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HISTORY OF DRILLING OPERATIONS IN THE KIRISHIMA GEOTHERMAL FIELD

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ABSTRACT

The Kirishima geothermal area is located in the southwest part of the Kirishima volcano group in Kagoshima Prefecture, Japan. Exploration of the Kirishima geothermal area by the Nittetsu Mining Co. was started in 1973. After evaluation of the surveys, Nippon Steel Corp. and Nittetsu Mining Co. drilled 21 exploratory wells: 8 slim holes, 9 production- and 4 reinjection. wells to depths between 1,000 and 2,000 m. Several new drilling procedures and techniques were introduced in some exploratory wells, for example, sidetrack operations using a casing section mill, drilling with aerated mud, and drilling ahead without returns using produced geofluids.

The Nittetu Kagoshima Geothermal Co. was established in 1990 by the Nippon Steel Corp. and Nittetsu Mining Co. Production drilling was concentrated in the Ohgiri District of the field along the Ginyu fault. Production wells were drilled into the fault zone. This zone was highly permeable and productive, and bit drop and loss of pumping pressure were noticed when the fault zone was intersected. A standard drilling plan was established; surface holes were predrilled and conductor pipes were set before using a large rig. Reinjection wells were directionally drilled to intersect a major fracture forming the western boundary of the fault zone.

When sufficient steam production was proven, the Kyushu Electric Power Co. constructed the Ohgiri power plant with a capacity of 30 MW. The Nittetsu Kagoshima Geothermal Co. supplies steam for this plant which was commissioned on 1 March 1996.

Drilling activities of exploration-, production-, and replacement wells after electricity production began in 1966 are described in this paper.

1. INTRODUCTION

The Kirishima Geothermal Field is located in South Central Kyushu Island (Fig. 1) on the southwest portion of the Kirisima volcanic mountain complex.

The local geologic map (Fig. 3) indicates a very active geothermal regime shown by the many natural surface manifestations of hot springs, fumaroles, and highly mineralized zones. The major geologic structure in this region is the Ginyu fault where gold ore was mined for many centuries. A conceptual sketch of the Ginyu fault is shown in Fig. 4. Drilling locations and directional drilling were planned to intersect the fault zone which is highly permeable and contains abundant thermal fluids.

Additional information about the Kirishima hydrothermal resource can be found in the Proceedings of the International Symposium on Energy with papers by Gokou et al. (1988), Maki et al. (1988), and Yokoi et al. (1988).

Information about types of rocks encountered, reservoir geology, sub-surface temperatures and the layout of the drill sites in the Ginyu district can be found in Figs. 3, 4, 5, and 6.

2. EXPLORATORY WELL DRILLING

2.1 Staged Exploratory Well Drilling

The regional surface surveys that preceded the exploratory drilling consisted of: geological mapping, geophysical soundings (gravity and resistivity), and chemical analysis of ground waters, hot springs, and gases from major fumaroles. Sampling and monitoring of active surface manifestation are continuing, mainly in the Kurinodake, Ginyu, Shiramizugoe, Yunoike, Tearai, Torizigoku, and Yamanosiro districts (see Fig 3).

The exploratory drilling was divided into three stages:

*Confirmation Investigations (1979-1981):
Three slim holes were drilled in the Shiramizugoe and Ginyu districts.
*Development (Prove-Up) Investigations (1982-1985):
Five slim holes and seven large diameter wells were drilled in the Ginyu, Shiramizugoe, and Yamanosiro districts.
*Development Drilling (1982-1985):
Six large diameter wells (5 production and 1 reinjection) were drilled into the known reservoir along the Ginyu fault.

2.2 Slim hole Exploratory Drilling

Initially, the slim holes were core-drilled with swivel rigs of HLL type. However, operations were switched to TSL and GSR rotary drilling rigs to improve drilling efficiency. Mud pumps used were D-100-70 and FX-FXD types (Gardner Denver) with capacities of 1,000 l/min. Coring was used to understand local stratigraphy, rock properties, and structural features. Both HQ and NQ diameter rods were used.

Fresh water was used as drilling fluid in the top part of the holes at lower rotary speeds; a light bentonite mud was used when rod vibrations occurred. For drilling with tricone bits, bentonite mud was employed at lower borehole temperatures;

BX and BH mud additives were used when temperatures exceeded 120-150 oC.

Lost circulation control measures consisted of use of Lost Circulation Materials (LCM) pumped through the bits, and flash cement plugs. Control of lost circulation often took a good deal of operating time.

Casing cementing material for slim holes was normally a slurry made from Portland cement; the placement procedure was by the inner string method to about 50 m depth. A special geothermal cement and the two plugs placement method were used to 200 m depth. A retarder was added to the slurry for the final hole depth. The slurry was formulated for a 1.8 specific gravity. Only one well could be completed using a full annulus cement job. One well failed the breakdown test. A rod twist off and one washout occurred. These problems were solved by use of stronger rods and introducing drilling jars.

2.3 Large Diameter Exploration Well Drilling

Operations for the large diameter wells included simultaneous drilling of two or more wells. Therefore, two or more drill rigs were in operation at the same time. The equipment for these rigs is summarized in Table 1. After a production well had encountered the reservoir, lost circulation was not controlled and either a lighter mud or fresh water was used as drilling fluid. The usual drilling fluid consisted of bentonite or a water based fluid with BX and BH additives. Guidance in drilling fluid mixing and testing was provided by a mud engineer. The tri-cone bits used were of IADC 1-2-3 type.

Six production wells (KE-13, -17, -19s, -21, -23, and –18) were directionally drilled using single shot magnetic surveying and a downhole motor when corrections were required. Cuttings were sampled to evaluate lithostratigraphy, and to identify the reservoir rocks. For drilling below the reservoir, a junk basket was run above the bottom hole assembly (BHA).

The large diameter well drilling operations encountered some problems and failures in the Ginyu district:

*Drill bits could strike bedrock at about 10 m depth.
*Numerous severe loss zones were encountered above 300 m depth (the reservoir cap rock occurs between 300-500 m depth).
*LCM controlled the losses more effectively than cement plugs in the 500-700 m depth interval.
*When the reservoir was encountered, severe bit drops occurred.

The control of lost circulation took on average 10-20 days per well. The cement slurry required was about 1.5 times the volume of the annulus.

Cementing of the conductor casing was done by the conventional inner string procedure. The surface and production casing strings were cemented by two plugs; these jobs were done by a cementing service company. Leak off pressurization tests were conducted after the cement had set. The cementing of both surface and production casings of reinjection wells were performed by the drilling contractor using the rig mud pumps. When the cement in the annulus did not return to the surface, top jobs were conducted.
Major problems were encountered by stuck drill pipes. Both oil spotting and hook over-pull were used to free the pipe. However, one well could not be cleared and a sidetrack operation was needed.

The well logging program consisted of running sonic, resistivity, caliper, self-potential, and temperature logs. This sequence of logs was routinely run after drilling to 400 m and 900m depth.

3. DEVELOPMENT WELL DRILLING

Based upon the testing of the exploratory wells, an agreement between Kyushu Electric Power Co. and Nittetsu Kagoshima Geothermal Co. was reached in 1989. Drilling of production wells started after this agreement.

3.1 Development Plan

The plan defined the necessary steam supply for 30MWe to be available by 1 March 1996 with the following details:

* The required steam had to support 30MW plant and had to be produced from a 1.2 km long portion of the Ginyu fault; the intersected fracture zone was estimated to be 70 m wide (projected on a horizontal plan).
* Seven production wells (1,300 m deep) and six reinjection wells (960 m depth) were planned.
*The strategy was to use two well pads for production wells, and two for reinjection wells.
*Production well drilling would use two rigs and reinjection drilling one rig.

3.2 The Planning Strategy

Any similar geothermal development contains a large risk factor and involves high costs. Thus, planning was based on previous technological and operational experiences. To reduce costs, the plan included construction time and costs for each well and projected progress. Delays and costs were reduced by assuring a smooth construction schedule. The development target, the productive zone along the Ginyu fault, had already been intersected by four exploratory wells. The geological features and sub-surface structures had thus been delineated. A simplified and standardised drilling strategy could therefore be defined.

3.3 Outline of Construction Plan

Drilling costs are greatly affected by mobilisation and demobilisation, therefore the method of rig skidding was adopted. Industry methods of analysis by the Program Evaluation and Review Technique and a standard rig skid procedure were used.
One existing drill pad was upgraded and a new one was constructed. The new location was selected to assure that well paths could be easily drilled into the fault zone. A production wellhead spacing of 13 m was selected to allow for flow testing. The reinjection wellhead spacing was 11 m, to allow room for repair and maintenance.

The drill rig selected for production drilling was a NM-2000 rig, its selection was based on our experience with the exploratory drilling.
Because the use of a large drill rig for shallow conductor holes is inefficient, pre-drilling was adopted. This, in addition to the rig skidding technique, saved a great deal of time.
Based on the early drilling experience, the conductor pipe could be shortened by 10 m. The intermediate and production casing lengths were shortened by 100 m.

4. REPLACEMENT WELL DRILLING

Two recent replacement wells have been drilled in the Kirishima Field. One reinjection and one production replacement well were drilled in the 1998-1999 period. The details of two drilling operations are described next.

4.1 Reinjection Well (NT-E5)

Drilling operations for the replacement reinjection well NT-E5 started in April 1998. An NM-2000 rig was mobilized to drill pad E. which had sufficient space for another well. The drilling and well plans were based on past reinjection well experience. Bedrock was known to be at 14 m depth, the total drilling depth was 1,210 m. The drilling time was from April 13 to July 30.

<u>Drilling of the 17-1/2 inch hole (1-3 June)</u>
A 17-1/2 inch tri-con bit was used. No lost circulation was encountered, and the 13-3/8 inch conductor pipe was installed to 14.0 m depth. The pipe was cemented with a Portland cement slurry of 1.7 specific density. Cement returns at the surface were achieved.

<u>Drilling of the 12-1/4 inch hole (June 3-22)</u>
A 12-1/4 inch tri-cone bit was used. Following the drilling out of the cement, severe losses of circulation were encountered in 14 zones. Losses were controlled using cement plugs. The drill string was changed out at 403 m and a wiper trip was made. The 9-5/8 inch casing was run to 400.15 m and cemented by two plugs procedure.

<u>Drilling of the 8-1/2 inch hole (June 22- July 9)</u>
An 8-1/2 inch tri-cone bit drilled out the cement in the 9-5/8 inch casing, a leak test was conducted. Drilling continued to a depth of 425.25 m when a down-hole motor assembly was run for a kick off using a steering tool. Severe circulation losses were encountered in the 440 – 490 m depth interval and directional drilling was interrupted. Cement plugs were set which solved the lost circulation problem. Directional drilling with a steering tool was conducted to a depth of 778.3 m; a hole angle BHA was then used. 'Blind' drilling continued to 1054.40 m where lost circulation was encountered; drilling continued to a total depth of 1210.37 m when temperature and resistivity were logged. An injection test was performed and the 7 inch casing was run to 1,210 m depth with slots positioned over the loss zones.

A mud logging program was initiated for the NT-E5 well, and temperature of the mud pit, cuttings and geological analysis were collected; to aid solids control, a de-sander and de-silter were installed. Below 403 m depth, a BX mud additive was used, and after the blind drilling, a light bentonite mud was used.
The amount of mud loss and the pit level were monitored and used to estimate the volume for the cement plug. An amount of 20 % - 25 % of sodium silicate was added. This treatment was very effective.

4.2 Production well drilling (NT-A5)

A drill pad, where previous development drilling had intersected the productive reservoir, was chosen as site for this production replacement well. Moreover, since the reservoir fluid level was lower than at the time of previous drilling, the 12-1/4 inch casing point was lowered from 800 to 900 m to allow initiation of production by the swabbing method.

Preparation work began on December 2, 1998, and the well construction on December 3 with the installation of the conductor pipe. The depth to the bedrock had been determined during drilling of the cellar. The conductor hole was drilled using a percussion industrial hammer; a 26 inch casing was run and cemented rapidly. This work proceeded in parallel with the setting up of the NM-2000 rig.
Drilling of the 17-1/2 inch hole began on December 28. The well was completed with a TD of 1,275.2 m on February 22 1999. A 7 inch casing string was installed, and swabbing commenced on March 1. The well produced a two-phase fluid after 8 swabbing jobs. The well construction was completed and de-mobilization occurred on March 24.

<u>Drilling of the 26 inch hole (December 7-11)</u>
Because the bedrock depth was known from the cellar drilling, the conductor hole was brought down to a depth of 47.0m by an industrial air percussion hammer. A great deal of clay in the sands was encountered and the depth had to be extended by 7 m. The 20 inch conductor pipe was installed and cemented as a top job. This first phase confirmed the advantage of the pre-drilling and parallel construction

strategy. Several advantages were noted:

*The schedule of pre-drilling and construction was easy to comply with.
*Use of the air hammer provided close monitoring of the rock type as the cuttings were exhausted directly onto the surface.
*Cementing of the conductor by the top job method was excellent.
*The pipe diameter was not expanded as in the past.

Drilling of the 17-1/2 inch hole (December 28 – January 25)

Drilling began on December 28 with a 17-1/2 inch tri-cone bit, a 9-5/8 inch shock sub was run above the bit. The thread of the pin of the crossover sub below the non-magnetic collar was damaged and the BHA parted at 365.8 m. An over-shot was run and caught the BHA fish. Severe circulation losses were encountered from the top to the bottom of the section. In the upper part, cement plugs with added sodium silicate were used; for the deeper zones the drill pipe cement flash method was employed.

Drilling of the 407.47 m section was completed on January 21, and a 13-3/8 inch casing was run and cemented on January 22. Cement return to the surface was achieved. After the cement had set, its level was at 4.74 m. Pressurising equipment was used to perform a successful leak test on January 26.

Drilling of the 12-1/4 inch hole (January 26 – February 26)

Drilling began at 407.7 m depth with a 12-1/4 inch tri-cone bit on January 26. At a depth of 499.00 m, the Kelly was replaced because the connection threads had been washed out. The threads on the pin at the bottom of the crossover sub below the non-magnetic drill collar were damaged at 563.50 m. Fishing of the BHA was attempted with an inside tap but was unsuccessful. Finally, an over-shot was used to retrieve the fish. The drilling fluid was switched from a BX to a BH additive at about 450 m. Drilling jars were introduced from 527.8 m depth An attempted kick-off at 711.4 m was discontinued because circulation loss was encountered. Control of lost circulation using the cement plug method and a kick-off was finally achieved at a depth of 703.0 m. An azimuth correction was executed by two runs with a NAVI DRILL directional assembly. The hole section was completed on February 13 at a depth of 913.0 m. And 9-5/8 inch casing was run following temperature and electric logs. Casing cement was completed on February 14 with complete cement slurry return to the surface. Pressure leak tests were completed on February 16.

The damaged threads on the pin of the cross over sub that occurred in both the 17-1/2 inch and 12-1/4 inch sections are now of a high strength, stress relief type to be used also in future.

Drilling of the 8-1/2 inch hole (February 16 – 27)

Drilling with an 8-1/2 inch tri-cone bit began at 913.0 m, but severe circulation loss was experienced at 926.1 m. Cement plugs were used and the loss zones were controlled. LCM drilling was used down to 1,136 m. Total fluid loss occurred at 1170.30 m and pump pressure was lost. These phenomena indicated that the reservoir had been penetrated.. To avoid reservoir cooling by the drilling fluid, the bit load was increased from 7 tons to 15 tons because an increased drilling rate was desirable. The drill pipe became stuck at 1200.8 m, and jarring was done 170 times to free the pipe. At the interval of 1203.02 to 1211.96 m, the load on the bit became zero, indicating that drilling was now within the reservoir. Drilling was completed at a depth of 1,275.02 m. After the temperature, electric and caliper logs had been taken, the 7 inch casing was run in.

Casing cementing

The cementing of the casing strings for this well resulted in returns to the surface each time. The reasons for the success were:

*The complete control of lost circulation at each loss zone.
*A uniform specific density of the slurry.
*Good designs for the slurries.
*The pumping rates were excellent
*The pit fluid condition was also excellent

The commercial product "Microbound HT" was mixed into the slurries with the aim of improving the bond between the casing and the rock formation. This helps to avoid development of a micro-annulus; bonding and cement quality will improve with steam production. It also increases durability of the cement in the annulus, thus avoiding its deterioration with time, and allows optimising of the specific density of the cement slurry. In the long term, maintenance of the well is equally important.

5.CONCLUSIONS

A summary case history has been presented that includes drilling during the exploratory, development and replacement phases at the Kirishima Geothermal Field. For us it was important to show how drilling costs can be reduced. Such reduction is needed to reduce the costs of electricity generated at the geothermal power plant. Management of long-term maintenance of the production wells is still a major issue which has to be addressed. It is expected that high quality drilling will increase the life time of the wells.

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Table 1. Rig equipment used for drilling replacement production and re-injection wells.

name	Production well	reinjection well
Draw-works Power	NM-2000 750 PS	6-1/2in unit 255 PS
Main pump Power	8-P-80 800 PS	OH-450 123kW×6P
Sub pump Power	JD-200A 173 PS	FXA 450 l/m 37kW×4P
Derrick	38m Cantilever mast	33m Standard mast
Substructure	8.8×16.6×5.5m	7.5×10.3×5.0m
Work line	28mm	22mm
Crown block	36×5	24×5
Casing hook	156 t	100 t
Water swivel	P-200 180t	OUHARA-6
Rotary machine	C-275	20 oil bus
B.O.P.	13-5/8 -3000	11-3/4 -2000
Kelley	4-1/4 × 40	4-1/2 × 40
Drill collar	8 6-1/2	10 8 6-1/2
Drill pipes	4-1/2×16.6E	4-1/2×16.6E

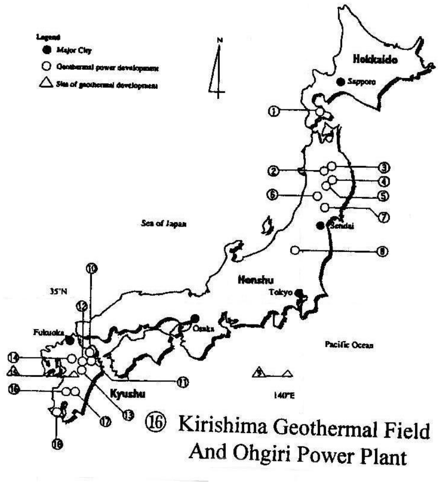

Figure 1. Location of Geothermal Power Plants and the Kirishima Field and the Ohgiri Power Station in South Central Kyushu Island.

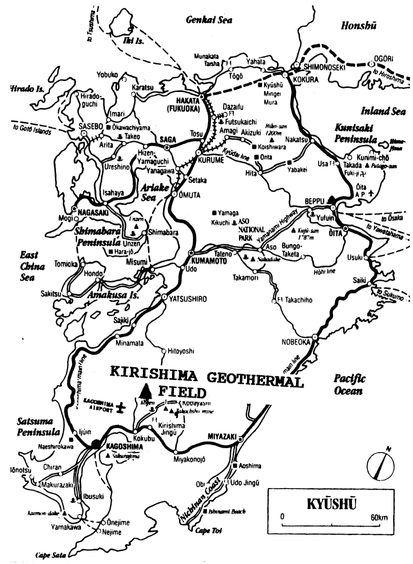

Figure 2. Location of the Kirishima Geothermal Field in South-Central Kyushu Island

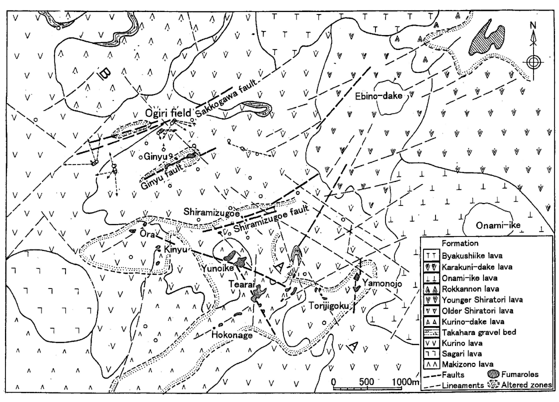

Figure 3. Geological Map of the Kirishima geothermal area

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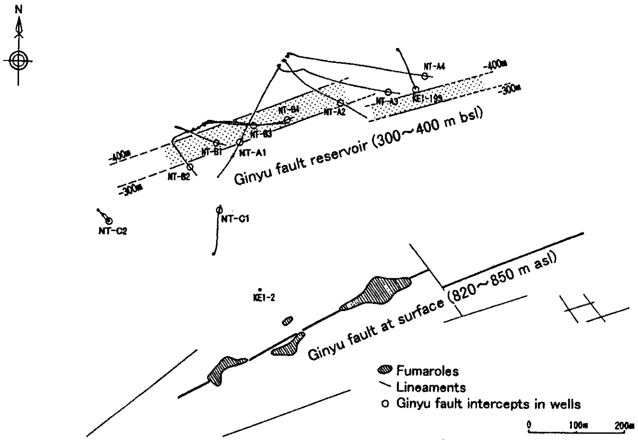

Figure 4. Correlation between surface trace and subsurface portion of the Ginyu fault.

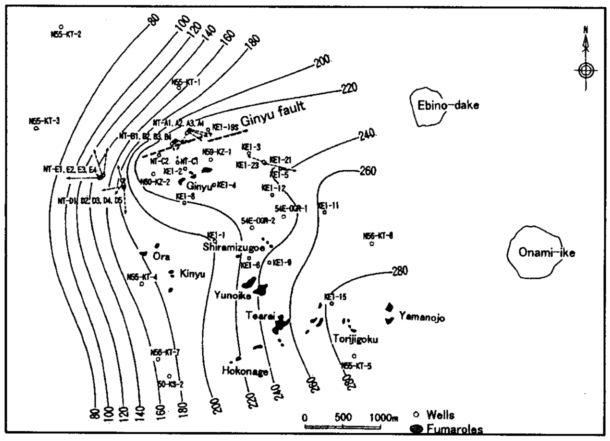

Figure 6. Temperature isotherms for the Kirishima Field at the –300 m (below sea level) level.

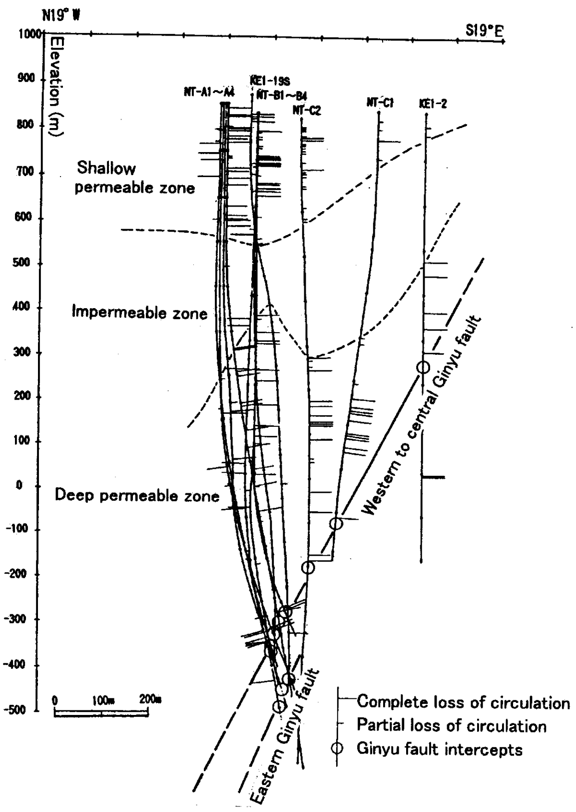

Figure 5. Ginyu Fault cross section to W-S19°showing well intersections.

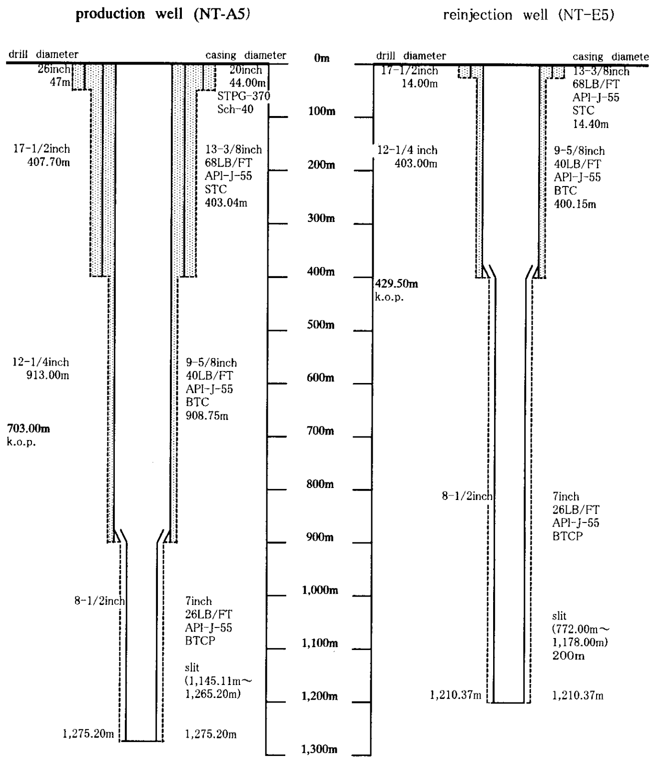

Figure 7. Wellbore diagrams for replacement wells drilled in 1998 and 1999.