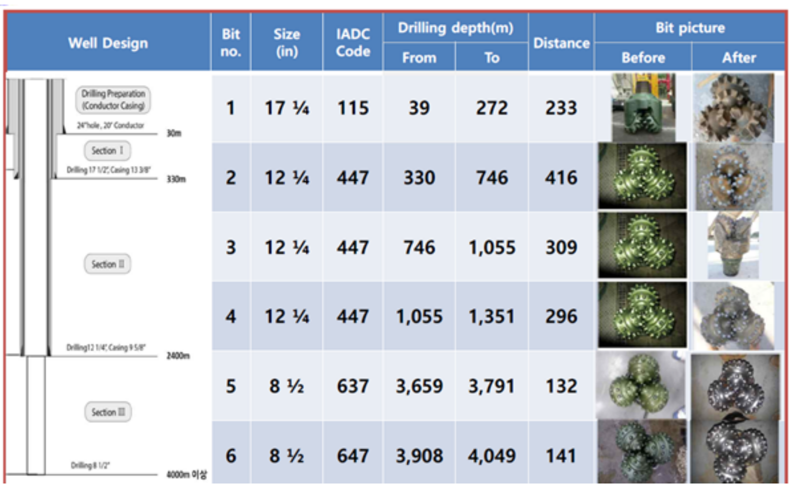
9.3 8 ½" Section

The 8 ½" hole section was drilled with a total of 10bits. The bits were as follows: 1 – IADC code 537X, 2 – IADC code 627Y, 5 - IADC code 637Y and 2 – IADC code 647Y). The 1,710 meters of hole was drilled in 1,086.3 hours with an average penetration rate of 1.57 meters per hour and 240 meters per bit.

The 8 ½" hole section was drilled with the following bit parameters 11 - 15 tons bit weight, 70 - 90 RPM and 2,100 liters per minute flow rate. The parameters on the bit were controlled by the bouncing of the drill string and the inability to get the damaged drill collars repaired for more weight on bit once the shock tool was run in the hole.

9.4 Bit Performance

The bits used in the PX-1 well exhibited a very uniform wear pattern to both inserts and bearings. The wear on the inner rows and insert breakage while not running a shock tool indicate an unstable drilling environment due to the bouncing of the drill string in the hard formations. Figure 5 a summary of the bits used in PX-1



Well Design	Bit no.	Size (in)	IADC Code	Drilling depth(m) From	Drilling depth(m) To	Distance	Bit picture Before	Bit picture After
	1	17 ¼	115	39	272	233		
	2	12 ¼	447	330	746	416		
	3	12 ¼	447	746	1,055	309		
	4	12 ¼	447	1,055	1,351	296		
	5	8 ½	637	3,659	3,791	132		
	6	8 ½	647	3,908	4,049	141		

Figure 5. A summary of bit used

10. DRILL PERFORMANCE

10.1 Drilling progress

The drilling progress of PX-1 for 4,127 m in depth is shown in Figure 6. The averages of the Rate of Penetrations (ROP), type of Bits, WOBs, RPMs and duration for the rock formations are as shown in Table 8.

10.2 Drilling time distribution

The below diagram (Figure 7) is an analysis of time distribution for the drilling operation. Total drilling hour for the PX-1 is 4,427 hours. The time for drilling is 47 % of the total hours, 1,424 hours and the trip hours are about 20 % since it included the time of the washout. The time of the circulation and the connection including BHA handling is about 5.59 %. About 2.78 % of the time are spent on the trouble shooting and about 1 % of the time are spent on the repair, maintenance and slip/cut drilling lines.

Table 8. A Summary; ROP, WOB, RPM, and Duration with the Rock type

Depth(m)	Rock type	ROP(m/h)	WOB(ton)	RPM	Duration(day)
0 ~ 206	Mudstone	2.55	2-6	50-80	5
206 ~ 330	Lapilli tuff	0.47	4-10	50-60	11
330 ~ 652	Crystall tuff	4.52	5-10	40-60	29.7
652 ~ 744	Mudstone/Sandstone/Shale	2.98	6-10	50-60	1.3
744 ~ 860	Crystall tuff	3.13	6-13	40-66	1.5
860 ~ 944	Mudstone/Sandstone/Shale	1.87	7-13	40-66	1.9
944 ~ 1040	Crystall tuff	2.04	7-13	45-65	2
1040 ~ 1169	Mudstone/Sandstone/Shale	2.45	7-15	50-65	2.2
1169 ~ 1250	Crystall tuff	2.30	10-15	45-65	1.5
1250 ~ 1418	Andesitic tuff	2.52	7-15	45-65	2.8
1418 ~ 1567	Andesite	1.48	9-15	50-65	4.2
1567 ~ 1996	Andesitic tuff	1.15	12-16	50-65	15.5
1996 ~ 2128	Andesite	2.15	7-14	55-65	2.6
2128 ~ 2198	Andesitic tuff	1.19	13-15	60-65	2.5
2198 ~ 2250	Andesite	2.04	13-15	60-65	1.1
2250 ~ 2356	Andesitic tuff	1.94	10.5-12	80	2.3
2356 ~ 3356	Granodirorite	2.34	11-13	70-90	17.8
3356 ~ 3726	Amphibolitic dyke	1.56	11-13	60-80	9.9
3726 ~ 3792	Granodirorite	1.22	11-12.5	60	2.3
3792 ~ 3824	Amphibolitic dyke	1.19	12-13	60-80	1.1
3824 ~ 4040	Granodirorite	1.56	12-13	80	5.7
4040 ~ 4062	Amphibolitic dyke	0.97	12-13	80	0.9
4062 ~ 4127	Granodirorite	1.05	13-15	75-80	2.6

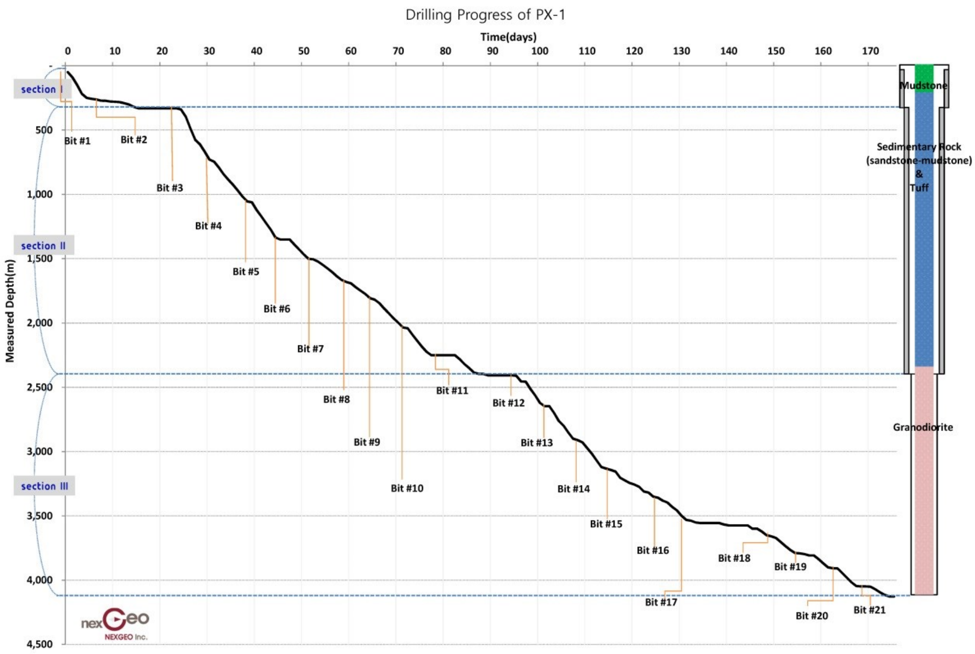


Figure 6. Drilling progress of PX-1

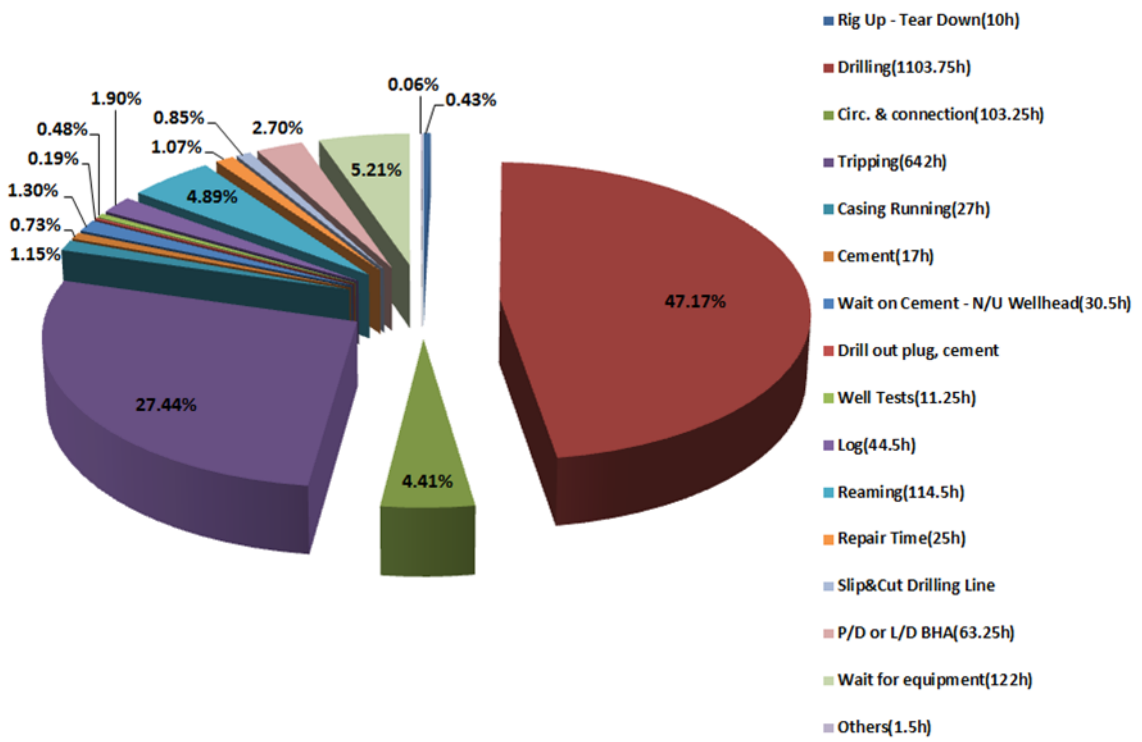


Figure 7. A Pie diagram the drilling operation time

11. WELLBORE TRAJECTORY

For the PX-1 well, the limits on the trajectory were not defined since it was planned as a straight wellbore. It was not possible to run deviation surveys until an inclinometer was purchased Tocto from Well Done in Germany. The depth and angles measured are as follow;

Table 9. Result of Inclination and Deviation survey

Depth(m)	Angle(degree)
308	0.5
1,010	3.25
1,210	8
1,445	6.75
2,406	6
2,647	3
2,911	4
3,359	7
3,556	3.5
3,792	8

12. WASHOUT

There were 11 drill pipe joints washout. 9 of them were happened within days as shown in Table 10. The washout locations are within about 60 cm from the connection part(Figure 8); 9 of them are below box and 2 of them are above pin. Also, the locations concentrate on depth range 1,500-1,800 m from rig floor, which might be related to the well trajectory. Unfortunately, the well inclination has not measured yet.

The chemical composition and mechanical properties of a washout pipes are determined as shown in Table 11 and 12 compared with API Specification. Chemical composition, Tensile strength, Yield strength, Elongation and Impact value of the Drill pipes meet the requirements of API spec 5DP. For determination of causes of the washout is still working on metallurgical and numerical analysis.

Table 10. Date, drill depth, distance and location of washout

Number of wash	Date	Drilling depth(m)	Distance of washed out pipe from surface(m)	Location of washed out pipe	Used time(h)
1	28th June	3142	1552	55cm below box connection	643.7
2	29th June	3155	2290	63cm below box connection	602.0
3	30th June	3203	1760	53cm above pin connection	685.0
4	2nd July	3244	1514	63cm below box connection	736.1
5	3rd July	3251	1647	53cm above pin connection	736.5
6	4th July	3273	1590	58cm below box connection	769.9
7	6th July	3319	1571	63cm below box connection	816.1
8	10th July	3389	1628	60cm below box connection	890.8
9	17th July	3556	1799	60cm below box connection	1049.2
10	14th Sep.	3567	1062	60cm below box connection	985.7
11	01st OCT	3808	351	62cm below box connection	-

Table 11. Result of the Chemical composition analysis

	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
WP(1)	0.230	0.250	1.12	0.011	0.004	0.860	0.170	0.040	0.080
WP(2)	0.249	0.246	1.10	0.006	0.004	0.876	0.161	0.038	0.110
WB	0.254	0.261	1.09	0.010	0.003	0.868	0.171	0.040	0.073
NW	0.243	0.268	1.10	0.009	0.002	0.863	0.164	0.034	0.062
API SPEC (5DP)	-	-	-	≤0.020	≤0.015	-	-	-	-

(WP : Wash pipe Pin part, WB : Wash pipe Box part, NW : None Wash pipe)

Table 12. Result of the Tensile Strength and Impact test

	Tensile Test Result			Impact Test
	Tensil(MPa)	Yeild(MPa)	Elongation(%)	(20 ℃)(J)
Pipe body	923	857	18	90
API SPEC(5DP)	≥793	≥724~931	≥ 13.0	Each≥38 Average≥43

Figure 8 Corrosion and location of washout

13. LESSON LEARNED

1. A manager who has experiences on geothermal project was needed whole duration of the project in the Nexgeo rather than hire a consulting service company. He should capable enough to integrate geology, drilling including directional drilling, mud, cementing,

bit and well loggings. Particularly he has a knowledge of mechanics on the drill rig will be a great advantage for repairs. And he should have open mind for the cultural differences.

2. The cost of the project is much higher than we estimated. The infrastructures for oil and gas drilling do not exist such as Korea, it has to prepare for the cost of delivery.

3. It is very important forward planning for the project operation such as drilling programs, cementing services, bits, mud materials and spare parts, obtaining the right services at right time and a good management structure is essential to have both time and cost

4. The API specification is not enough for the guarantee the quality of the drill pipe. The Chinese drill pipes we had washouts are meet the chemical composition and strength with API specification

ACKNOWLEGEMENTS

This work was supported by the New & Renewable Energy Technology Development Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) through a grant funded by the Korean government's Ministry of Trade, Industry & Energy (No.20123010110010).

REFERENCES

AMC Oil & Gas(2013) NEXGEO Exploration Pohang PX-1 Drilling Fluids, End of Well Report. 49pp.

Aydinli, H.A(2013) Px-1 Re-Entry Well, Final Drilling Report, NEXGEO International Report 39pp.

Song, Y., Kim, H.C and Lee, T.J.(2010) Geothermal Development in Korea: Country updated 2005-2009, *World Geothermal Congress 2010,* Bali, Indonesia, Paper No.121.

Terry, G and D. Teza(2012) NEXGEO Well PX-1, Status Report.