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HIGH-ANGLE DIRECTIONAL DRILLING AT TAKIGAMI GEOTHERMAL FIELD

Hisashi Jotaki
Idemitsu Oita Geothermal Co.,Ltd.,Daihyaku-Mirai Bldg.,3-1 Niage-machi,Oita,870-0046,Japan

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ABSTRACT
Ten directional wells which used Measurement While Drilling system (MWD and high torque downhole motor) were drilled by Idemitsu Geothermal Co.,Ltd.since 1993 at Takigami Geothermal Field. Maximum angle of four wells exceeded more than 50 °. These are what we call High-Angle Directional Drilling for convenience.
A well TR-5 was planned to reach a high permeable zone at long distance of the existing reinjection wells and to intersect geological fault at a right angle. This well reached maximum angle to 56°and turned hole azimuth 42°with holding hole angle.
A well TR-6 could not have any loss zone originally and was utilized to drill a sidetrack well for another direction at 8-1/2"open hole section. This sidetrack well were required a long distance from a original hole and finally reached maximum angle to 66°.
We applied a conventional rotary drilling rig with MWD system for these wells and drilled out geological target of them correctly.
High-Angle Directional Drilling could expand the drilling area to minimize the pressure interference among wells at a same rig site. And a geological fault and high permeable zone were drilled out at arbitrary direction with accuracy.
There were some technical problems at these wells. One of problem was removal of cuttings in 17-1/2" and 12-1/4" hole section. We have coped with this problem by pumping high viscosity mud and short trip of bit. Another problem was that weir-line Electronic Logging could not run 50-60°inclination of open hole section. We will need another Electronic Logging System (Tough Logging Conditioning System) in future.
Technical innovation of High-Angle Directional Drilling can expand a production and an injection area over currently in use.
Moreover, total well's cost was drastically cut down by shortening a drilling progress, for we could reduce survey times and trip times and we could increase penetration rate 2-3 times faster than previous well due to effective utilization of MWD system.

1. INTRODUCTION

We have drilled ten directional wells that used MWD and high torque down hole motor since 1993 at Takigami Geothermal Field.
These wells were drilled by conventional drilling rig without top drive system (Drawworks: National N80B, Mud pump National 8P80x2), a mud pulse MWD (Schlumberger Slim-1) and a high torque downhole motor (Schlumberger PowerPak motor).
Maximum hole angle(inclination) of four wells could reach over 50°and we expanded the drilling area which we had abandoned to use old directional drilling technique(magnetic single shot). And if a well had no permeable zone and a badly depression of original capacity, a sidetrack of well could be drilled another zone for a long distance. This new drilling technique can not only expand the drilling area but also drill out the drilling target with accuracy.
MWD system could minimized a directional survey time and hole orienting time. Moreover a high torque downhole motor contributed to increase penetration rate and life of bit. Finally we could reduce drilling cost by shortening the drilling progress.

2. RESULT OF DIRECTIONAL WELL APPLIED WITH MWD SYSTEM

Total drilling length of ten wells was almost 14,806 m and total drilling intervals of MWD system was about 70 % (10,672 m) of a total drilling length. TR-3S,TR-4,TR-5 and TR-6S were maximum angle were over 50°(Table1).
In first stage at TP-1 and TR-1, we applied MWD system for one hole size section from KOP (Kick Off Point) to end of build up angle and turn azimuth. This reason were the drilling target were large radius and the well trace were not so complicated to control severely and MWD system's cost was seemed extravagance to apply from KOP to TD (Total Depth).
However at TR-2~TR-6S,we needed to control well trace so severely to avoid collision and drill out geological fault correctly.
And then we changed mind to use MWD system from KOP to TD.
The drilling targets of some well were only 2.5 m radius, but we could drill out target easily. Another reason was that we had recognized the penetration rates of TP-1 and TR-1 were more increased than previous wells.

3. AN EXAMPLE OF TR-5 REINJECTION WELL

This well was planned to reach a high permeable zone of east reinjection area. This well was required long distance from the existing reinjection wells to minimize the pressure interference and it was needed to intersect a geological fault at a right angle (Figure1).

3.1 17-1/2" Hole Section

KOP was fixed at 147 m , hole inclination was built up to 55°and hole azimuth was controlled 68°from true north at 806m.
Build up rate was 2.5°~3.5°/30 m.
Maximum dog leg severity was 5.4°/30 m.
Drilling parameter were 6~15 tons weight on bit ,60 rpm rotary speed (plus downhole motor's rotation 80 rpm) and an average penetration rate was 5.67 m/hr.

BHA: 17-1/2"Bit(IADC4-3-5) x A962Motor(1.15-1.5°Bent and 17-1/4"Stb.) x 8"ShortNMDC x 11"Stb. x Float Sub x UBHO Sub x 8"Short NMDC x 8"NMDC(2) x 8"DC(5) x 8"EQ Jars x 8"DC(2) x 5"HWDP(24)…

12-1/4" Hole Section

Turned hole azimuth 42°between 806 m(azimuth 68°from true north) to 1182 m(azimuth 110°from true north) with holding hole inclination 54°.
Turn rate was 2°~4°/30 m.
Maximum dog leg severity was 5.3°/30 m.
Drilling parameter were 10~24 tons weight on bit ,45 rpm rotary speed(plus downhole motor's rotation 150 rpm) and an average penetration rate was 8.85 m/hr.

BHA: 12-1/4"Bit(IADC4-3-5) x A800Motor(1.5°Bent and 12-1/8"Stb.) x 8"ShortNMDC x 12"Stb. x Float Sub x UBHO Sub x 8"Short NMDC x 8"NMDC(2) x 8"DC(6) x 8"EQ Jars x 8"DC(2) x 5"HWDP(24)…

3.3 8-1/2" Hole Section

This section reached hole inclination 56°at 1236 m and drilled to 1417 m with MWD system. We changed MWD system to conventional rotary system below 1417 m because we encountered a partial loss (280 l/min) at 1388 m.
Drilling parameter of MWD system were 10 tons weight on bit, 60 rpm rotary speed (plus downhole motor's rotation 200 rpm) and an average penetration rate was 11.69 m/hr from 1236 m to 1417 m.
Drilling parameter of conventional drilling were 15 tons weight on bit, 60 rpm rotary speed and an average penetration rate was 6.81 m/hr from 1417 m to 1700 m.

BHA:MWD system 8-1/2"Bit(IADC5-1-7) x A675Motor(0.78°Bent and 8-3/8"Stb.) x 6-1/2"ShortNMDC x 8-3/8"Stb. x Float Sub x UBHO Sub x 6-1/2"NMDC(2) x 6-1/2"DC(5) x 5"HWDP(7) x 6-1/2"EQ Jars x 5"HWDP(17)…
Conventional Rotary 8-1/2"Bit(IADC5-1-7) x 8-1/2"Stb. x 6-1/2"Shrot DC x 8-1/2"Stb. x 6-1/2"NMDC x 8-1/2"Stb. x 6-1/2"NMDC x 6-1/2"DC(4) x 5"HWDP(7) x 61/2"EQ Jars x 5"HWDP(17)…

4. AN EXAMPLE OF TR-6 REINJECTION WELL

This well could not have any loss zone originally. And we decided to drill a sidetrack well for another direction at 8-1/2"open hole section. This sidetrack well were required a long distance from a original hole and finally reached maximum hole inclination to 66°(Figure2).

8-1/2" Hole Section

KOP was fixed at 1339 m (95/8"csg. at1327 m). KOP's directional survey data was 31°inclination and 238°azimuth from true north. This well was turned azimuth from 238 to 173°and built up to 58°inclination at 1792 m. Dog leg severity was controlled 3~6°/30 m. This well kept on building angle to 66°at 1890 m and drilled to 2110 m TD with holding inclination and azimuth. We used MWD system from KOP to TD.
Drilling parameter were 6-16 tons weight on bit, 50-60 rpm rotary speed (plus down hole motor's rotation 200 rpm) and an average penetration rate was 5.62 m/hr.

BHA: 8-1/2"Bit(IADC5-1-7) x A675Motor(0.78-1.5°Bent and 8-3/8"Stb.) x 6-1/2"ShortNMDC x 8-3/8"Stb. x Float Sub x UBHO Sub x 6-1/2"NMDC(2) x 6-1/2"DC(5) x 5"HWDP(9) x 6-1/2"EQ Jars x 5"HWDP(11)…

5. PROBLEMS OF HIGH-ANGLE DIRECTIONAL DRILLING

We encountered technical problems and dealt effectively with some of them.

5.1 Removal of Cuttings

We treated basic procedure for removal of cuttings as follows.
•conditioning mud for high viscosity
•circulation out with a very high viscosity mud occasionally
•increase pump rate (change a reaming assembly or put a nozzle for rotor)
•short trip every 100-200 m drilling interval
In actual operation, we encountered some bottom fill and cuttings bed problems at 17-1/2" and 12-1/4" hole section. On the other hand, we could drill 8-1/2" hole section without these problems. We have recognized that a pumping rate was most important to remove cuttings. But we could not change a bigger mud pump under many restrictions in field operation.

5.2 Drilling under Lost Circulation

We could measure directional data under lost circulation because a signal was transferred inside of drill pipe. But we could not have a enough pumping rate for a restriction of down hole motors' pumping capacity and avoided to pump LCM through down hole motor at 17-1/2" and 12-1/4" hole sections. We selected KOP and controlling section 150m-1100m depth that were not distributed for lost circulation zone at Takigami.
In 8-1/2"hole section, when we encountered the fracture(lost) zone, we changed BHA from MWD assembly to conventional rotary assembly basically and kept on drilling with lost circulation. Some of wells, when we drilled out under lost circulation with MWD, we recognized that cuttings were squeezed into fracture zone and hole conditioning became so good.

5.3 Electronic Logging (E-log)

We could run E-log to 55°open hole section in TR-5,but we could not run a same E-log to 61°open hole section in TR-4 and did not try to run E-log in TR-6. Conventional weir-line E-log seemed to be limitation 50-60°inclination with related dog leg severity. If we will try to run E-log in High-Angle Geothermal Well, Tough Logging Conditioning System to be run with drill pipe will be required.

6. A SHORTENING OF DRILLING PROGRESS

We could shorten a progress of well to use MWD system, because we reduced survey time, increase penetration rate and so on.

6.1 Factors of Shortening Drilling Time

MWD system can reduce directional survey time more than an old system (magnetic single shot and high rpm motor system).
We could control a directional well so easily without a trouble of hole orienting. Our drilling target of old system was used to be 25-50 m radius. But now target radius of this system could

reduce to 2.5-5 m radius without progress delay.
We could reduce trip times without changing BHA. This system could either orient or keep drilling with same BHA.
Penetration rate of this system (High Torque Motor) was become 2-3 times faster than old system (High rpm Motor). And we could increase more weight on bit (WOB) for using High Torque Motor (Table2).

6.2 Comparison of Drilling Progress between Old System and New
System

We drilled TT-22, TT-23, TR-4 and TR-5 at same reinjection area whose formation and casing program were very similar to each other.
TT-22 and TT-23 were drilled by old directional drilling system. On the other side,TR-4 and TR-5 were drilled by MWD system.
When we compared those well, we recognized TR-4 and TR-5's MWD system reduced 18-39 days of total drilling progress (Days). It was 35 % shortening of drilling progress(71 days+58 days→34 days +49.5 days). And on drilling rate (Drilling) without CSG, lost circulation, E-log and injection test,TR-4 and TR-5 were average 75 m/day against 37 m/day of TT-22 and TT-23(Table 3).

6.3 A Cut Down of Drilling Cost

It is very difficult to disclose about drilling cost because of each well's particular difference. And then, we report bit life and bit cost of some wells.
Because bit life and penetration rate were extended, bit cost of this system (using High Torque Motor) was reduced to 66 % than old one (using High rpm Motor) (Table 4).

CONCLUSIONS

We could drill High-Angle Directional Wells to extend the drilling area with MWD system. This system and conventional rotary rig without a top drive system could brought us to drill the 56-66°high angle(inclination) wells like TR-5 and TR-6.
And also we could extend production and reinjection area further.
In Japan, we have much undeveloped geothermal resources in nature parks, for we can not develop topsoil for rig site. We wish to develop those underground resources in nature parks by an application of High-Angle Directional Drilling in future.
MWD system brought us a shortening of drilling progress, because we could reduce directional survey time and orienting time and we could increase WOB and penetration rate, moreover.
Finally, we can reduce drilling cost by the benefit of these new technologies.

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Table 1. Result of MWD' Well at Takigami Geothermal field

Well	Depth	KOP	Max.Angle	Deviation	MWD interval	Remarks
TP-1	2151m	1050 m	40°	393m	1050 ~ 1711 m	Production,Slim-1 and PowerPak
TR-1	1914m	234 m	41°	868m	234 ~ 909 m	Reinjection,Slim-1 and PowerPak
TR-1S	1505m	806 m	34°	518m	806 ~ 1450 m	Reinjection,Slim-1 and PowerPak
TR-2	1461m	275 m	42°	557m	275 ~ 1438 m	Reinjection,Slim-1 and PowerPak
TR-3	1550m	263 m	38°	493m	263 ~ 1550 m	Reinjection,Slim-1 and PowerPak
TR-3S	1540m	1133 m	63°	619m	1133 ~ 1408 m	Reinjection,Slim-1 and PowerPak
TR-4	1540m	248 m	61°	481m	248 ~ 1524 m	Reinjection,Slim-1 and PowerPak
TR-5	1700m	147 m	56°	944m	147 ~ 1700 m	Reinjection,Slim-1 and PowerPak
TR-6	2110m	160 m	66°	436m	160 ~ 2110 m	Reinjection,Slim-1 and PowerPak
TR-6S	1601m	327 m	43°	439m	327~1495 m	Reinjection,Slim-1 and PowerPak

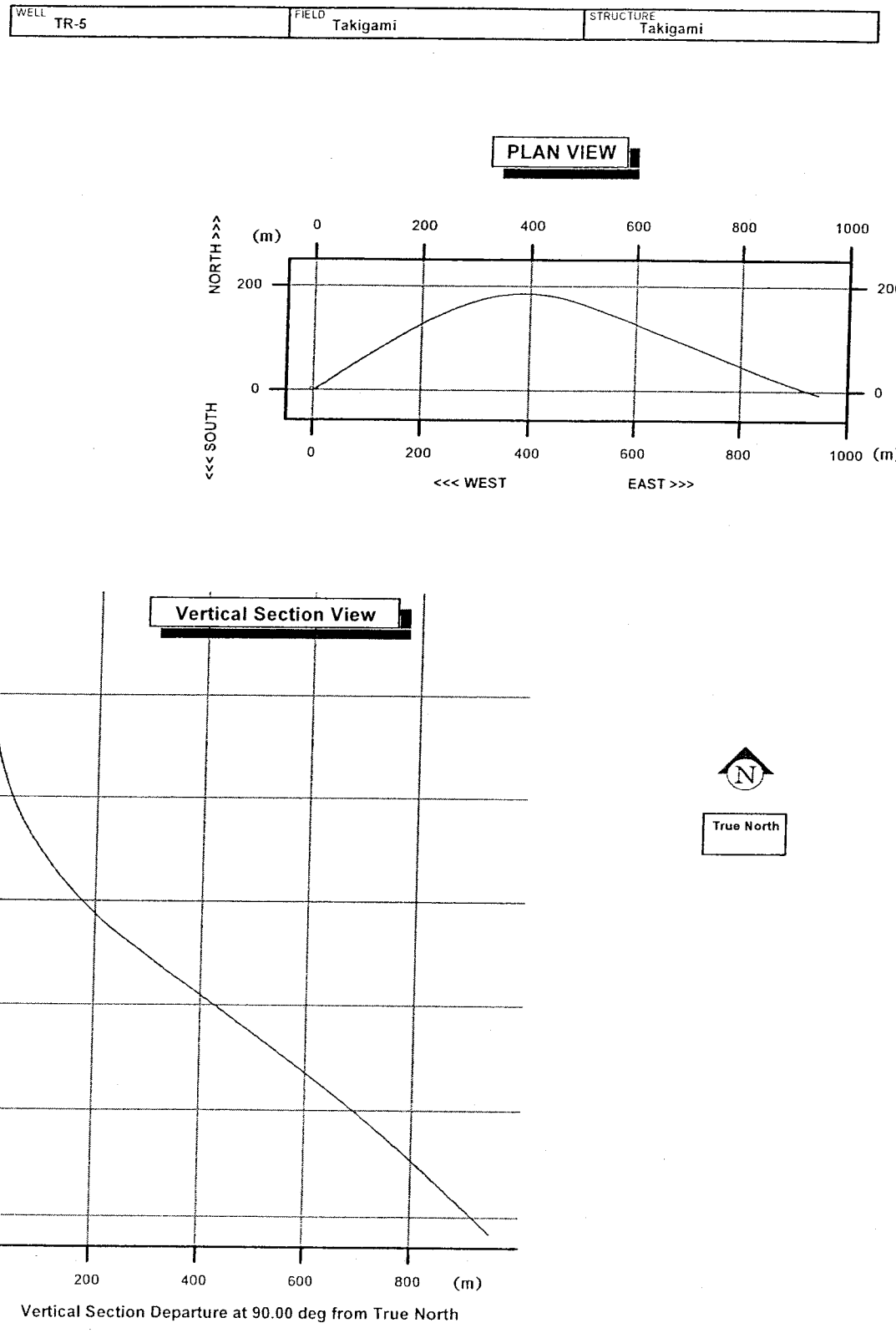

Figure 1. Actual Directional Plots of TR-5

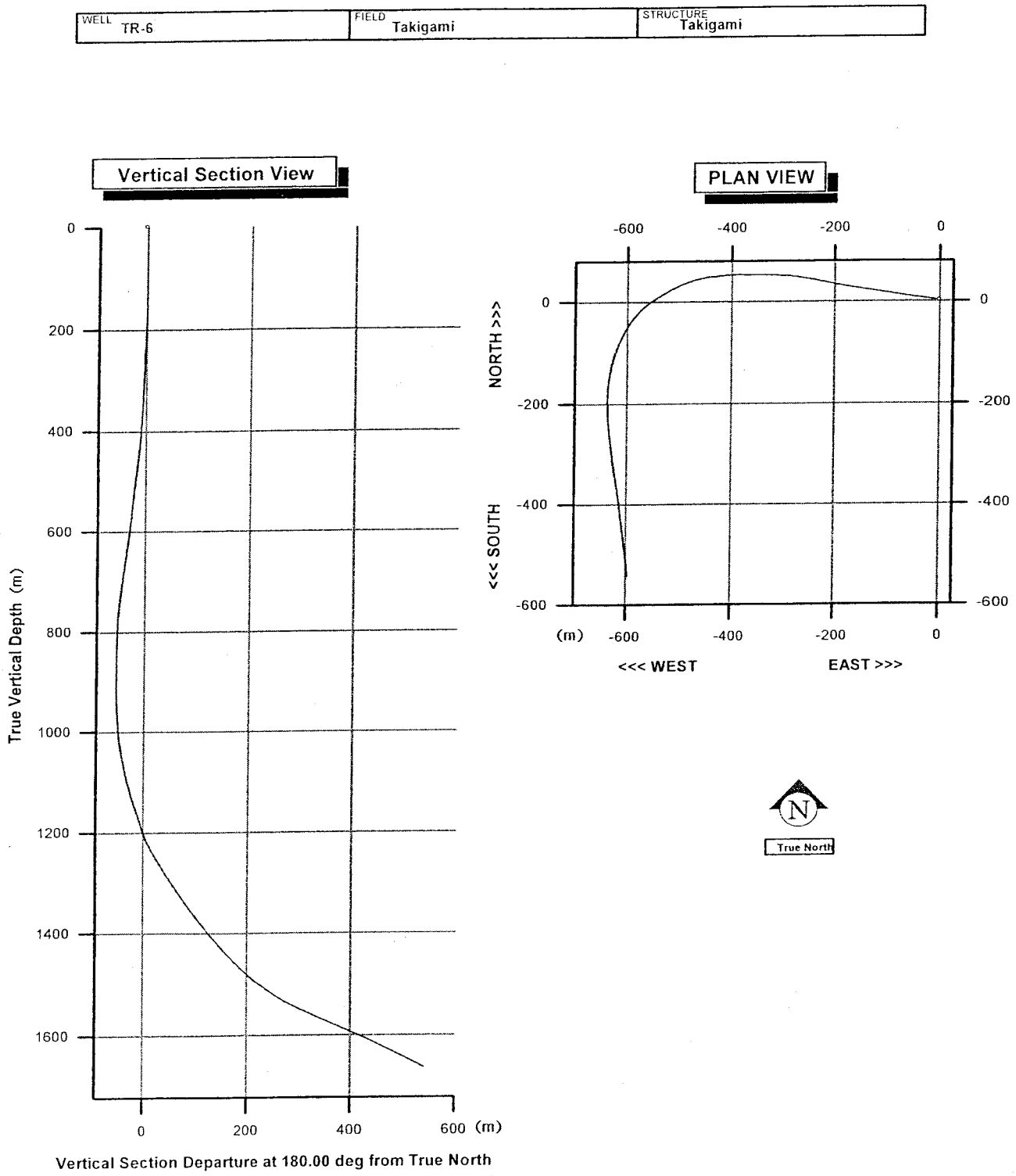

Figure 2. Actual Directional Plots of TR-6

Table 2. Comparison of High rpm Motor and High Torque Motor

Bit ／ Depth	Item	High rmp Motor(TT-22)	High Torque Motor(TR-1~6S)
17 1/2" 150~900m (Injection Area)	Weight on bit (ton)	7 ~ 12	12 ~ 22
	Penetration rate (m/hr)	3 ~ 6	5 ~ 12

Table 3. Comparison of Drilling Progress between Old System and New System

Well	Depth	Days	Drilling	LC	Casing	Test	Others	Remarks
TR-4	1540m	34	16.5	4	6.5	6.5	4	·unit : day ·LC : Lost circulation ·Test: Injection test and E-log ·Rig up & down were excluded
TR-5	1700m	49.5	26.5	6	8	8	7	
TR-22	1488m	71	48.5	7.5	9	9	6	
TR-23	1740m	58	39	0	8	8	3	

Table 4. Bit Life and Bit Cost

Item	Bit Diameter	High rpm Motor (TT-20,-22)	High Torque Motor (TR-1~6S)
Bit Life	17 1/2"	60 ~ 90m/piece	150~400m/piece
	12 1/4"	50 ~ 100m/piece	150~350m/piece
Bit Cost (Relative Evaluation)		100	66