BHA AND DRILLING PARAMETERS DESIGN FOR DEVIATION CONTROL IN DIRECTIONAL WELLS- MENENGAI EXPRIENCE

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ABSTRACT

Directional wells in geothermal exploitation are preferred to vertical wells since unlike vertical wells more than one well can be drilled on a site, they can be drilled around obstacles and the wells have higher probability of intersecting more production zones. To effectively drill the directional wells, the wells are drilled towards a target as per required inclination and azimuth. To control the direction of the well and the rate of drilling to ensure the wells are drilled safely and to completion, a proper design of the bottom hole assembly (BHA) and drilling parameters should be done. The designs to achieve the directional target vary from one well to another depending on the formation being drilled. At Menengai, directional wells are kicked-off with a mud motor in the 12¼″ hole section at a depth of 400m to about 500m. Hold the angle to a depth of 800m and then drop the angle slightly to 9⅝″ casing depth. For the entire 8½″ hole section, to the angle is dropped slightly to the total depth of the well. This paper looks at designs for the bottom hole assemblies and the drilling parameters that were used for a sample of directional wells drilled to completion. Any unforeseen challenges like getting stuck, drill string failure, high drilling torque while drilling and the probable causes of such drilling challenges. The actual directional well trajectories in comparison to the planned directional trajectories will also be considered to determine the effectiveness of the different BHA designs in deviation control. From the analysis of the designs, a proper BHA design will be proposed for each of the hole sections while kicking off, holding angle, dropping the angle and building the angle. The paper uses data from 2 directional wells, MW21A and MW09B. The BHA's used while drilling the 2 wells will be analyzed for their effectiveness in the Menengai formation.

1.0 INTRODUCTION

Directional drilling allows for drilling of a number of wells on the same well pad. Directional drilling reduces the cost of generation by making it possible to have a common pipeline to the generating unit serving several wells on the same well pad (Ngugi 2002). While drilling directional wells, having established the drilling target and the casing setting depths, the dimensional geometric shape of the well needs to be determined. Typically this will be either a 'J' or an 'S' shaped well profile. The more simple 'J' well shape is normally comprised of an initial vertical section to the 'kick-off' point (KOP); followed by a curve of constant radius determined by the "rate of build" to the end of build (EOB), following by a straight section hole at a constant angle from the vertical: (final drift angle)

The 'S' well shape is normally comprised of an initial vertical section to the KOP; followed by a 'build section' with a curve of constant radius; following by a straight section hole at a constant angle from the vertical: (at the maximum drift angle); the drill bit is then allowed to fall (from the start of fall point (SOF) at a constant 'rate of fall' to the final drift angle, at the end of fall point (EOF); followed by a straight of hole

with the drift angle being maintained at the final angle of inclination (Hole 2006). Figure 1, depicts a typical 'S shaped' well which are the typical directional wells drilled in Menengai.

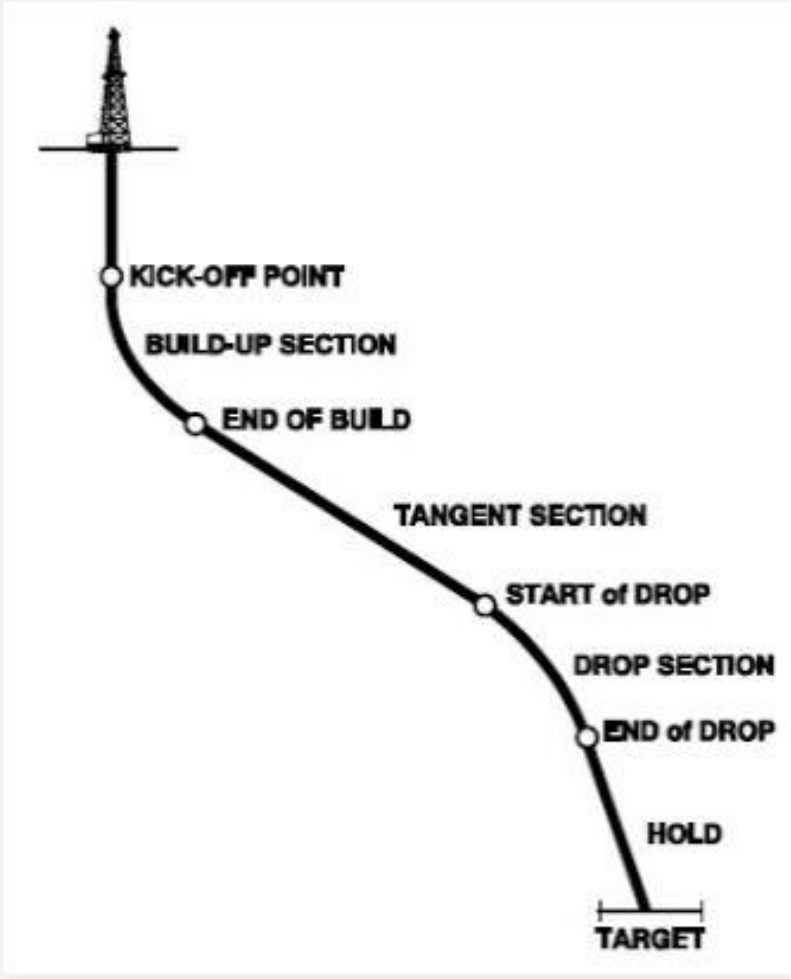

Figure 1: Menengai directional well design

A well plan is derived from the geology information provided. The well plan comprises; the total depth of the well, maximum torque and drag limitations, high dogleg severity in the build section of the well and high torque and drag for the deeper section of the hole, the formations through which the build section must pass as high build up rate is not achievable in soft formations (Siamento Z. and Thorhallsson S. 2011)

2.0 DRILLING THE DIRECTIONAL WELLS

2.1 Drilling MW21A

MW21A is located within the central Menengai stress transfer zone. The well is targeted to tap the NE-SW trending faults, with an azimuth of 130°, the target depth of 2500m with a planned displacement at TD of 500m (MW21 Prognosis). The well was kicked off at 402m and drilled with steerable BHA to 606m. At this depth it was planned to run a rotary building assembly to a depth of 800m with a locked up BHA with a near bit stabilizer and two string stabilizers, and then run a pendulum BHA to drop the angle slightly to TD depth for this section of hole. Survey at a depth of 870m, indicated the well was off track, and a steerable BHA had

to be run to correct both the inclination and the azimuth. A mud had to be used to the 9⅝″ casing depth at 1155m. The 8½″ hole section was drilled initially with rotary pendulum BHA, but later a steerable BHA was run to correct the azimuth. Stuck condition was experienced at 1430m and well terminated at 2090m due to high torque. This was attributed to severe doglegs arising from the corrections while drilling.

2.2 BHA Configurations, MW21A

The BHA configurations from Target well Control reports while drilling the well are in Table 1 below;

Table 1: MW21A BHA Configurations

BHA No.	BHA Configuration
BHA 1	12 1/4" TRICONE, 8" V'DRILL LSX MOTOR 1.15 ABH, 12/1/8" SLEEVE STAB, cw ported float, 11 3/4" NM STRING STAB, UBHO, 2x 8" NMDCs, 6x 8" DCs, X/O,5x 6 1/2" DCs, 6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 2	12 1/4" TRICONE, 8" V'DRILL LSX MOTOR 1.15 ABH, 12/1/8" SLEEVE STAB, cw ported float, 11 3/4" NM STRING STAB, UBHO, 2x 8" NMDCs, 6x 8" DCs, X/O,5x 6 1/2" DCs6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 3	12 1/4" TRICONE, 12 7/32" NEAR BIT STAB, cw non ported float and Totco ring, 8" NMDC12 7/32" NM STRING STAB, 8" NMDC, 11 1/2" NM STRING STAB, 6x 8" DCs, X/O, 5x 6 1/2" DCs, 6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 4	12 1/4" TRICONE, 12 7/32" NEAR BIT STAB, cw non ported float and Totco ring, 8" NMDC12 7/32" NM STRING STAB, 8" NMDC, 11 1/2" NM STRING STAB, 6x 8" DCs, X/O, 5x 6 1/2" DCs, 6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 5	12 1/4" TRICONE, 12 7/32" NEAR BIT STAB, cw non ported float, 8" DC cw Totco ring, 8" NMDC12 7/32" NM STRING STAB, 8" NMDC, 11 1/2" NM STRING STAB, 6x 8" DCs, X/O, 5x 6 1/2" DCs, 6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 6	12 1/4" TRICONE, 8" V'DRILL LSX MOTOR 1.15 ABH, 12/1/8" SLEEVE STAB, cw non ported float, 11 1/2" NM STRING STAB, UBHO, 2x 8" NMDCs, 6x 8" DCs, X/O, 5x 6 1/2" DCs6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 7	12 1/4" TRICONE, 8" V'DRILL LSX MOTOR 1.15 ABH, 12/1/8" SLEEVE STAB, cw non ported float, UBHO, 2x 8" NMDCs, 6x 8" DCs, X/O, 5x 6 1/2" DCs,6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP
BHA 8	12 1/4" PDC, 12 7/32" NB STAB, cw non ported float / totco ring, 8" NMDC, 11 1/2" STRING STAB8" NMDC, 12 7/32" NM STRING STAB, 6X 8" DC, X/O, 5x 6 1/2" DCs,6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 9	12 1/4" TRICONE, 12 7/32" NB STAB, cw non ported float / totco ring, 8" NMDC, 12 7/32" NM STRING STAB8" NMDC, 11 1/2"" STRING STAB, 6X 8" DC, X/O, 5x 6 1/2" DCs,6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 10	12 1/4" TRICONE, 12 7/32" NB STAB, cw non ported float / totco ring, 8" NMDC, 12 7/32" NM STRING STAB8" NMDC, 11 1/2"" STRING STAB, 6X 8" DC, X/O, 5x 6 1/2" DCs,6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP, 5"DP
BHA 11	12 1/4" TRICONE, 8" V'DRILL LSX MOTOR 1.15 ABH, 12/1/8" SLEEVE STAB, cw non ported float, UBHO, 2x 8" NMDCs, 6x 8" DCs, X/O, 5x 6 1/2" DCs,6 1/2" JARS, 3x 6 1/2" DCs, 12x 5" HWDP
BHA 12	81/2" TRICONE BIT, 6 1/2" BIT SUB, 9x 6 1/2" DC's, 12x 5" HWDP, 5" DP TO SURFACE
BHA 13	8 1/2" TRICONE BIT, 8 7/16" NB STAB, 6 1/2" NMDC, 8 13/32" STRING STAB, 6 3/4" NMDC8 1/4" STRING STAB, 5 x 6 1/2" DC's, 6 1/2" HYDRAULIC JAR, 3x 6 1/2" DC's, 12 x 5" HWDP, 5" DP TO SURFACE
BHA 14	8 1/2" RC BIT, 6 3/4" LSX AIR MOTOR 1.15 ABH SLICK, 8 1/2" R/ REAMER, 6 3/4" FLOAT SUB, 6 1/2" UBHO SUB, 6 1/2" NMDC, 6 3/4" NMDC, 5 x 6 1/2" DC,s, JAR, 3 x 6 1/2" DC,s, 12 x HWDP5" G105 DP TO SURFACE
BHA 15	8 1/2" RC BIT, 6 3/4" LSX AIR MOTOR 1.15 ABH 8 1/8" SLV, 8 1/2" R/ REAMER, 6 3/4" FLOAT SUB, 6 1/2" UBHO SUB, 6 1/2" NMDC, 6 3/4" NMDC,8 1/2" R/REAMER 5 x 6 1/2" DC,s, JAR, 3 x 6

	1/2" DC's, 12 x 5 " HWDP,5" G105 DP TO SURFACE
BHA 16	8 1/2" RC BIT, 6 3/4" LSX AIR MOTOR 1.15 ABH 8 1/8" SLV, 8 1/2" R/ REAMER, 6 3/4" FLOAT SUB, 6 1/2" UBHO SUB, 6 1/2" NMDC, 6 3/4" NMDC, 8 13/32" STRING STAB, 5 x 6 1/2" DC,s, JAR, 3 x 6 1/2" DC's, 12 x 5 " HWDP,5" G105 DP TO SURFACE

2.3 MW21A Drilling and Survey Data

The drilling parameters and survey results while using the above BHA's is shown in Table 1 Survey data shows data at the depth when the BHA was pulled out. Data was derived from MW21A well completion report.

Table 2: MW21A Drilling and Survey Data

MW21A DIRECTIONAL DRILLING DATA											
Hole Scn.- BHA	**From (m)**	**To (m)**	**Interval (m)**	**WOB (Klbs)**	**ROP (m/hr)**	**RPM**	**Remarks**	**Actual Survey Data**		**Planned Data**	
								Incl. (°)	**Azi. (°)**	**Incl. (°)**	**Azi. (°)**
12¼″-1	405	577	172	10 - 15	0.9	50	Steerable	17.9	134.5	17.5	130
12¼″-2	577	606	29	10 - 15	1.2	40	Steerable	18.1	135.8	18.1	130
12¼″-3	606	644	38	15	0.9	90	Rotary hold	17.3	135.8	18.1	130
12¼″-4	644	675.5	31.5	5 - 15	2.2	30 - 90	Rotary hold	14.1	137.6	18.1	130
12¼″-5	675.5	741	65.5	10 - 15	3.2	60	Rotary build	12.9	138.1	18.1	130
12¼″-6	741	796	55	5 - 15	2.8	40	Steerable	11.9	126	18.1	130
12¼″-7	796	968	172	10	2.3	40	Steerable	27.1	142.3	18.1	130
12¼″-8	968	1016	48	10	1.5	40	Steerable	26	143.9	18.1	130
12¼″-9	1016	1043	27	15	1.0	100	Rotary	26.3	142.9	18.1	130
12¼″-10	1043	1059.7	16.7	20	1.5	40 - 60	Rotary	34.8	134.5	18.1	130
12¼″-11	1059	1155	96	15 - 20	0.9	40	Steerable	38.6	131.9	18.1	130
8½″-1	1155	1168	13	15	0.9	40	Rotary	38.8	131.9	18.1	130
8½″-2	1168	1226	58	15 - 20	1.1	70 - 80	Rotary	39.9	134.3	18.1	130
8½″-3	1226	1415.7	189.7	10 - 20	2.8	60	Steerable	32.1	136.9	18.1	130
8½″-4	1415.7	1639.2	223.5	10 - 20	3.0	60	Steerable	14.5	138	18.1	130
8½″-5	1639.2	2080	440.8	18 - 20	2.8	50 - 60	Steerable	9.7	122.3	18.1	130

2.4 Drilling MW09B

MW09B is a direction well with an azimuth of 215°, located in the dome area, central caldera part of the Menengai field. The well was planned to be kicked off at 370m, build an angle to have sufficient separation at production casing from vertical well MW09 and then drop the inclination angle gradually to TD.

The well was kicked off with a steerable BHA at 370m, drilled ahead while both sliding and rotating to 578m, after achieving desired inclination, POOH the steerable BHA to run a lock BHA to maintain the angle to 878m, before drilling ahead with a pendulum dropping assembly to production casing depth at 1181m.

For the 8½″ hole section, a rotary dropping assembly was used to drill to 1399m, before running a holding assembly to maintain the angle for a drilled depth of 250m, then a pendulum dropping assembly to the TD of the well at 2063m.

2.5 BHA Configurations, MW09B

The BHA configurations (Target Well Control reports) that were used to drill the well are shown in Table 3:

Table 3: MW09B BHA Configurations

BHA No.	BHA Description
BHA 1	12 1/4" INSERT BIT, 8" VECTORDRILL LSX MOTOR W/0.78 BEND, 11 1/2" STEEL STRING STAB, 8" FLOAT SUB, 8" UBHO SUB, X2 8" NMDC, X6 8" DC, X/O, X6 6 1/2" DC, X12 5" HWDP
BHA 2	12 1/4" INSERT BIT, 12 7/32" NB STAB c/w FLOAT VALVE, 1x 8" DC, 12 1/8" STEEL STRING STAB, 8" UBHO SUB, 2x 8" NMDC, 11 1/2" STEEL STRING STAB, 6x 8" DC, X/O, 6x 6 1/2" DC, 12x 5" HWDP
BHA 3	12 1/4" INSERT BIT, 8" BIT SUB c/w FLOAT VALVE, 8" PDC, 12 1/8" STEEL STRING STAB, 8" UBHO SUB, 2x 8" NMDC, 11 1/2" STEEL STRING STAB, 6x 8" DC, X/O, 6x 6 1/2" DC, 12x 5" HWDP
BHA 4	12 1/4" INSERT BIT, 8" BIT SUB c/w FLOAT VALVE, 8" PDC, 12 1/8" STEEL STRING STAB, 8" UBHO SUB, 2x 8" NMDC, 11 1/2" STEEL STRING STAB, 6x 8" DC, X/O, 6x 6 1/2" DC, 12x 5" HWDP
BHA 5	8 1/2" ROCK BIT. BIT SUB(FLOAT AND TOTCO) NMDC, PONY NMDC, 8 1/2" STAB, 6 1/2 ", 8 1/4" STAB, 6 X 6 1/2 DC , 12 X 5 HWDP
BHA 6	8 1/2" ROCK BIT, 8 7/16" NB STAB (FLOAT AND TOTCO) NMDC, PONY NMDC, 8 1/2" STAB, 6 1/2 " DC, 8 1/4" STAB, 6 X 6 1/2 DC , 12 X 5 HWDP
BHA 7	8 1/2" ROCK BIT, BIT SUB(FLOAT AND TOTCO) NMDC, PONY NMDC, 8 1/2" STAB, 6 1/2 " DC, 8 1/4" STAB, 6 X 6 1/2" DC , 6 X 5" HWDP, JAR, 5 X 5" HWDP

2.6 MW09B Drilling and Survey Data

Table 2 shows MW09B drilling and survey data (MW09B well completion report). Survey data is survey at the depth the BHA was pulled out.

Table 4: MW09B Drilling and Survey data

MW09B DIRECTIONAL DRILLING DATA											
Hole Scn-BHA	From (m)	To (m)	Interval (m)	WOB (Klbs)	ROP (m/hr)	RPM	Remarks	Actual Survey		Planned Data	
								Incl. (°)	Azi (°)	Incl. (°)	Azi (°)
12¼"- 1	370	578.5	208.5	10 - 22	1.8	50	Steerable	22.6	224.6	18.6	215.6
12¼"- 2	578.5	880	301.5	10 - 13	3.8	60 - 100	Rotary hold	24.5	225.5	23.39	214.6
12¼"- 3	880	1181.8	301.8	20 - 30	5.0	80	Rotary hold	28	219.8	27.6	214.6
8½" - 1	1181.8	1379.6	197.8	15 - 25	2.4	65	Rotary Pendulum	25.5	216.9	23.39	214.6
8½" - 2	1379.6	1638.7	259.1	20 - 25	4.6	80 - 90	Rotary hold	23.9	217.2	18	214.6
8½" - 3	1638.7	2063	424.3	20 - 25	8.3	80	Rotary Pendulum	18.4	218.8	16	214.6

3.0 RECOMMENDATIONS ON BHA DESIGN AND DRILLING PARAMETERS

From the drilling of the two directional wells, its recommended that four (4) well designed BHA's are sufficient to drill directional wells at Menengai from kick off to completion of the well. This will save trip time and increase rate of penetration while drilling and hence reducing significantly the costs of directional wells. The recommended BHA's are;

I. Steerable BHA for kicking off the well for the build section
II. Lock up 12¼″ BHA for the hold section
III. 12¼″ Pendulum BHA to be run at the end of the hold section to production casing
IV. 8½″ Dropping assembly for the main hole section

3.1 Steerable BHA

The steerable BHA should comprise of a motor with a stabilizer sleeves a bit under gauge (12-1/8″). The motor should have a bend of between 0.6-0.8°, with an 11½″ string stabilizer run above the motor. Drilling will be by both sliding and rotating guided by the specifications of the motor, formation and the rest of the BHA configuration. Time drilling could be applied to ensure desired well trajectory is achieved. Well should be able to get the desired trajectory at a depth of 580m, after kicking off between 400-450m.

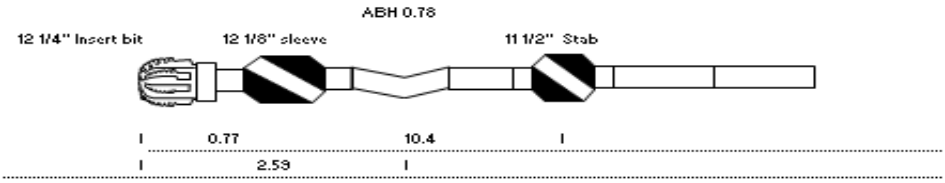

Figure 2: 12¼″ Steerable BHA

3.2 Lock up Assembly- 12¼″ Hole

This BHA should hold both the inclination and azimuth angles. Its desired to run a near bit stabilizer and two string stabilizers with the outside diameters decreasing slightly all the way from the bit to the last stabilizer up the BHA. Parameters to be used with this BHA should be determined by a performing a drill off test. High weights should be used with moderate rotation speeds of between 50-60 revolutions per minute. One bit run is sufficient to drill the hold section that could be between 200-400 metres.

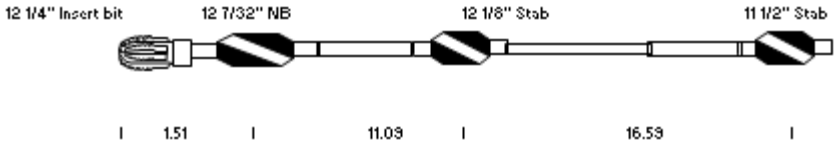

Figure 3:12¼″ Rotary lock up assembly

3.3 12¼″ Pendulum Assembly

This BHA mainly comprises of two string stabilizers whose positioning varies. The BHA is run after at the end of hold section for minor corrections to be done before the production casing. If a slight build in angle is required more bit weight is used while if a slight drop is required, less weight will be applied. More rotation speed of between 80-100 revolutions per minute can be used with this BHA configuration

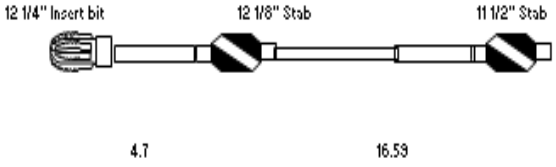

Figure 4: 12¼″ Pendulum BHA

3.4 Dropping Assembly-8½″ hole

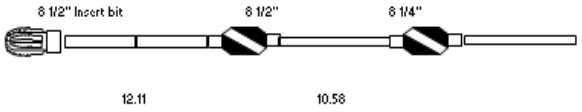

Figure 5: 8½″ Dropping BHA, 8½″

The configuration is similar pendulum BHA for the previous hole section. For this section, the angle should drop slightly all the way to the total depth of the well. Weight of up to 80% of the BHA weight below the jar should be used with high rotation speeds of 100 revolutions per minute.

The positioning of the stabilizers will be determined by the surveys taken during drilling and changed during bit change.

4.0 CONCLUSION

MW09B which was drilled after MW21A had far less BHA runs after lessons learnt while drilling MW21A were incorporated while designing the directional drilling program for MW09B. With more studies on the effective design of the directional well, few trips will be done for BHA change, maximize bit life and run the motors for far less drilling intervals thus reducing the costs of drilling directional wells.

Drilling of successive directional wells has taken fewer resources with drilling challenges much reduced due to experienced gained drilling in the field. As more directional wells are drilled, better designs for the BHA and drilling parameters will be incorporated to reduce the drilling days, drill wells more safely to the desired targets.

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