LV-2016-110

Landsvirkjun

Krafla – Well K-41

Phase 3: Drilling for Production Part

down to 1313 m

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ÍSOR
ÍSLENSKAR ORKURANNSÓKNIR

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Key page

Landsvirkjun

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Co operators:	

Abstract:

Well K-41 is a directionally drilled production well for the Krafla power plant. It is sited on the same drill pad as wells KJ-15, KJ-32 and KJ-33. The well pad is west of Hveragil gully, and the aim of the drilling was to penetrate fractures associated with the Hveragil fracture zone and in the Vesturhlíðar area further east. This report addresses the drilling history and data acquisition of the 3rd phase. This includes subsurface mapping of the lithology and alteration in the well based on drill-cuttings, estimating subsurface temperatures from key alteration minerals and relating drill-data and geophysical logs of lithology to constrain formation boundaries and identify potential aquifers. K-41 was pre-drilled with a 21" drill bit for 18⅝" surface casing to 100 m and with 17½" drill bit for 13⅜" anchor casing down to 293.5m. The 2nd phase was drilled with 12" bit for 9⅝" casing to 1039 m and the 3rd phase was drilled with a 8½" bit for a 7" liner down to 1313 m. The stratigraphy of phases 3 in well K-41 is composed of basaltic intrusions and basaltic hyaloclastite formations. The alteration in this phase is generally high. Many minerals have disappeared, such as zeolites, fine grained clays and laumontite. The main alteration minerals in this phase are quartz, epidote, wollastonite and coarse grained clays. A total loss of circulation occurred at 1142 m while penetrating a soft tuff formation. After this, the rest of the well was drilled in a total loss of circulation. The main feed zones in the well are located at 1120, 1140, 1230, 1245 and 1275 m. The final injection test indicated an injectivity index of 11 (L/s)/bar.

Key words:

Krafla, well K-41, geothermal field, high temperature, Power generation, brine, steam, geological log, feed zones, Sleipnir, Landsvirkjun, Iceland Drilling, ÍSOR

ISBN no.:

UWI (Unique Well Id): B60411

Approved by Landsvirkjun's project manager

Project manager's signature	Reviewed by
Magnús Ólafsson	Sigvaldi Thordarson, Benedikt Steingrímsson

Ágrip

Hola K-41 er stefnuboruð vinnsluhola fyrir orkuverið í Kröflu. Holan er á sama borplani og holur KJ-15, KJ-32 og KJ-33. Borplanið er vestur af Hveragili og markmið borunarinnar er að bora í gegnum sprungur sem tengjast sprungukerfinu í Hveragili og Vesturhlíðum lengra til austurs. Þessi skýrsla lýsir borsögunni, borgögnum og gagnavinnslu 3. áfanga. Með svarfskoðun á borstað er gerð grein fyrir jarðlögum og ummyndun bergs með tilliti til ummyndunarsteinda sem gefa upplýsingar um berghita. Ennfremur er gefið yfirlit um borgögn úr sjálfvirku skráningarkerfi Sleipnis, sem og borholumælingum sem gerðar voru á meðan borverkinu stóð. Öll þessi gögn eru notuð til frekari túlkunar, m.a. til þess að greina jarðlagamót og hugsanlegar æðar í holunni. K-41 var forboruð með 21" borkrónu fyrir 18⅝" yfirborðsfóðringu niður að 100 m og með 17½" krónu fyrir 13⅜" öryggisfóðringu niður á 293,5 m dýpi. 3. áfangi var boraður með 12" krónu fyrir 9⅝" vinnslufóðringu niður á 1039 m dýpi og með 8½" krónu fyrir 7" leiðara. Jarðfræðin í þessum áfanga sýnir að jarðlögin samanstanda af basískum innskotum og móbergi, þ.e.s. breksíu og túffi. Ummyndunarstigið er frekar hátt í áfanganum. Þónokkrar steindir hafa nú horfið, eins og zeólítar, fínkorna leir og laumontít. Helstu ummyndunarsteindir í 3. áfanga eru kvars, epidót, wollastónít og gróffjaðra leir. Algert skoltap varð á um 1140 m dýpi þegar borað var í gegnum mjúkt túfflag. Holan var svo kláruð í algeru skoltapi.

Table of contents

Tables

Figures

1 Introduction

Drilling of well K-41 in the Krafla geothermal field was conducted by Iceland Drilling (Jarðboranir) for Landsvirkjun. Well K-41 is drilled from the same well pad as the 2097 m deep KJ-15 drilled in 1980 (Gautason et al., 2016), the 1875 m KJ-32 drilled in 1998 (Guðmundsson et al., 1998) and the 2011 m deep KJ-33 drilled in 1999 (Guðmundsson et al., 1999). The wells are located west of the Hveragil gully. Well KJ-15 is vertical but the others are directionally drilled, KJ-32 towards „north“ but KJ-33 towards northeast and K-41 towards east-northeast into Vesturhlíðar production field in Krafla (Figure 1). The direction of K-41 was planned to be 70° (Thordarson, 2015b) and the well drilled to at least 1700 m MD (Thordarson, 2015a). The trajectory of K-41 was planned to find permeability connected to fractures under explosion craters and CO_2 flux anomaly from the soil in Vesturhlíðar of Krafla (Mortensen, 2013). The well was planned to be at good distance from existing wells, such as KT-40, KJ-34 and KJ-20. The well will, however, not be drilled too far east under Krafla mountain and not much deeper than 2000 m to avoid HCl-rich and corrosive fluids (Mortensen, 2013).

Table 1. *Further details of K-41. Coordinates are in ISNET93*

Well name	Unique ID	East (X)	North (Y)	Elevation (m)	Planned depth (m)
K-41	58041	602984	580998	571	1700–2000

To reach the target zones the direction of the well was set at 70 ±5° : inclination 35 ±3° (310–1000 MD) and 70°± 5°: inclination 35±15° (1600–2000 MD), with reference to true north. The kick-off was planned 20 m below the anchor casing, at 310 m. The angle built up was planned to be 2,5° with the final inclination of 35°.

Depths in this report refer to measured depth (MD) relative to Sleipnir´s rig floor (5.64 m above ground level), except if otherwise is stated.

The drilling contractor, Iceland Drilling (Jarðboranir), carried out the drilling operations with Landsvirkjun monitoring the work. Iceland GeoSurvey (ÍSOR) managed cutting inspection, geophysical logging, gyro surveying and geothermal consulting.

The planned design of well K-41 (Figure 2) and the division of the drilling into section was as follows:

- Phase 0: Pre-drilling for the surface casing with 21" drill bit to ~90 m depth. Cased with 18⅝".
- Phase 1: Drilling for the anchor casing with 17½" drill bit down to ~290 m depth. Cased with 13⅜".
- Phase 2: Drilling for the production casing with 12¼" drill bit down to ~1100 m depth. Cased with 9⅝".
- Phase 3: Drilling of the production part with 8½" drill bit to 1700–2000 m depth, cased with 7" perforated liner.

This report is about the 3rd and the final phase of the drilling of K-41. The drilling of K-41 started on 21 July 2016 with predrilling using 21" bit down to 100 and 18⅝" surface casing followed by drilling with 17½" bit to 293.5 m depth for an anchor casing set at 292.6 m. The second phase followed with drilling with a 12¼" bit to 1039 m for the 9⅝" production casing that landed at 1031 m depth This report on the third phase presents the geological part of the drilling, including e.g. lithology, alteration and feed points, as well as the geophysical logging of the well. The report is structured into the following chapters: the *first chapter* gives an introduction. *The second chapter* reports on the drilling operations during drilling of phase 3. *The third* describes the geological strata and alteration, observed by the on-site geologist, and openings in the well. *The fourth chapter* compares well K-41 to other wells in the area. *The fifth chapter* includes the wireline loggings of phase 3, carried out by ÍSOR´s logging engineers.

The aim of this report is to document the geological- and geophysical part from the drilling of phase 3 in K-41, and present all the data collected and provide data interpretations. Appendix A contains all daily reports written by the borehole geologist during drilling operations, presenting preliminary results.

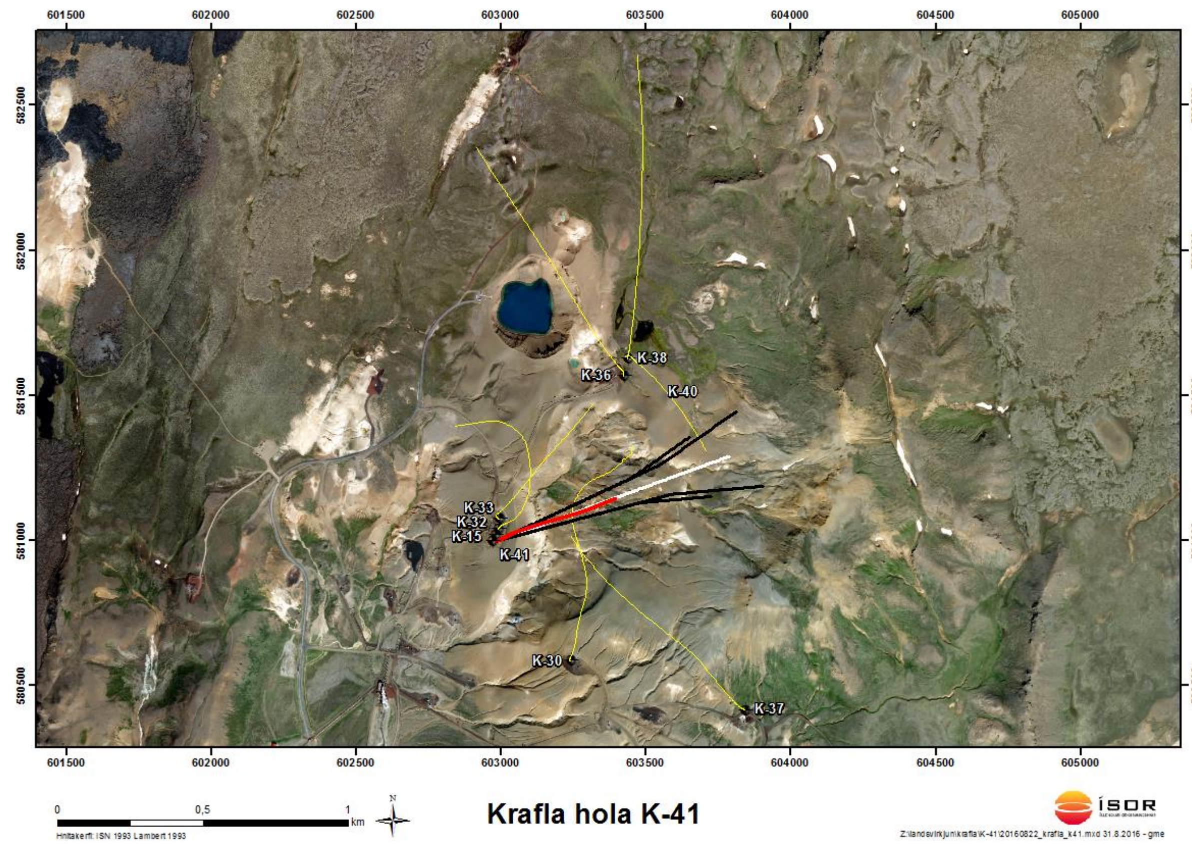

Figure 1. *The location and planned trajectory of well K-41 in Krafla.*

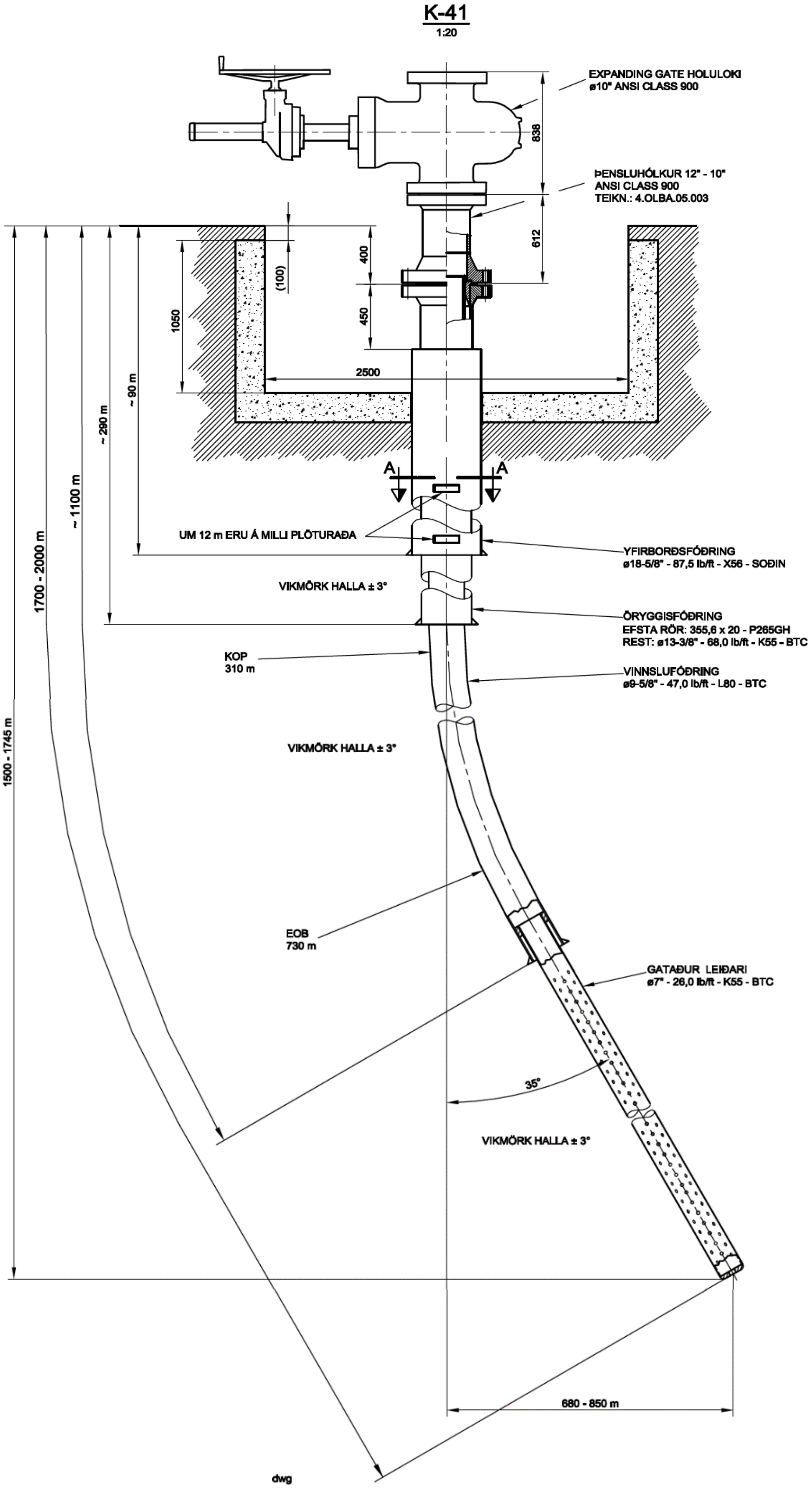

Figure 2. *Well design of well K-41.*

2 Drilling operations

2.1 Overview

Drilling operations of K-41 are divided into phases 0–3. This report only refers to phase 3, from 1039 m to 1313 m MD. Phase 3 started on Tuesday, August 16th (workday 28) and was completed Friday, August 30th (workday 42).

Sleipnir was transported to the drillpad in Krafla in July 2016. The drillpad is located south of Víti, at 571 m a.s.l. (Figure 1). After rigging up, drilling of well K-41 started July 21st and phase 0 (pre-drilling) was completed the 25th of July (workday 6). Phase 1 was completed at midnight on July 31st (workday 12) and phase 2 august 15th (workday 27) Phase 3 started on Tuesday August 16th and was completed August 30th. A new bottom hole assembly for phase 3 was run in hole August 16th (Figure 4).

Drilling with a 8½" drill bit into formation started at August 17th. The float collar was tagged at 1009 m and the casing shoe at 1031 m. The drilling for the 7" liner went on without any major problems until 1142 m where the string got stuck (August 18th, workday 30). It was stuck for 48 hours. Once the string was free at noon August 20th temperature and caliper logging was done before continuing drilling on workday 34 (August 22nd). Drilling continued to 1259 m where the string got stuck again in the morning of August 23rd. After being stuck for 24 hours, a temperature log was carried out in the string August 24th. A decision was made to let the well heat up again over night and do another temperature log the day after. Efforts to free the string continued after the logging and was successful. Once free, the string was pulled out of hole and a simpler bottom hole assembly was run in hole in order to drill further beyond the deepest feed zone. Drilling was stopped at 1313 m on workday 40. The liner is sitting at the bottom of the well, at 1309 m, the top of the liner is at 1006.9 m.

An overview of the drilling and details of the casing depths are shown in Table 2. Figure 3 and Table 3. show the drilling progress of well K-41 throughout the work.

Table 2. *Drilling and casing depths in well K-41.*

Drill-Rig	Phase	Drill bit	Depth (m)	Depth Reference	Casing Type	Casing Depth
Sleipnir	0	21"	100	Sleipnir RF*	18⅝"	99.7
Sleipnir	1	17½"	293.5	Sleipnir RF*	13⅜"	292.6
Sleipnir	2	12¼"	1039	Sleipnir RF*	9⅝"	1031
Sleipnir	3	8½"	1313.0	Sleipnir RF*	7"	1006.9-1309

** RF = rig floor. Sleipnir´s rig floor is 5.64 m above ground level.*

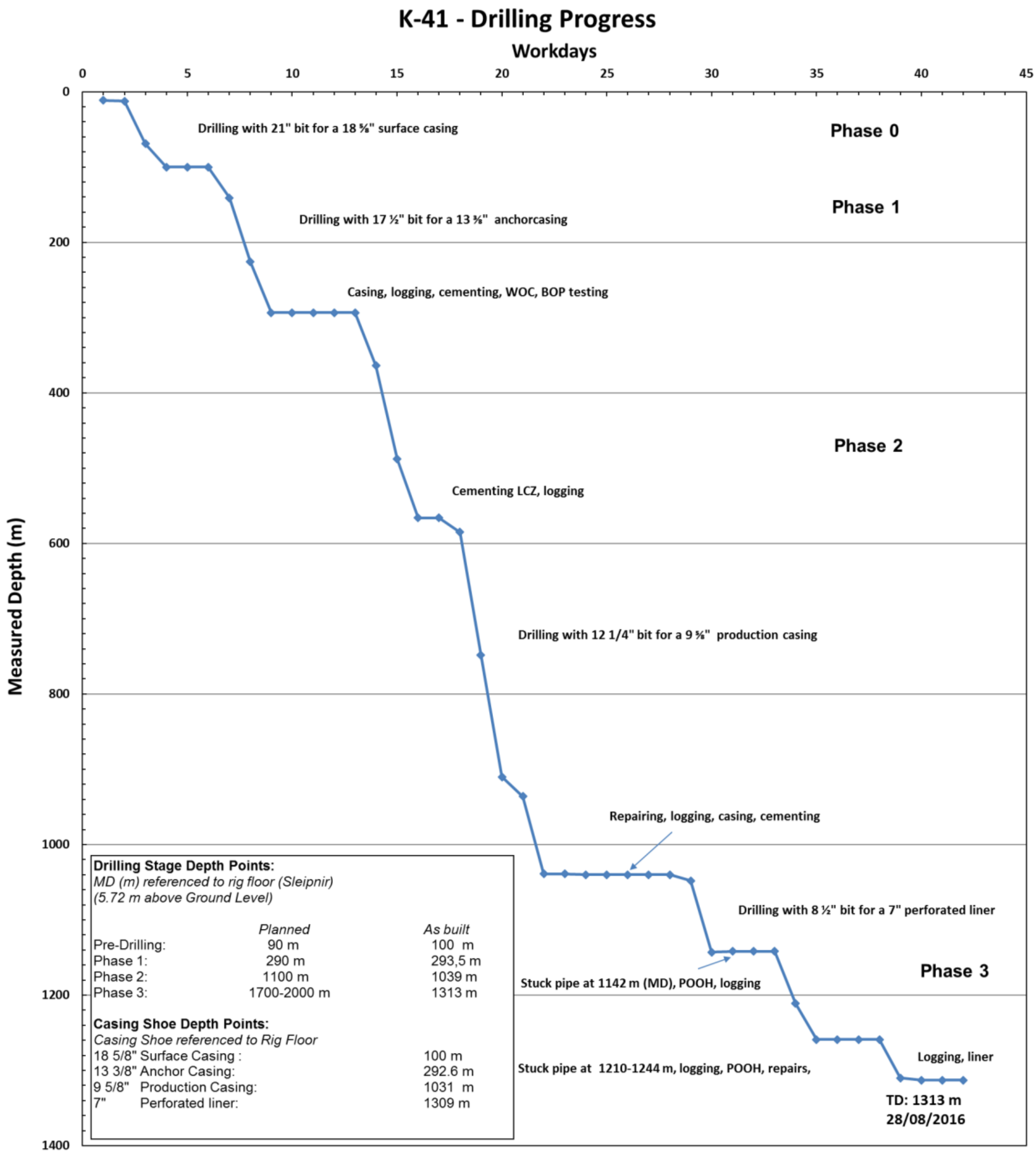

Figure 3. *Drilling progress of well K-41.*

Table 3. *Drilling progress of well K-41.*

	Date	Workday	Drilled (m)	Time (hrs)	Average ROP (m/hr)	MD (m)	Comment
Phase 3	14.8.2016	26	0,0	0,00	-	1040	
	15.8.2016	27	0,0	0,00	-	1040	
	16.8.2016	28	0,0	0,00	-	1040	
	17.8.2016	29	8,0	1,25	0,2	1048	
	18.8.2016	30	95,0	11,00	0,1	1143	
	19.8.2016	31	0,0	0,00	-	1142	Stuckpipe
	20.8.2016	32	0,0	0,00	-	1142	Stuckpipe
	21.8.2016	33	0,0	0,00	-	1142	Stuckpipe
	22.8.2016	34	69,0	10,50	0,2	1211	
	23.8.2016	35	48,0	6,75	0,1	1259	
	24.8.2016	36	0,0	0,00	-	1259	Stuckpipe
	25.8.2016	37	0,0	0,00	-	1259	Stuckpipe
	26.8.2016	38	0,0	0,00	-	1259	Stuckpipe
	27.8.2016	39	51,0	11,50	0,2	1310	
	28.8.2016	40	3,0	0,50	0,2	1313	
	29.8.2016	41	0,0	0,00	-	1313	
	30.8.2016	42	0,0	0,00	-	1313	

2.2 Drilling for the perforated liner (7") - Phase 3

Drilling into formation commenced in the evening of August 17th. When a depth of 1046 m had been reached a gyro survey was carried out. Drilling continued from midnight where a total of 95 m were drilled with 7–8 ton WOB, pressure of 92–96 bar, torque of 820–860 daNm and 40 L/s pumping. At 8:00 on August 18th no loss of circulation was measured until reaching 1123 m where losses of 17 L/s were observed at 35 L/s pumping. After drilling down to 1142 m, the circulation loss was 22 L/s loss. During circulation, before inserting the next drill pipe, mud pressure dropped and the drill string got stuck resulting in higher torque (Figure 5).

As seen in Figure 5 the rate of penetration during drilling was high and the circulation time between drill pipes long. As the drill string got stuck none of the injected water returned to surface. According to the drilling parameters shown in Figure 5, the drill string got stuck during circulation at ~09:57. During drilling through 1116 m, weight on bit decreased from 8 tons to 3 tons and for some reason the injection rate was decreased from 40 L/s to 35 L/s with consequent drop in mud pressure. Cutting analysis shows brecciated and less altered lithology above 1116 m. At that depth the lithology changed abruptly to more tuffaceous and altered breccia. The cuttings became smaller, more altered and oxidized.

In order to try to get the string free, an air compressor was used to pump down air, as well as injecting water and polymer pills. Some movement of the string was observed, mostly a downward motion. After trying to get free for almost 48 hrs, the string finally got loose at noon on August 20th. The crew then started to pull out of hole.

ICELAND DRILLING	**BHA Graphical Report** **Rig: Sleipnir** Job No: 28178	**Iceland Drilling** **Rig No: 28000** Job Name: K 41

BHA No:	4	**Date In:**	16-ágú.-16 22:23	**Depth In (m):**	1.039,0
		Date Out:		**Depth Out (m):**	

XO, Length: 0,76 m
OD: 162,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: 529
144,79 m from top to Bit

HWDP, Length: 9,48 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST823
144,03 m from top to Bit

HWDP, Length: 9,49 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST822
134,55 m from top to Bit

HWDP, Length: 9,49 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST867
125,06 m from top to Bit

HWDP, Length: 9,48 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST852
115,57 m from top to Bit

HWDP, Length: 9,49 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST871
106,09 m from top to Bit

HWDP, Length: 9,48 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST861
96,60 m from top to Bit

JAR, Length: 5,92 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: 651622-00
87,12 m from top to Bit

HWDP, Length: 9,49 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW866
81,20 m from top to Bit

HWDP, Length: 9,46 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW859
71,71 m from top to Bit

HWDP, Length: 9,47 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
hw
S/No: HW828

HWDP, Length: 9,49 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW816
52,78 m from top to Bit

HWDP, Length: 9,48 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW814
43,29 m from top to Bit

DC, Length: 9,35 m
OD: 168,000 cm, ID: 73,000 cm
Top Thread 4.5IF
S/No: 774
33,81 m from top to Bit

STAB, Length: 2,07 m
OD: 168,000 cm, ID: 70,000 cm
Top Thread 4.5IF
8 1/4
S/No: ST133

MWD, Length: 10,32 m
OD: 172,000 cm, ID: 54,000 cm
Top Thread 4.5IF
S/No: 10454604
22,39 m from top to Bit

STAB, Length: 2,21 m
OD: 175,000 cm, ID: 73,000 cm
Top Thread 4.5IF
8 1/8
S/No: ST138

MMTR, Length: 9,62 m
OD: 172,000 cm
Top Thread 4.5IF
S/No: 13022
9,86 m from top to Bit

BIT, Length: 0,24 m
S/No: 5244264
0,24 m from top to Bit

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Figure 4. *Bottom hole assembly run in hole on August 16th.*

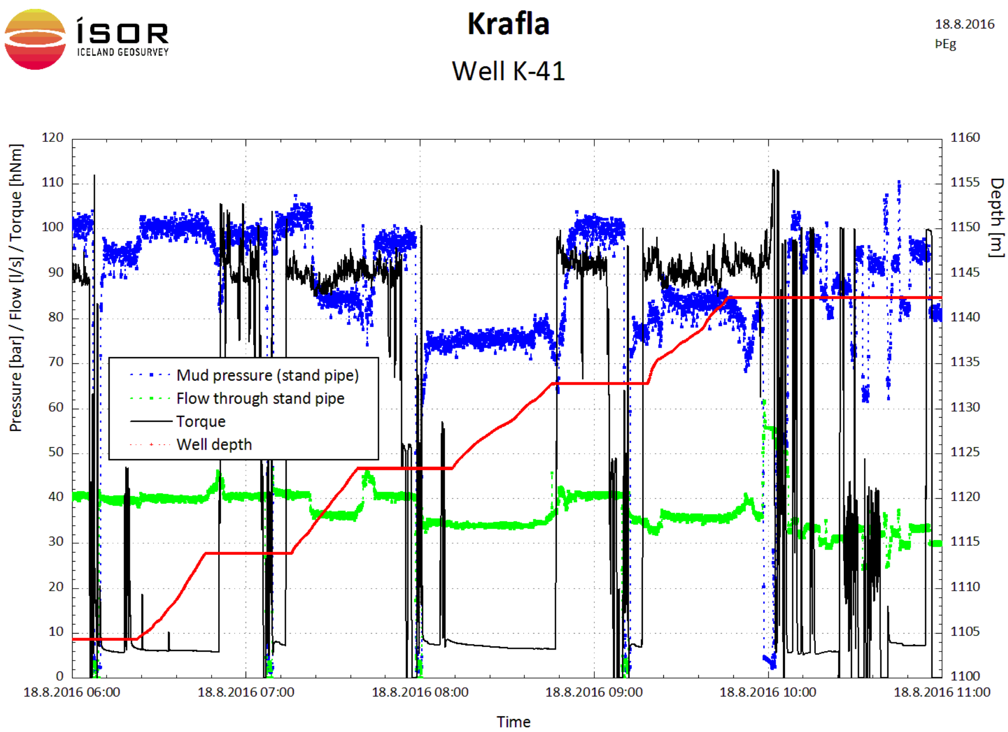


Figure 5. *Drill parameters (mud pressure, flow through stand pipe, torque and depth of well) the hours before the drillstring got stuck on August 18th.*

ÍSOR´s logging engineers ran a temperature log and X-Y caliper log and carried out one step injection test. The purpose was to locate aquifers, estimate the shape of the well in particular to look for signs of cave-ins and to get an estimate of the injectivity index for the well in its present condition. A decision was made to continue drilling with a "locked" bottom hole assembly but without motor and MWD (Figure 6). After some maintenance work on the top drive and the jib, as well as putting in a new jar drilling continued on August 22nd (Figure 7). Injection of polymer pills can clearly be seen, once during drilling of each single and again at the end of each single. Torque increases gradually (purple). The significantly lower stand-pipe pressure (red) during drilling of the last single is probably related to slightly lower pumping rates (blue).

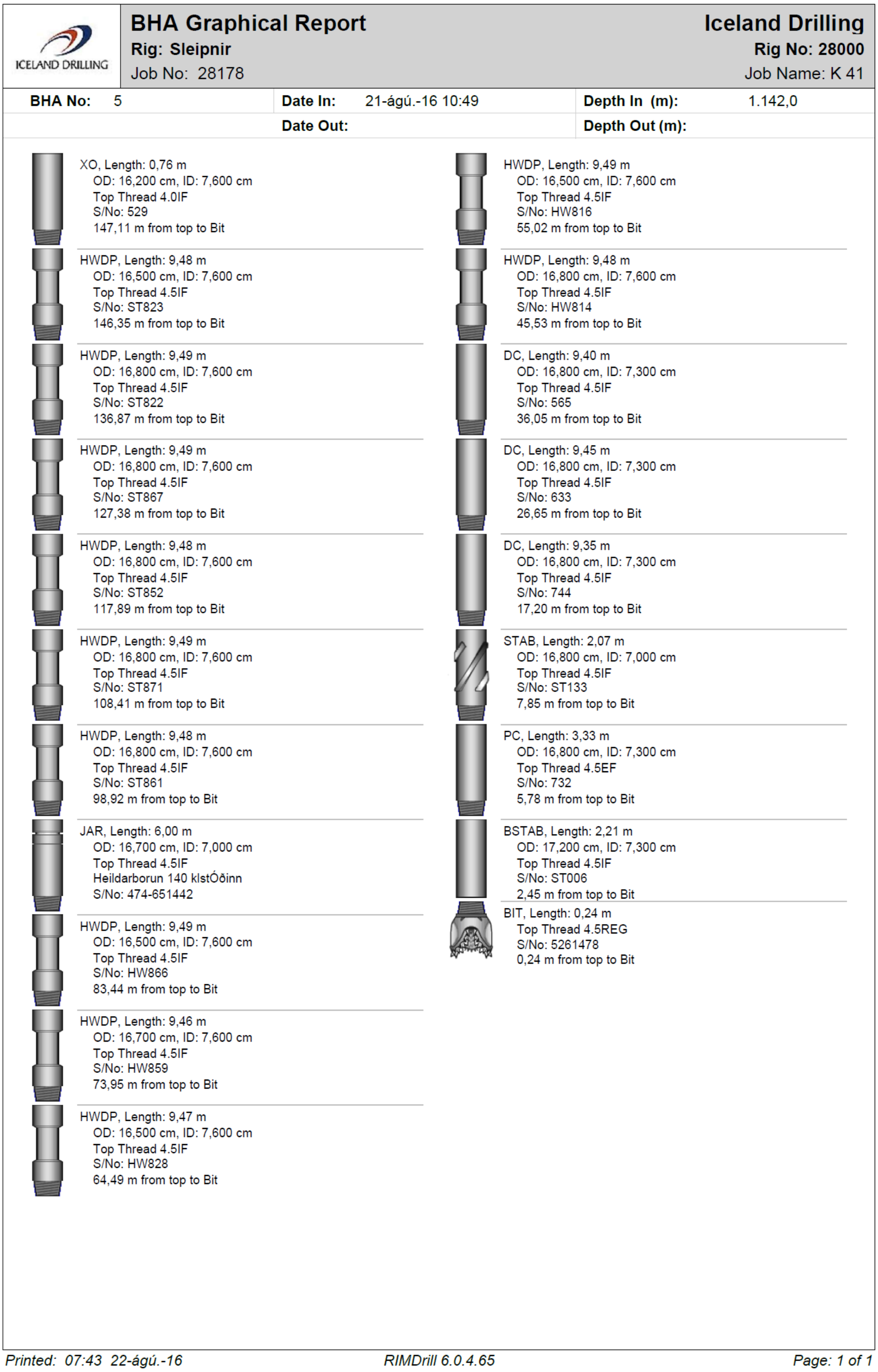
However, the slow climb of the standpipe pressure on the first single after midnight August 23rd (Figure 8) may indicate that further loss zones have been intersected by the well. In addition, the stand pipe pressure was quite high during drilling around 1240 m at 5 o'clock compared to the stand-pipe pressure recorded on the next single at around 6 o'clock (~1250 m) with similar injection rates.

After inserting the next single at 1259 m the drill string was stuck (Figure 9). At first, some movement of the string was possible, but soon it got completely stuck.

As can be seen in Figures 8 and 9, the string got stuck soon before 07:00. At ~4:30 in the morning, the flow rate was increased from 40 L/s to 41 L/s and at the same time, the stand pipe pressure increased. The flow rate and the stand pipe pressure remained at this level for the next single (~1250–1259 m). As the next single was put in, the flow rate remained the same but the stand pipe pressure dropped slightly, indicating a change in flow from the well to the formation suggesting that the bit had intersected a loss zone. The location of this potential loss zone can however not be determined accurately but one of the temperature logs show a minor feed zone at 1255.

This single was finished and the well was reamed without any problems. When putting in the next single the string got stuck. The last single was then removed again before starting to try to get the string free.

After being stuck for 24 hours a decision was made to let the well heat up and do a temperature survey. ÍSOR´s logging engineers arrived on site and started logging at 9:30. After difficulties with logging using a temperature probe, a K-10 was run in hole to log temperature and pressure. The drill bit was at 1252 m, the second stabilizer was 7,85 m above (at 1244 m) and the jar was located 89,44 m above the drill bit or at 1162,5 m. The temperature log indicates that the drill string was stuck from ~1210–1244 m and that the fill was sitting on top of the upper stabilizer. It also showed that the well has not heated up significantly and was still cold at the bottom. Therefore, it was decided to let it heat up overnight and do a second temperature log the next morning.



BHA Graphical Report | **Iceland Drilling**
Rig: Sleipnir | **Rig No: 28000**
Job No: 28178 | Job Name: K 41

BHA No:	5	**Date In:**	21-ágú.-16 10:49	**Depth In (m):**	1.142,0
		Date Out:		**Depth Out (m):**	

XO, Length: 0,76 m
OD: 16,200 cm, ID: 7,600 cm
Top Thread 4.0IF
S/No: 529
147,11 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST823
146,35 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST822
136,87 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST867
127,38 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST852
117,89 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST871
108,41 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST861
98,92 m from top to Bit

JAR, Length: 6,00 m
OD: 16,700 cm, ID: 7,000 cm
Top Thread 4.5IF
Heildarborun 140 klstÓðinn
S/No: 474-651442

HWDP, Length: 9,49 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW866
83,44 m from top to Bit

HWDP, Length: 9,46 m
OD: 16,700 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW859
73,95 m from top to Bit

HWDP, Length: 9,47 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW828
64,49 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW816
55,02 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW814
45,53 m from top to Bit

DC, Length: 9,40 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: 565
36,05 m from top to Bit

DC, Length: 9,45 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: 633
26,65 m from top to Bit

DC, Length: 9,35 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: 744
17,20 m from top to Bit

STAB, Length: 2,07 m
OD: 16,800 cm, ID: 7,000 cm
Top Thread 4.5IF
S/No: ST133
7,85 m from top to Bit

PC, Length: 3,33 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5EF
S/No: 732
5,78 m from top to Bit

BSTAB, Length: 2,21 m
OD: 17,200 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: ST006
2,45 m from top to Bit

BIT, Length: 0,24 m
Top Thread 4.5REG
S/No: 5261478
0,24 m from top to Bit

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Figure 6. *Bottom hole assembly run in hole on August 21st.*

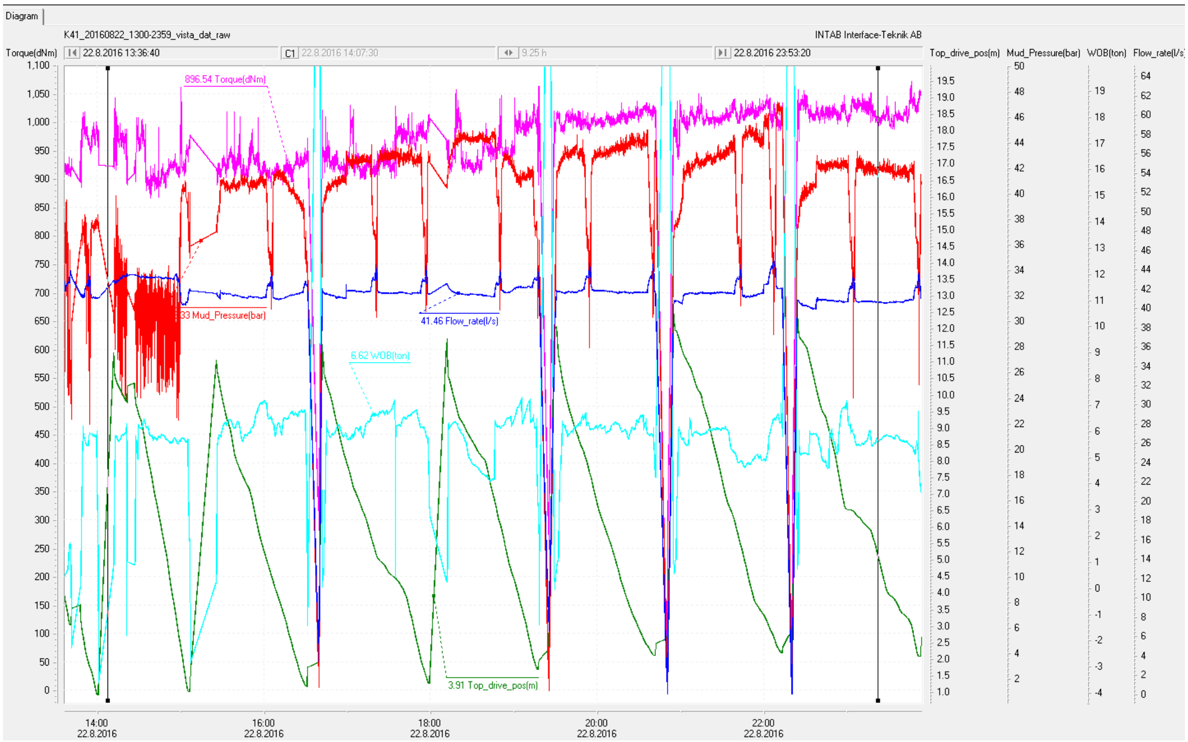


Figure 7. *Key parameters during drilling on August 22nd.*

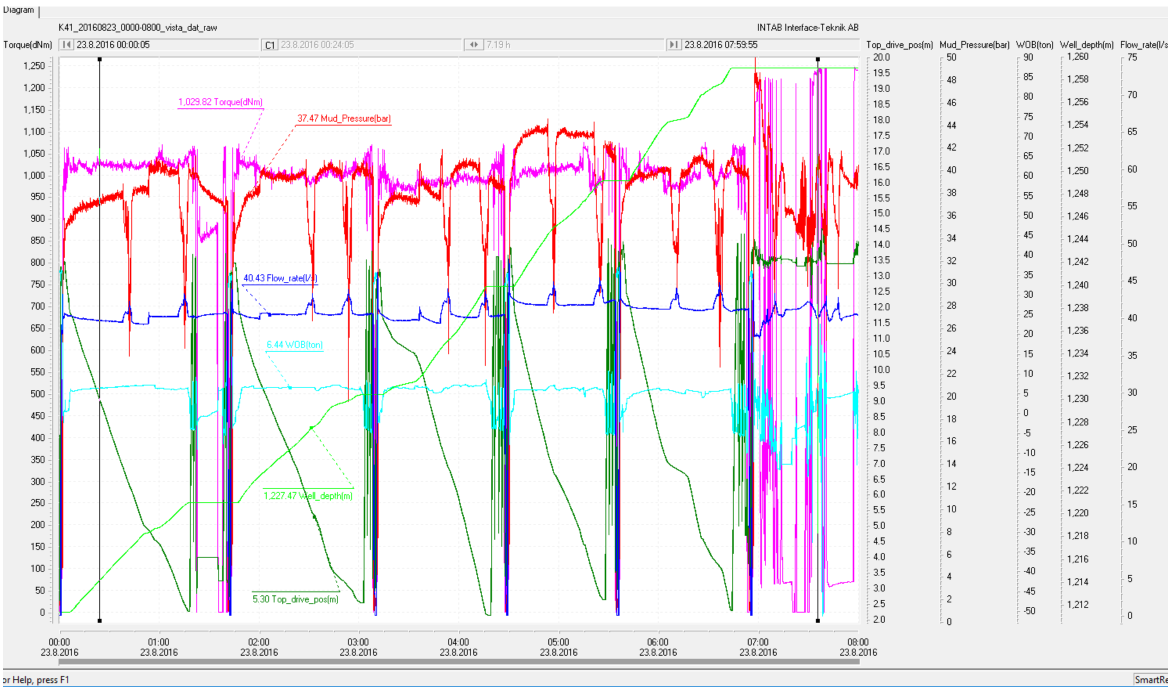


Figure 8. *Key parameters during drilling from midnight to 8 o´clock on August 23rd as the string got stuck.*

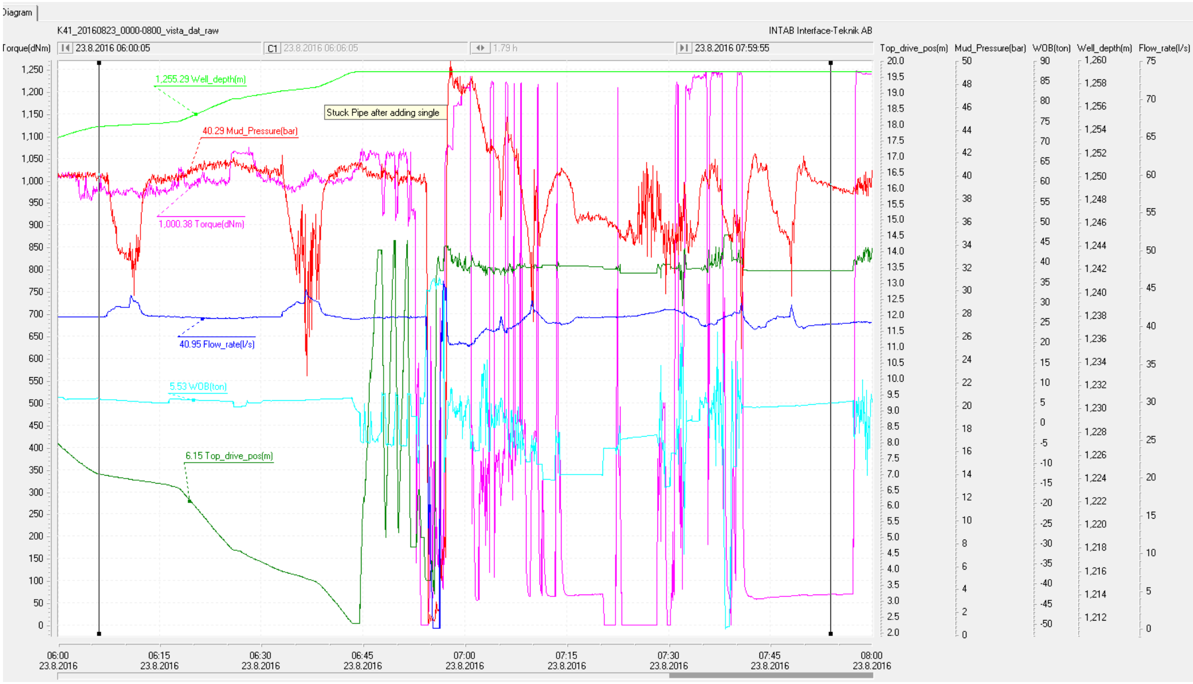


Figure 9. *Key parameters during „stuck-pipe" event in the morning of August 23rd .*

After being stuck for 48 hours a second temperature log was carried out by ÍSOR´s logging engineers. This log showed the well was around 30°C hotter than 24 hours before, and was now up to 140°C. The hottest part of the well was located above the fill. 1000 L of cold water were pumped down the well at 19 L/s in order to push the heat pulse down to the fill and heat it up more. Then on August 25th (workday 37) the pumps were shut off and the driller started jarring and trying to rotate the string at the same time. This worked and the string started rotating at 14:30. For the next few hours the drill bit moved slowly up. When pumping at 25 L/s, the pressure went up to 2,3 bar. At 20:30 the string got completely free and pulling out of hole started. The bit was back at surface in the evening of August 27th but pulling out of hole went slowly due to breakdown of the hydraulic system. The bit was in good condition with only modest signs of wear (Figure 10).

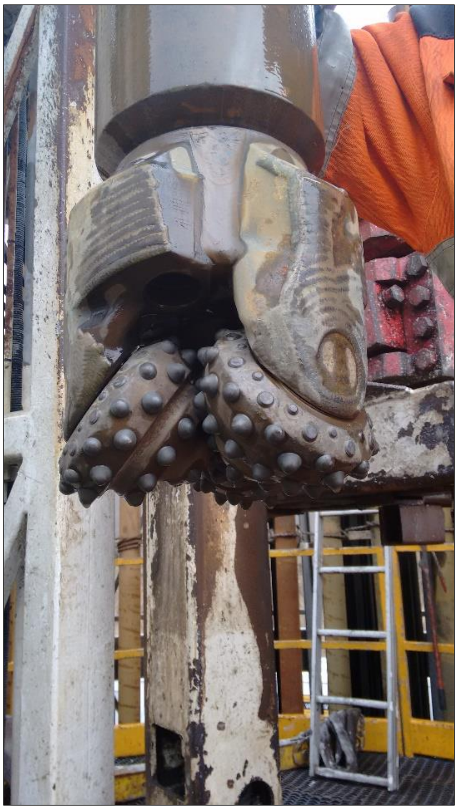


Figure 10. *Drill bit back on the surface in good condition on August 27th.*

After breaking out the last collars and centralizer the well was accessible for the logging. The logging engineers ran in with a combined P and T tool. The idea was to repeat the short step test carried out on August 20th when the well was 1140 m deep. Unfortunately, the profiles were affected by air plugs in the water column. These were believed to be the result of the air-injection while trying to get the drill string free.

Injection rate was increased to 30 L/s with the tool at 1000 m. However, the resulting pressure change due to increased injection made little sense so it was clear that the test would not give useful data.

To get a more accurate injectivity index and more comparable to the previous test, the following was done. Pumping into the well was stopped at around 20:10 and the kill line opened to bleed the air out of the well. At this point it became apparent that the kill-line valve had been open during the logging (BOP below was closed) and therefore the well had potentially received an additional injection of air during the initial logging. The well was left in this "degassing mode" for three hours. After three hours, and prior to shutting the kill-line valve, the temperature and pressure probe was lowered from 1000 m deeper into the well to examine the hydrostatic pressure profile. No signs of air plugs were observed. However, the probe hung up at 1128 m depth.

After shutting the kill-line valve, injection of Q = 19 L/s was initiated. After the tool had stabilized at that injection rate the rate was increased to Q = 30 (L/s)/bar with the tool located at 1000 m. An injectivity index of 13.5 (L/s)/bar was obtained for this step. This value should be compared to 2.3 (L/s)/bar which was obtained on August 21st. Injectivity index values for several wells in Krafla can be found in Table 4.

Table 4. *Injectivity index values for several wells at Krafla. The values are as listed by Mortensen et al. (2009a) except for K-40 which is from Mortensen et al. (2009b).*

Well	Well ID	Date	I-Index [(L/s)/bar]
K-13A	58113	26.09.1989	3.0
K-30	58030	26.07.1997	1.0
K-31	58031	07.10.1997	4.6
K-32	58032	14.09.1998	3.0
K-33	58033	08.08.1999	3.5
K-34	58034	09.09.1999	5.5
K-35	58035	05.07.2007	3.0
K-36	58036	18.11.2007	11
K-37	58037	18.01.2008	3.7
K-38	58038	20.07.2008	3.0
K-39	58039	31.10.2008	6.6
K-40	58040	28.08.2009	16
K-41	58041	26.08.2016	(~~2,3,~~ 13,5)

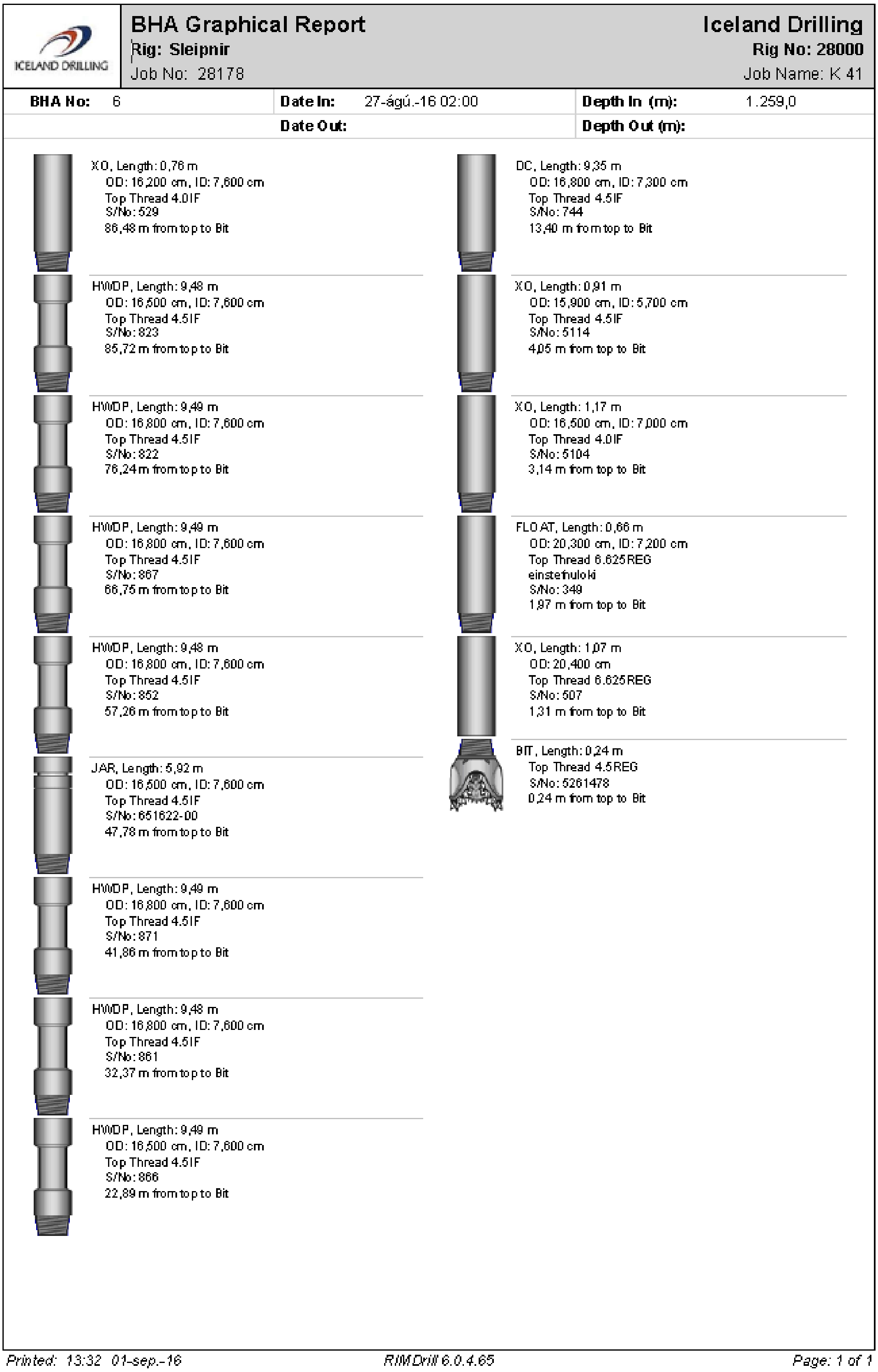
The loggers ran the tool to bottom again after the step test was finished and established that the bottom fill in the well was approximately 6 m. When the logging was completed a new and more simple bottom hole assembly was run in hole (Figure 11) The plan was to deepen the well by some 50 m below the ~1259 m aquifer. The drillers found a 3 m bottom fill which was cleaned up prior to resuming drilling. Drilling then continued in total loss of circulation with a ~6–7 ton WOB and ROP's < 10 m/hr and torque ~ 900 dNm. The pipe got stuck again at 1270 m for a short while. But after that the drilling was relatively problem free.

Drilling the production section was completed at 1313 m (MD) depth at 00:30 August 28th. Each single was reamed since getting stuck at 1259 m and the section above 1259 m got a "wiper" trip of sorts after the pipe got unstuck.

After pumping for ~2 hours at bottom and injecting polymer pills, the crew pulled the bit back to ~1100 m and then went back in to check for bottom fill. Bottom fill turned out to be ~5 m. The well bottom was cleaned with pumping and polymer pills again and the bit was pulled back and then run in again to check for bottom fill at 8:00. The bottom fill turned out to be ~3 m. This fill was left in the well.

ÍSOR´s logging engineers ran a temperature log and a gyro survey inside the drill-string. After the string was pulled out of hole, the logging engineers carried out gamma, neutron-neutron, resistivity and caliper logs as well as acoustic tele-viewer. When this logging was done, a 7" perforated liner was run in hole (Table 5). The liner sits on the bottom fill at 1309 m depth, the hanger is at 1009 m and the top of liner is at 1006.9 m. The casing tally run report can be seen in Table 6. A conventional injection test was carried out on August 30th. It composed of three injection steps with the tool at 1008 m. Several spinner logs were run prior to, during the steps and after the injection test.

As the injection test was completed, injection was stopped and the well was shut in. This concluded the drilling of well K-41 on Workday 42, August 30th 2016.


BHA Graphical Report
Rig: Sleipnir
Job No: 28178

Iceland Drilling
Rig No: 28000
Job Name: K 41

BHA No:	6	**Date In:**	27-ágú.-16 02:00	**Depth In (m):**	1.259,0
		Date Out:		**Depth Out (m):**	

XO, Length: 0,76 m
OD: 16,200 cm, ID: 7,600 cm
Top Thread 4.0IF
S/No: 529
86,48 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 823
85,72 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 822
76,24 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 867
66,75 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 852
57,26 m from top to Bit

JAR, Length: 5,92 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 651622-00
47,78 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 871
41,86 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 861
32,37 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: 866
22,89 m from top to Bit

DC, Length: 9,35 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: 744
13,40 m from top to Bit

XO, Length: 0,91 m
OD: 15,900 cm, ID: 5,700 cm
Top Thread 4.5IF
S/No: 5114
4,05 m from top to Bit

XO, Length: 1,17 m
OD: 16,500 cm, ID: 7,000 cm
Top Thread 4.0IF
S/No: 5104
3,14 m from top to Bit

FLOAT, Length: 0,66 m
OD: 20,300 cm, ID: 7,200 cm
Top Thread 6.625REG
einstefnuloki
S/No: 349
1,97 m from top to Bit

XO, Length: 1,07 m
OD: 20,400 cm
Top Thread 6.625REG
S/No: 507
1,31 m from top to Bit

BIT, Length: 0,24 m
Top Thread 4.5REG
S/No: 5261478
0,24 m from top to Bit

Printed: 13:32 01-sep.-16 RIMDrill 6.0.4.65 Page: 1 of 1

Figure 11. *The last bottom hole assembly for well K-41 that drilled the well from 1259 to 1313 m.*

Table 5. *Casing information report for the 7" perforated liner.*

Casing Information Report		Iceland Drilling	
Rig: Sleipnir		Rig No: 28000	
Job No: 28178		Job Name: K 41	
Casing Information			
Run Date/Time:	29-ágú.-16 13:00		
		Leak Off Test (kg/cu m):	
Well Section:	PROD4	**String Type:**	LINER
String Top MD (m):	0,0	**String Top TVD (m):**	
Casing Shoe MD (m):	302,1	**Casing Shoe TVD (m):**	
String Nominal OD (cm):	17,78	**String Nominal ID (cm):**	15,94
Bit Diameter (cm):	21,59	**Avg. Open Hole Diam. (cm):**	21,59
Centralizers: No:		**Manufacturer/Type:**	
Depths:			
Hanger Type:		**Manufacturer:**	
Comments:	Transferred from Casing Tally Detail on 29-ágú.-16 01:10- 2 pakkar af lími notaðir á skó og hengistikki,,liner settist í 1009 m,top of liner 1006,94 m.		

String Component Details

Joints	Item	Length (m)	OD(cm)	ID (cm)	Weight (kg)	Grade	Connection	Torque
1	SHOE	0,280						
26	JOINT	301,510						
1	LHANG	0,270						
Totals: 28		302,060						

Table 6. *Casing tally run report for the 7" liner.*

Casing Tally Run Report			Jarðboranir		
Rig: Sleipnir			Rig No: 28000		
Job No: 28178			Job Name: K 41		
String Nominal OD (cm):	17,78	String Type:	LINER		
Items Run:	28	Length Run:	302,060	Top Depth:	1.006,940
Items Excluded:	0	Length Excluded:	0,000	Bottom Depth:	1.309,000
Items Tallied:	28	Length All Items:	302,060	Cut Off Length:	0,000

Run No.	Joint No	Item	Length	Top	Bottom	Description	Comments	Cnt	Scr
1		LHANG	0,280	1.308,720	1.309,000	0,00 x 0,00			
2	26	JOINT	12,940	1.295,780	1.308,720	0,00 x 0,00	ógataður leiðari		
3	25	JOINT	12,940	1.282,840	1.295,780	0,00 x 0,00	ógataður leiðari		
4	24	JOINT	12,840	1.270,000	1.282,840	0,00 x 0,00	ógataður leiðari		
5	23	JOINT	11,370	1.258,630	1.270,000	0,00 x 0,00			
6	22	JOINT	11,350	1.247,280	1.258,630	0,00 x 0,00			
7	21	JOINT	11,380	1.235,900	1.247,280	0,00 x 0,00			
8	20	JOINT	11,360	1.224,540	1.235,900	0,00 x 0,00			
9	19	JOINT	11,360	1.213,180	1.224,540	0,00 x 0,00			
10	18	JOINT	11,360	1.201,820	1.213,180	0,00 x 0,00			
11	17	JOINT	11,360	1.190,460	1.201,820	0,00 x 0,00			
12	16	JOINT	11,450	1.179,010	1.190,460	0,00 x 0,00			
13	15	JOINT	11,550	1.167,460	1.179,010	0,00 x 0,00			
14	14	JOINT	11,230	1.156,230	1.167,460	0,00 x 0,00			
15	13	JOINT	11,580	1.144,650	1.156,230	0,00 x 0,00			
16	12	JOINT	11,360	1.133,290	1.144,650	0,00 x 0,00			
17	11	JOINT	11,710	1.121,580	1.133,290	0,00 x 0,00			
18	10	JOINT	11,360	1.110,220	1.121,580	0,00 x 0,00			
19	9	JOINT	11,470	1.098,750	1.110,220	0,00 x 0,00			
20	8	JOINT	11,380	1.087,370	1.098,750	0,00 x 0,00			
21	7	JOINT	11,370	1.076,000	1.087,370	0,00 x 0,00			
22	6	JOINT	11,380	1.064,620	1.076,000	0,00 x 0,00			
23	5	JOINT	11,380	1.053,240	1.064,620	0,00 x 0,00			
24	4	JOINT	11,370	1.041,870	1.053,240	0,00 x 0,00			
25	3	JOINT	11,370	1.030,500	1.041,870	0,00 x 0,00			
26	2	JOINT	11,630	1.018,870	1.030,500	0,00 x 0,00			
27	1	JOINT	11,660	1.007,210	1.018,870	0,00 x 0,00			
28		SHOE	0,270	1.006,940	1.007,210	0,00 x 0,00			

3 Lithology, alteration, intrusions and circulation losses

The drilling crew collected cutting samples at two meters' interval during the drilling of phase 3 in well K-41. Depth values of the samples are in reference to the rig floor of Sleipnir (5.64 m above ground level). The samples were collected in 150 ml plastic containers. ÍSOR's borehole geologists analyzed the cutting samples onsite during drilling of phase 3 and determined the lithology and the alteration mineral assemblage through the aid of a binocular microscope. Additional data on the main drilling parameters from the drill rig data system were collected, wire-line logs as well as measured circulation losses were compared with the lithological units drilled trough. Lithology, alteration and drilling data can be seen in Figures 13–16 but the legend for these figures is shown in Figure 12.

3.1 Lithology of phase 3

A detailed lithological log for phase 3 of well K-41 can be seen in Figure 14 where different lithological units were described. The lithology of drilling phase 3 was hyaloclastite with less altered intrusions. The intrusive rocks were fine-medium grained, dense and poreless with little alteration. The hyaloclastite mainly consisted of breccia and tuff with freshly looking and dark basalt mixed with altered tuff. At 1116 m there were some obvious changes in the lithology. The cuttings became smaller, more tuffaceous, more altered and more oxidized. Going down this layer, the amount of basaltic fragments decreases and the formation looks more like tuff. This decrease, however, is very slow and its almost the same over this section. Therefore it is not correct to estimate this as a clean tuff layer. This is probably a tuff formation with few thin intrusions cutting through it or the edge of an intrusion. This is supported by the geophysical logs.

Neutron-neutron response indicates a dense formation, a hard intrusive rock at 1040–1104 m (Figure 21). This correlates somewhat with the cutting analysis, where the intrusions were beleived to reach down to ~1090 m (but not to 1104 m). At 1091 m, the caliper log shows a minor washout (Figure 20). This corresponds well with a thin and very altered tuff formation at 1090–1094 m. The caliper log also shows an increase in the well diameter at 1100–1170, indicating a softer formation with inflow zones. This correlates well with the cutting analysis, where at this depth interval, fewer hard, fresh and thick intrusions were observed, but more of breccia and altered tuff formations including few thin intrusions. The inflow zones are supported by the temperature logs (Figure 18), where inflow can be seen from 1100–1110 m as well as a sharp inflow at 1140 m. The first interval is the formation where loss of circulation of started, and at 1140 m, the total loss of circulation occurred.

The description of the drill cuttings sampled from well K-41 during phase 3 is as follows:

Phase 3 (1031–1142 m)

1031–1048: INTRUSION

Fine to medium grained basaltic intrusion with no notable alteration. Dark-grey to black color. Few cubic crystals of pyrite and some sections are mixed with tuff fragments similar to the one described above which are associated with secondary minerals such as chlorite, pyrite and epidote.

1048–1054: BASALTIC BRECCIA

Basaltic breccia, fine-medium grained basalt with tuff fragments. Secondary minerals include chlorite, pyrite and epidote

1054–1086: INTRUSION

Fresh, dark, dense and poreless fine-medium grained basalt with little alteration. Some tuff fragments in some sections. Similar to the intrusion ending at 1048 m. These intrusions are supported by the neutron-neutron response.

1086–1090: BASALTIC BRECCIA

Freshly looking basalt mixed with more altered tuff. Different crystal sizes and alteration varies. Wollastonite.

1090–1094: BASALTIC TUFF

Very light, white or greenish, altered tuff. Here, the caliper log indicates a minor washout.

1094–1116: BASALTIC BRECCIA

Same breccia as above. Darkish basaltgrains, fresh, mixed in with more altered tuff fragments.

1116–1142 BASALTIC BRECCIA

Obvious changes in lithology. Cuttings become more tuffaceous, cuttings are smaller, green and pink fragments. More altered and more oxidized. This is likely to be a tuff layer cutting through many thin intrusions.

3.2 Intrusions

In phase 3 the host rock was hyaloclastite with two major intrusions. The top of the first one is in phase 2 with the bottom at 1048. Then going into a breccia before penetrating an intrusion again at 1056–1086 m. The intrusions consisted of dark grey to black, dense and poreless fine grained basalt. Not altered, little but some presence of pyrite. In some sections the intrusion was mixed with tuff grains. In the last formation before loss of circulation, the layer consisted of tuff layer cutting through few thin intrusions. This is supported both by cutting analysis, as well as geophysical logging (NN log, seen in Figure 21).

The natural gamma radiation log indicates that these intrusions are basaltic, with low silicic concentrations. Above 1080 m the silicic concentrations are somewhat higher than below. No major anomalies were though seen in the natural gamma radiation log.

The resistivity log shows little changes which supports the thin intrusive layers in the tuff formation.

In wells KJ-32 and KJ-33, intrusions were observed at similar depths.

3.3 Alteration

A summary of the distribution of alteration minerals in phase 3 in well K-41 is presented in Figure 15 . A regular progressive hydrothermal alteration with increasing depth was noticed from the alteration mineral assembly throughout the well. In phase 3, quartz, epidote and coarse grained clay was found in most samples. Wollastonite was found in one sample at 1090 m. The rocks were greenish and often there was coarse grained clay in vesicules.

3.4 Circulation losses during drilling of phase 3

Circulation losses were monitored during drilling of phase 3 in K-41. Early morning on August 18th no loss of circulation was measured until reaching 1123 m where losses of 17 L/s were observed at 35 L/s pumping. Cutting analysis showed brecciated and less altered lithology above 1116 m. At that depth the lithology changes abruptly to tuffaceous formation cutting through many thin intrusions. The cuttings became smaller, more altered and oxidized. After drilling down to 1142 m, the circulation loss was 22 L/s loss at >40 L/s pumping rate. During circulation, before inserting the next drill pipe, mud pressure dropped and the drill string got stuck. As the drill string got stuck none of the injected water returned to surface and therefore the rest of the drilling was conducted at total loss of circulation (Figure 13).

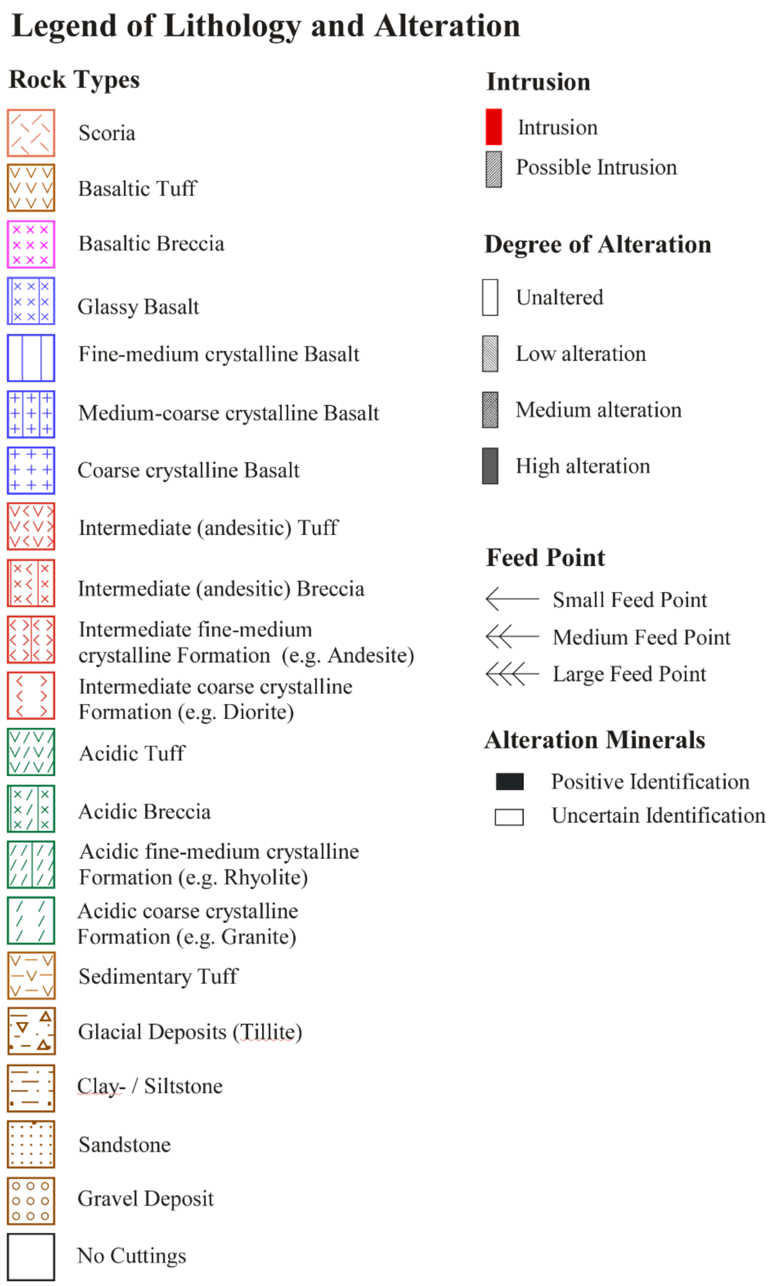


Figure 12. *Lithology legend for Figures 13–16.*

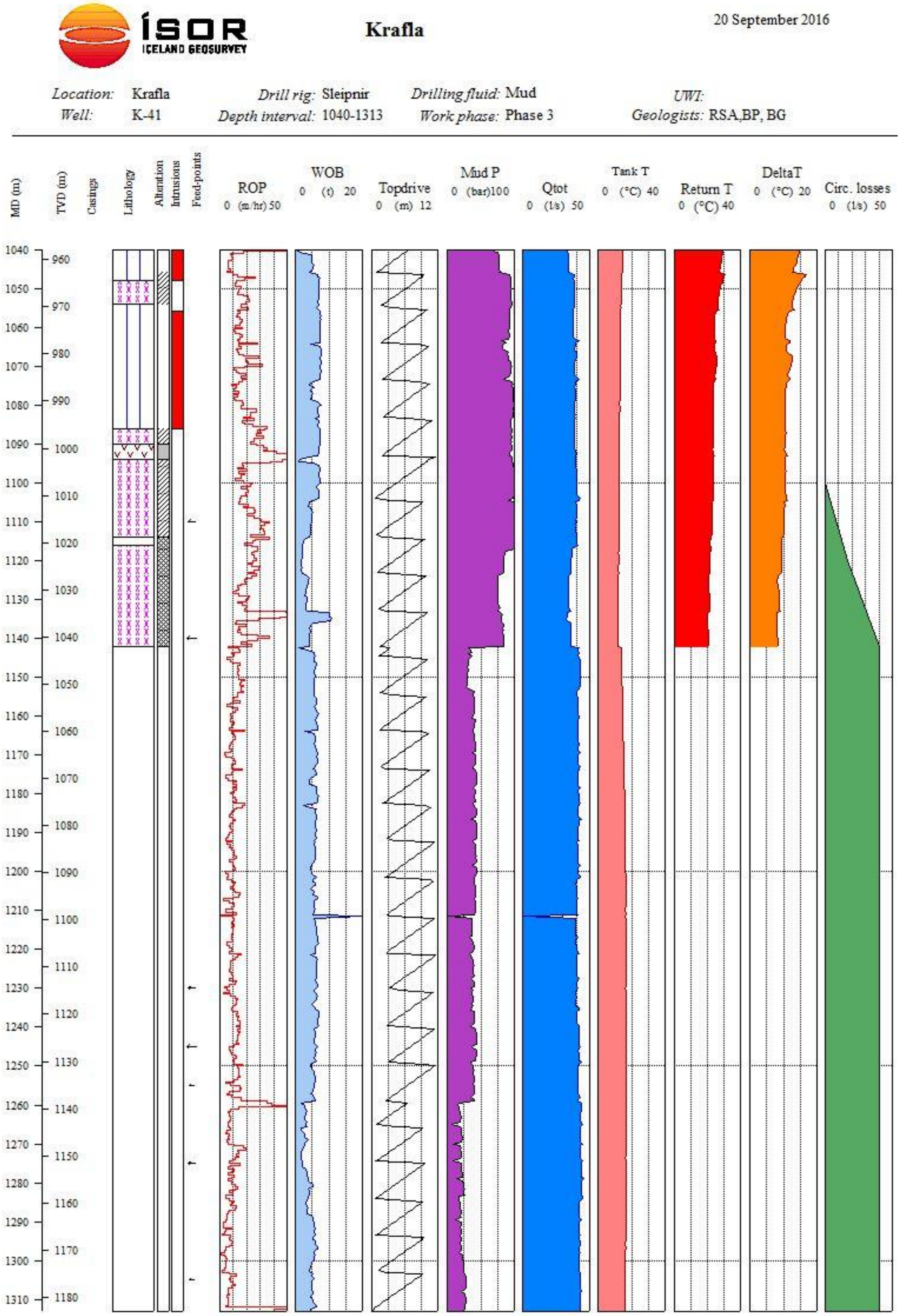


Figure 13. *Lithology and drilling data for phase 3.*

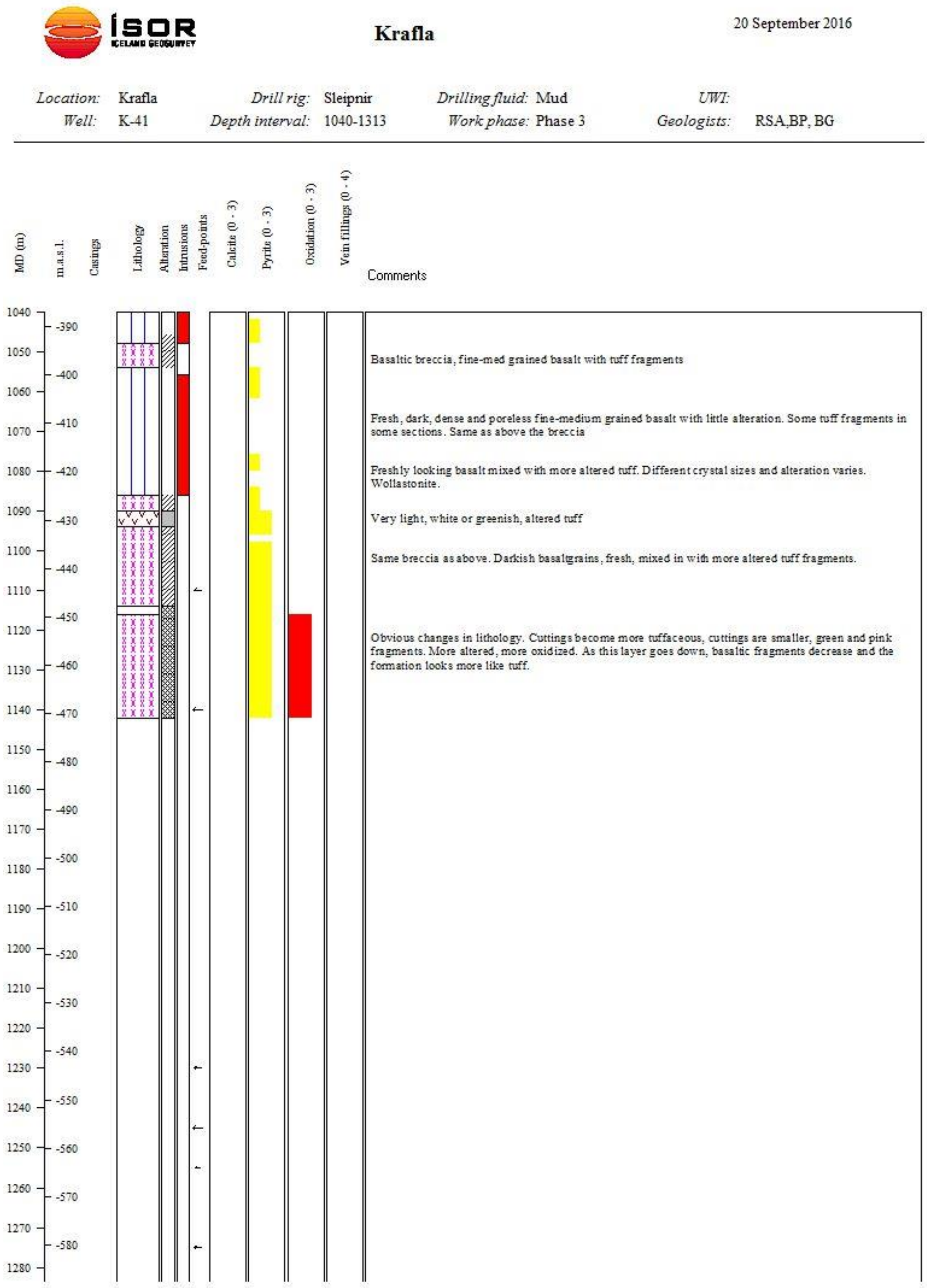


Figure 14. *Lithology and alteration minerals for phase 3.*

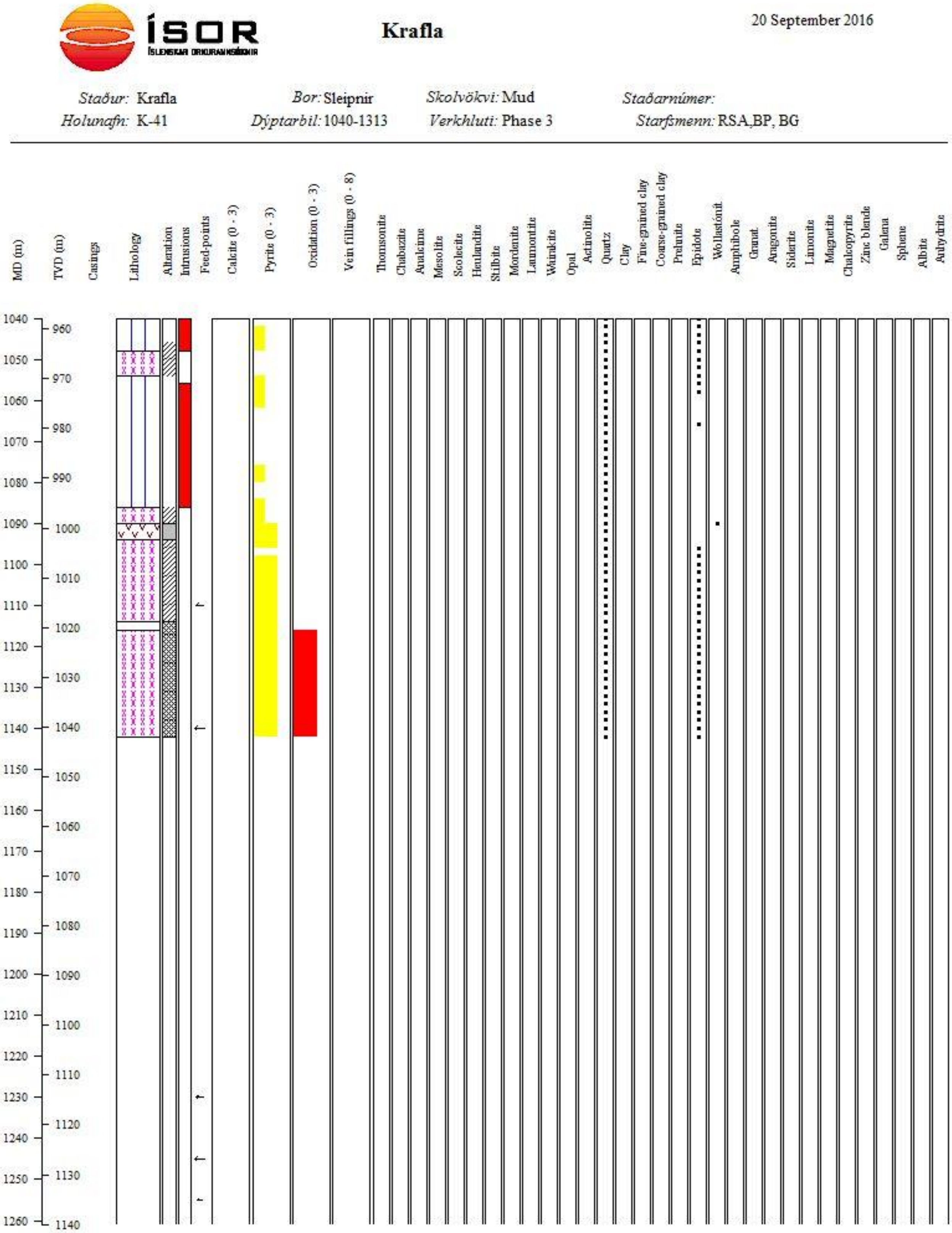


Figure 15. *Alteration minerals for phase 3.*

4 Comparison of wells

The lithology shows a good correlation with the geology in nearby wells KJ-32 and KJ-33 (Figure 16). In all three wells, there is a hyaloclastite unit at the top down to ~200 m followed by basaltic units down to ~500 m. This is followed by another brecciated hyaloclastite sequence, differing somewhat in thickness. These units contain some less altered basalt and basaltic intrusions. The brecciated units seem to be thicker in well K-41, and intrusions more frequent in the two other wells. This section, in the three wells, extending to about 600 to 700 m depth, corresponds to section where circulation losses were encountered, and further studies of temperature data showed several aquifers. Below that depth, the lithologies of the three wells show more differences, probably related to the difference in trajectory of the wells getting more spaced to each other (Figure 1). Well K-41 for example is mostly drilled through in the bottom part fine to medium grains basaltic flows, separated by few thin basaltic breccias and tuff intervals. Whereas well KJ-32 is mostly showing tuffaceaous lithologies in the same interval. In all these three wells, it seems that intrusions are becoming more apparent at ~900 m. This can be associated with circulation losses that started around this depth in all wells. The circulation losses seemed to increase rapidly at similar depth intervals in all three wells, as well as in wells K-37 and K-41 (Figure 16).

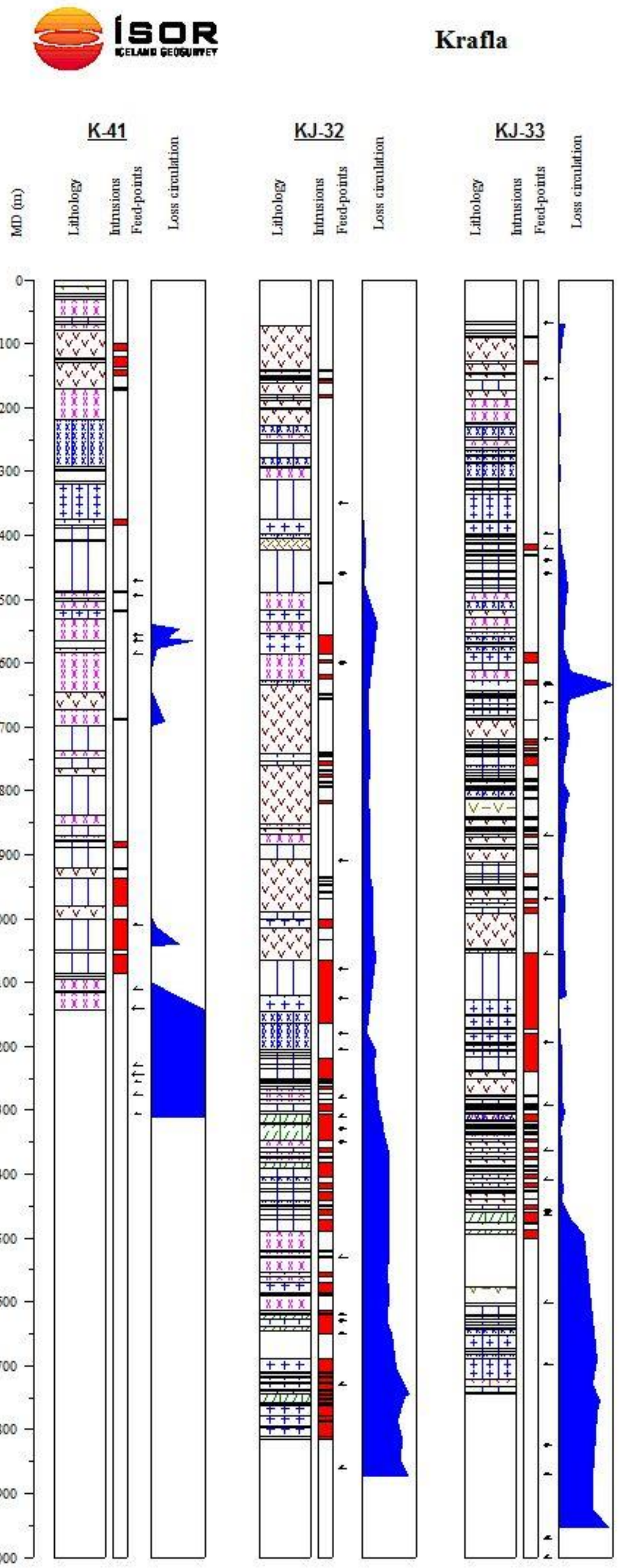


Figure 16. *Comparison of the lithology, intrusions, feedpoints and losses in wells K-41, KJ-32 and KJ-33. The locations and trajectories of these wells can be found in Figure 1.*

5 Wireline logging

Wireline logging in the 3rd phase of drilling K-41 may be categorized as follow:

- Gyro logs to measure azimuth and inclination in order to check if the well path is within acceptable limits.
- Temperature logs in open hole in order to map its temperature profile and locate feed zones. The thermal stage of the well decides how other measurements can be conducted, depending on their maximum temperature limits.
- Caliper log to map the well's shape, i.e. cavities and possible obstacles inside the well that require further reaming. In addition, the caliper log gives a good reference for the interpretation of televiewer data.
- Lithological logs to get physical information on the formation that the well intersects. This includes resistivity logs, neutron-neutron response and natural gamma radiation.
- Acoustic televiewer log in order to map the fracture structure of the well and determine fault direction (strike) and inclination (dip) mainly aimed at open zones.
- Flow measurements with spinner in order to precisely determine loss zones of the production part of the well.
- Single step and multirate injection tests in order to obtain permeability information. Also to get information on reservoir and well properties that govern the flow towards and into the well.

In this chapter the logging activity and the logging results for the drilling of well K-41 for the 7" perforated liner (drilling of phase 3) are introduced and discussed, but the analysis and the results of the televiewer logging will be given in a separate report. Overview of the wireline loggings is shown in Table 7.

Table 7. *Geophysical logs in phase 3 of K-41.*

Date	Time	Log type	Depth (m)	Purpose	Q [L/s]	Remarks
17.8.2016	21:16-21:58	Gyro	803-1005	Incl. & azimuth	0	
20.8.2016	23:02-23:57	T/P	0-1077	T/P, Feed zone	-19	Profile down, tool stopped logging at 1077 m.
21.8.2016	00:06-00:16	T/P	1000-1135	T/P, Feed zone	-19	Profile down, restarted at 1000 m.
21.8.2016	00:27-01:50	T/P	1000-1000	Injection test	-30	Pumping increased from 19 L/s to 30 L/s
21.8.2016	01:58-02:43	T/P	30-1000	T/P, Feed zone	-30	Profile up
21.8.2016	04:07-04:18	XY-Caliper	1010-1135	Well diameter		
24.8.2016	15:42-16:35	Temperature	5-1245	Temperature		Tool stopped logging. Failure in logging truck. No pumping
25.8.2016	11:28-12:14	Temperature	5-1255	Temperature		No pumping
26.8.2016	17:53-18:42	T/P	10-1253	T/P, Feed zone	-19	Profile down
26.8.2016	18:58-19:41	T/P	1000-1000	Injection test	-30	Pumping increased to 30 L/s at 19:10.
26.8.2016	23:17-01:04	T/P	1000-1000	Injection test	-19/ -30	
27.8.2016	01:04-01:40	T/P	0-1000	T/P, Feed zone	-30	Profile up
28.8.2016	08:30-09:08	Temperature	0-1285	Temperature	-19.3	19.3 L/s pumped on string.
28.8.2016	10:56-11:40	Gyro	920-1280	Incl. & azimuth		
29.8.2016	00:20-01:00	Temperature	0-1308	Temperature-feed zone	-19.2	
29.8.2016	02:44-03:06	XY-Caliper	1010-1308	Well diameter		
29.8.2016	04:41-05:22	Neutron-Neutron	1010-1308	Lithology		
29.8.2016	04:41-05:22	Gamma	1010-1308	Lithology		
29.8.2016	06:40-06:51	Resistivity	1000-1308	Lithology		MP in ground in car
29.8.2016	064:00-06:61	SP	1000-1308	Lithology		MP in ground in car
29.8.2016	09:50-11:23	Televiewer	1019-1308	Lithology		Resolution 3.9 mm 144ppr
30.8.2016	04:20-05:15	T/P	20-1307	T/P, Feed zone	-19.2	Profile down
30.8.2016	04:20-05:15	Flow	20-1307	Flow	-19.2	
30.8.2016	05:06-05:57	Flow	900-1300	Flow	-19.2	
30.8.2016	05:15-05:59	Flow	1020-1307	Flow	-19.2	
30.8.2016	05:59-07:32	T/P	1080-1080	Injection test	-29.8	Pumping increased from 19.2 to 29.8 at 06:12.
30.8.2016	05:59-07:32	Flow	1080-1080	Flow	-29.8	Pumping increased from 19.2 to 29.8 at 06:12.
30.8.2016	07:31-08:03	Flow	1080-1300	Flow	-29.8	
30.8.2016	07:32-09:27	T/P	1080-1080	Injection test	-40.2	Pumping increased from 29.8 to 40.2 at 08:27.
30.8.2016	07:32-09:27	Flow	1080-1080	Flow	-40.2	Pumping increased from 29.8 to 40.2 at 08:27.
30.8.2016	09:27-11:22	T/P	1080-1080	Injection test	-25	Pumping decreased from 40.2 to 25 at 10:22.
30.8.2016	09:27-11:22	Flow	1080-1080	Flow	-25	Pumping decreased from 40.2 to 25 at 10:22.
30.8.2016	09:27-10:07	Flow	1080-1300	Flow	-40.2	
30.8.2016	11:22-12:54	T/P	0-1300	T/P, Feed zone	-25	Profile up
30.8.2016	11:22-12:54	Flow	0-1300	Flow	-25	
30.8.2016	11:24-11:57	Flow	1080-1300	Flow	-25	

The drilling of phase 3 started August 17th with drilling in the cement float collar at 1009 m depth. The first log in phase 3 was a gyro log conducted on August 17th when the well depth was 1046 m. Only one additional gyro log was performed in phase 3, on 28th of August. The drill string got stuck at 1142 m depth on August 18th. When the drill string got free and was pulled out of the hole, ÍSOR´s logging engineers ran a temperature log, X-Y caliper log and a one-step injection test on August 20th. At 1259 m, the string got stuck again when adding in a new single. ÍSOR´s logging engineers carried out two temperature logs in order to locate the fill and estimate its size when the string was stuck. When the string got free, POOH started and when it was finished, the logging engineers ran a short one step injection test.

Drilling the production section was completed on August 28th at 1313 m (MD) depth. After cleaning and a short wiper trip, ÍSOR´s logging engineers carried out temperature and gyro logs inside the drill string and then the drill string was pulled out of hole.

Geophysical logging started right after the bottom hole assembly (BHA) had been pulled out at midnight August 28th. The logging program consisted of the following measurements: Temperature, XY-caliper, electric properties, including normal resistivity and spontaneous potential, neutron-neutron response (back scattering of thermal neutrons), natural gamma radiation from the formation and acoustic televiewer. Table 7 shows an overview of all geophysical logs carried out during phase 3 in well K-41. After the 7" perforated liner had been run in hole a multi rate injection test was conducted with a PTS tool logging simultaneously pressure, temperature and flow (spinner).

5.1 Gyro surveys

Table 8 shows the design parameters for the directional drilling of well K-41 including the kick-off-point (KOP), angle build-up (AB), inclination and azimuth. To reach the target zones, the direction of the well was set to 70°± 5°/15° (above/below 1000 m) and inclination to 35±3°/5° (above/below 1000 m), to a depth of 1700–2000 m (MD). Logging engineers from ÍSOR carried out two gyro surveys in phase 3 of well K-41 and the corresponding depth intervals are listed in Table 9.

Table 8. *Target for inclination and azimuth in well K-41.*

Azimuth	KOP	AB	Inclination	Target
70°	310 m	2.5°/30 m	35°	1700-2000 m (MD)

The first gyro survey was conducted on August 17nd and the well was logged down from 803 to 1005 m depth. The second gyro survey was conducted on August 28th when drilling of phase 3 was finished. This time the depth interval from 902 m to 1280 m was logged. Table 9 shows the gyro surveys run in well K-41 and in Table 10 the combined results of all gyro surveys in K-41 are presented, including derived parameters. Figure 17 shows the calculated well path from the measured inclination and azimuth data together with the designed well path and corresponding deviation limits. The results show that the inclination at 1280 m depth is 32.85° and the azimuth 70.4°.

Table 9. *Gyro surveys carried out in phase 3 of well K-41.*

Date	Depth interval (m)	Tool
17.8.2016	803-1005	SPT 1408
28.8.2016	920-1280	SPT 45

Table 10. *Inclination, azimuth and derived parameters for well K-41.*

Measured Depth [m]	Inclination [°]	Azimuth [°]	Horizontal displacement [m]	TVD [m]	ISNET93 Coordinates		
					East [m]	North [m]	Elevation [m]
0	0.00	0.0	0	0	602984.2	580998.1	571
50	0.21	221.1	0	50	602984.1	580998.0	521
100	0.20	241.9	0	100	602983.9	580997.9	471
150	0.42	197.2	1	150	602983.8	580997.7	421
200	0.50	208.1	1	200	602983.7	580997.3	371
250	0.95	206.3	2	250	602983.4	580996.8	321
273	1.08	206.3	2	273	602983.2	580996.4	298
300	0.98	195.8	2	300	602983.0	580995.9	271
330	2.03	80.9	2	330	602983.5	580995.8	241
350	3.81	69.8	2	350	602984.4	580996.1	221
380	6.58	66.8	3	380	602987.0	580997.1	191
413	9.49	65.3	7	413	602991.2	580999.0	159
440	11.46	63.3	12	439	602995.6	581001.1	132
470	14.49	62.2	19	468	603001.6	581004.2	103
500	17.16	61.8	27	497	603008.8	581008.0	74
530	19.82	62.0	36	526	603017.2	581012.5	46
557	21.06	63.3	46	551	603025.6	581016.8	20
590	23.82	65.9	58	581	603036.9	581022.2	-10
620	26.37	68.3	71	609	603048.7	581027.2	-38
651	28.78	72.8	85	636	603062.2	581031.9	-65
680	30.47	69.6	99	661	603075.8	581036.6	-90
720	31.95	71.8	120	695	603095.3	581043.4	-124
750	34.23	72.1	136	721	603110.9	581048.5	-150
780	34.76	72.8	153	745	603127.1	581053.6	-174
803	35.25	72.7	167	764	603139.7	581057.5	-193
830	35.32	73.5	182	786	603154.6	581062.0	-215
860	35.74	73.8	199	811	603171.3	581066.9	-240
890	35.74	74.6	217	835	603188.2	581071.7	-264
920	35.11	73.5	234	859	603204.9	581076.5	-288
950	35.25	74.8	252	884	603221.5	581081.2	-313
980	34.93	71.8	269	908	603238.1	581086.2	-337
1010	34.15	73.9	286	933	603254.3	581091.2	-362

Table 10. *Inclination, azimuth and derived parameters for well K-41.*

Measured Depth [m]	Inclination [°]	Azimuth [°]	Horizontal displacement [m]	TVD [m]	ISNET93 Coordinates		
					East [m]	North [m]	Elevation [m]
1040	34.36	73.6	303	958	603270.5	581095.9	-387
1070	33.98	71.0	319	983	603286.6	581101.0	-412
1100	34.14	68.7	336	1008	603302.3	581106.8	-437
1130	34.59	67.6	353	1032	603318.0	581113.1	-461
1160	34.27	67.8	370	1057	603333.7	581119.6	-486
1190	33.76	67.9	387	1082	603349.3	581125.9	-511
1220	33.17	68.9	403	1107	603364.6	581132.0	-536
1250	32.46	68.3	420	1132	603379.8	581137.9	-561
1280	32.85	70.4	436	1158	603394.9	581143.6	-587

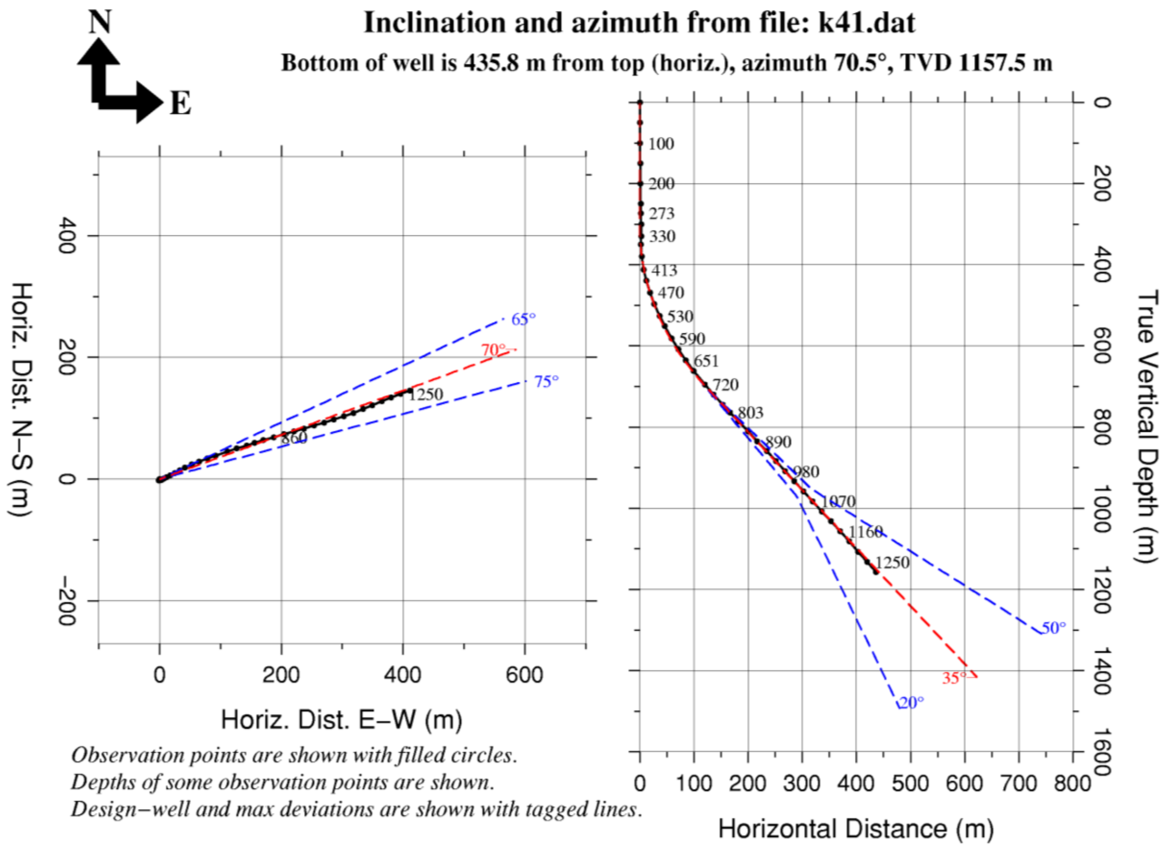


Figure 17. *Calculated well path from the measured inclination and azimuth data together with the designed well path and corresponding deviation limits.*

5.2 Temperature, XY-caliper and geophysical logs.

The drill string got stuck at 1142 m depth on August 18th. After trying to get it free for 48 hrs., the string finally got loose. When pulling out of hole was finished, ÍSOR's logging engineers ran a temperature log, X-Y caliper log and a short one step injection test. The purpose of it was to locate aquifers, estimate the shape of the well-bore, in particular to look for signs of cave-ins, and finally, to get a preliminary estimate of the injectivity index for the well in its present condition.

The logging engineers arrived at the rig site around 21:30 August 20th and could start the logging at 23:00. The logging was completed at around 05:00 on August 21st. The temperature log is shown on Figure 18 (red curve). The temperature was measured with 19 L/s injection, with no return of water. The probe stopped at 1135 m indicating ~ 7 m bottom fill. All the injected fluid exits the well somewhere below 1135 m. A short injection test was carried out at 1000 m depth when injection rate was increased from 19 L/s to 30 L/s, resulting in a pressure increase of ~4.8 bar. The injection index obtained from this short test was therefore 2.3 (L/s)/bar. After the injection test was finished, the 4-arm XY-caliper tool was used to log the well's diameter and the results are shown on Figure 19. The bottom part of the last section drilled (phase 2) with the 12 ½" bit can be seen from 1031 to 1039 m. A minor washout occurs between 1090 and 1100 m. Below that the ellipticity of the well seemed to increase towards the bottom, were a washout can be seen around 1130 m depth.

When the caliper log was finished the drill rig crew started to RIH a BHA with 8 ½" bit. At 1259 m depth, the string got stuck just before 07:00 on August 23rd when adding a new single. After being stuck for 24 hours a decision was made to let the well heat up and do a temperature survey in order to locate the fill outside the string and estimate its length. ÍSOR´s logging engineers arrived on site and started logging at 9:30 on August 24th. After difficulties with the surface readout temperature probe, a K-10 memory tool was used to log temperature and pressure (Figure 18, blue curve). The temperature log indicated that the drill string was stuck from ~1230–1250 m and the fill was sitting on top of the lower stabilizer, see Figure 6. It also showed that the well had not heated up significantly and was still cold at the bottom. Therefore, it was decided to let it heat up overnight and do a second temperature log.

After being stuck for 48 hours a second temperature log was carried out by ÍSOR´s logging engineers on August 25th (Figure 18, green curve). The log showed that the well was around 30°C hotter than 24 hours earlier, and was now up to 140°C. The hottest part of the well was located above the fill but the fill was still likely to be at ~1210–1244 m. Note that there is a shift in depth of 10 m between the two heat-up logs. The latter finds the bottom (drill bit) at 1255 m which is correct not 1245 as in the first log. At 20:30 on August 25th the string got unstuck and its POOH started and when it was finished, the logging engineers ran a short injection test.

The logging engineers logged the well with a combined pressure/temperature tool on August 26th during 19 L/s injection rate. Results of the temperature log can been seen on Figure 18 (magenta curve). The log shows internal flow in the well with inflow at ~1120 m and 1140 m joining the injection and flowing down towards the bottom. The idea was then to do the short injection step test to compare with the one carried out about a week earlier when the depth was 1140 m. Unfortunately, the pressure profiles were affected by air plugs in the water column. These were believed to be the result of air-injection while trying to get unstuck. However, the logging confirmed that the bottom fill in the well was approximately 6 m.

Injection rate was increased to 30 L/s with the tool at 1000 m. However, the resulting pressure change made little sense so it was clear that the test would not give useful data.

To get an injectivity index comparable to the previous test, the following was done. Pumping into the well was stopped at around 20:10 on August 26th and the kill line valve opened to let the air out of the well. At this point it became apparent that the kill-line valve had been open during the logging (even though the BOP bellow was closed) and therefore the well had potentially sucked air during injection while the logging and the step rate test was carried out. The well was left in this "degassing mode" for three hours. During that time, it burped significantly early on and the burp was then followed by a steady stream of air from the well.

After three hours, and prior to shutting the kill-line valve, the combined temperature/ pressure probe was lowered from 1000 m (MD) deeper into the well to study the pressure profile for air. No signs of air plugs were observed.

After shutting the kill-line valve, injection rate of 19 L/s was initiated with the tool at 1000 m. After the tool had stabilized at that injection rate, the injection was increased to 30 L/s and the pressure monitored for one hour. An injectivity index of 13.5 (L/s)/bar was obtained, a great improvement to 2.3 (L/s)/bar which was obtained when the well was 1142 m deep. Following these results, it was decided to RIH with a simple BHA and try to deepen the well for some 50 m below the aquifer at ~1259 m for "garbage collection."

Drilling of the production section was completed on August 28th at 1313 m (MD) depth. When cleaning and a short wiper was finished, the logging engineers carried out temperature and gyro logs inside the drill string and then the drill string was POOH. Geophysical logging started after the bottom hole assembly (BHA) had been pulled out.

The program started with a temperature log on Thursday August 29th at 00:20 during with 19.2 L/s injection on kill line. The temperature profile is shown on Figure 18 (purple curve). After the temperature survey was finished a caliper log was run. Then, conventional geophysical logs were conducted, neutron-neutron response and natural gamma radiation, resistivity and televiewer log. The results of the logging programme will be overviewed and discussed in this chapter but the results of the televiewer survey will be represented in a separated report.

The temperature log shows similar internal flow as the log from August 26th with inflow at 1100–1120 m and at 1140 m. Inflow is now also seen at 1150–1160 m. Below 1160 m depth the temperature profile is isothermal indicating flow in the well all the way to the bottom of the well. Further discussion about permeable zone is taken together with analysis of the flow (spinner) measurements later in this report.

The caliper log shows that the end of the production casing is at 1031 m depth and the bottom of the 2nd phase drilling is at 1039 m. At 1091 m there is a minor washout which corresponds to a small tuff interval. The cuttings at this interval showed very light, white or greenish, highly altered tuff. At the depth interval from 1100 m to 1160 m, where there are several inflow zones according to the temperature logs, there is an increased diameter of the well indicating softer formation. According to cutting analysis, this interval consists of somewhat altered breccia, as well as highly altered tuff, possibly cutting through an intrusion.

From 1040 m down to 1105 m depth the neutron-neutron response (n-n log) indicates a dense low porosity formation, probably a hard intrusive rock. This correlates somewhat with the cutting analysis, where the intrusion is said to reach down to ~1090 m, but not 1105 m. There below the n-n log indicates softer formation with thin intrusions at regular intervals. This supports the idea that the last cuttings were not in fact breccia, but a tuff formation with thin intrusions cutting the layer. According to the natural gamma radiation log the intrusive formation located from 1040 m down to 1105 m is basaltic from 1080 m depth where its silica content is higher above 1080 m. However, no major anomalies are seen in the natural gamma radiation and it confirms that most of the intrusions seen in the n-n log are basaltic, i.e. of low silicic content.

The resistivity log shows little changes in the production part. It varies between 10 Ωm and 100 Ωm but it supports the interpretation of thin intrusive layers from the n-n log.

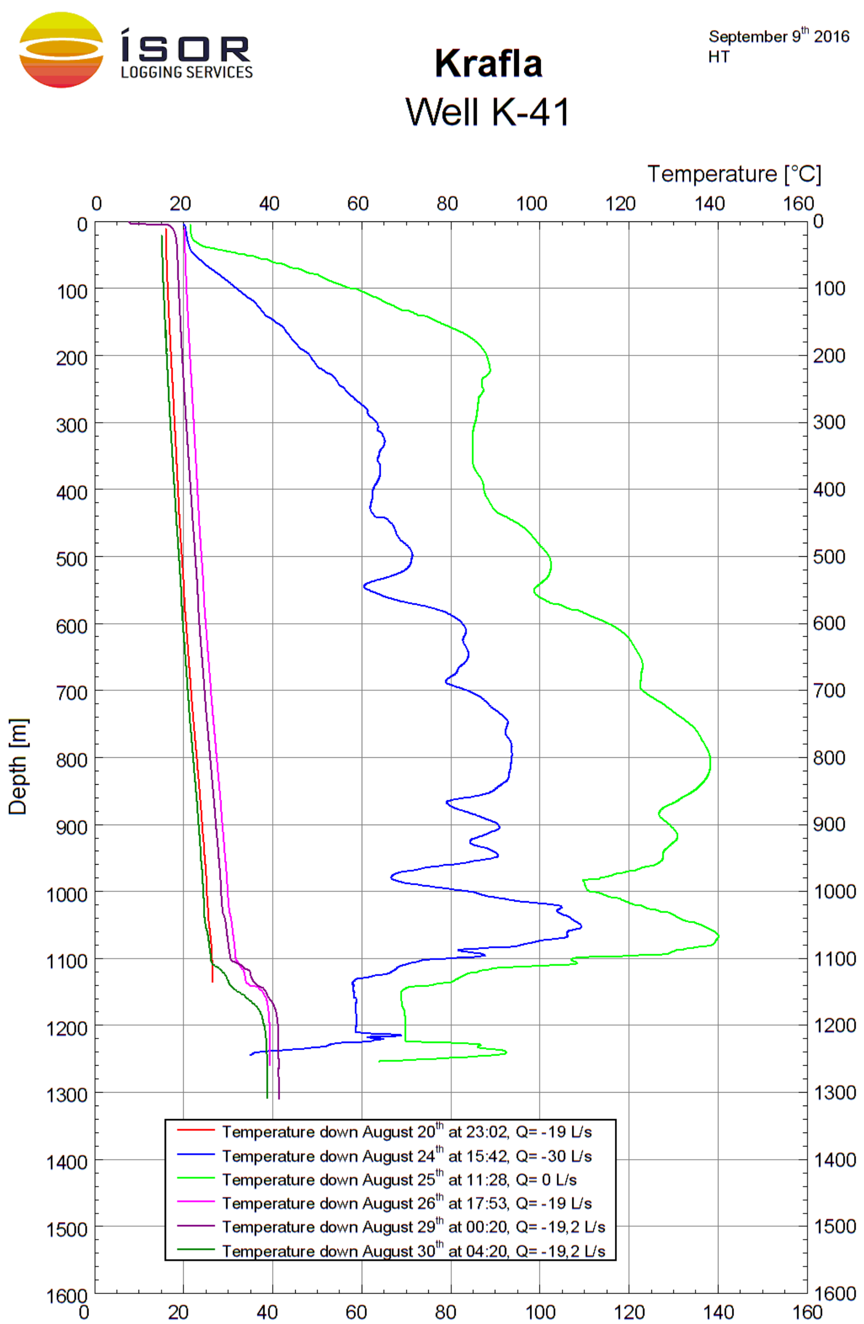


Figure 18. *Temperature logs in well K-41 at drilling phase 3.*

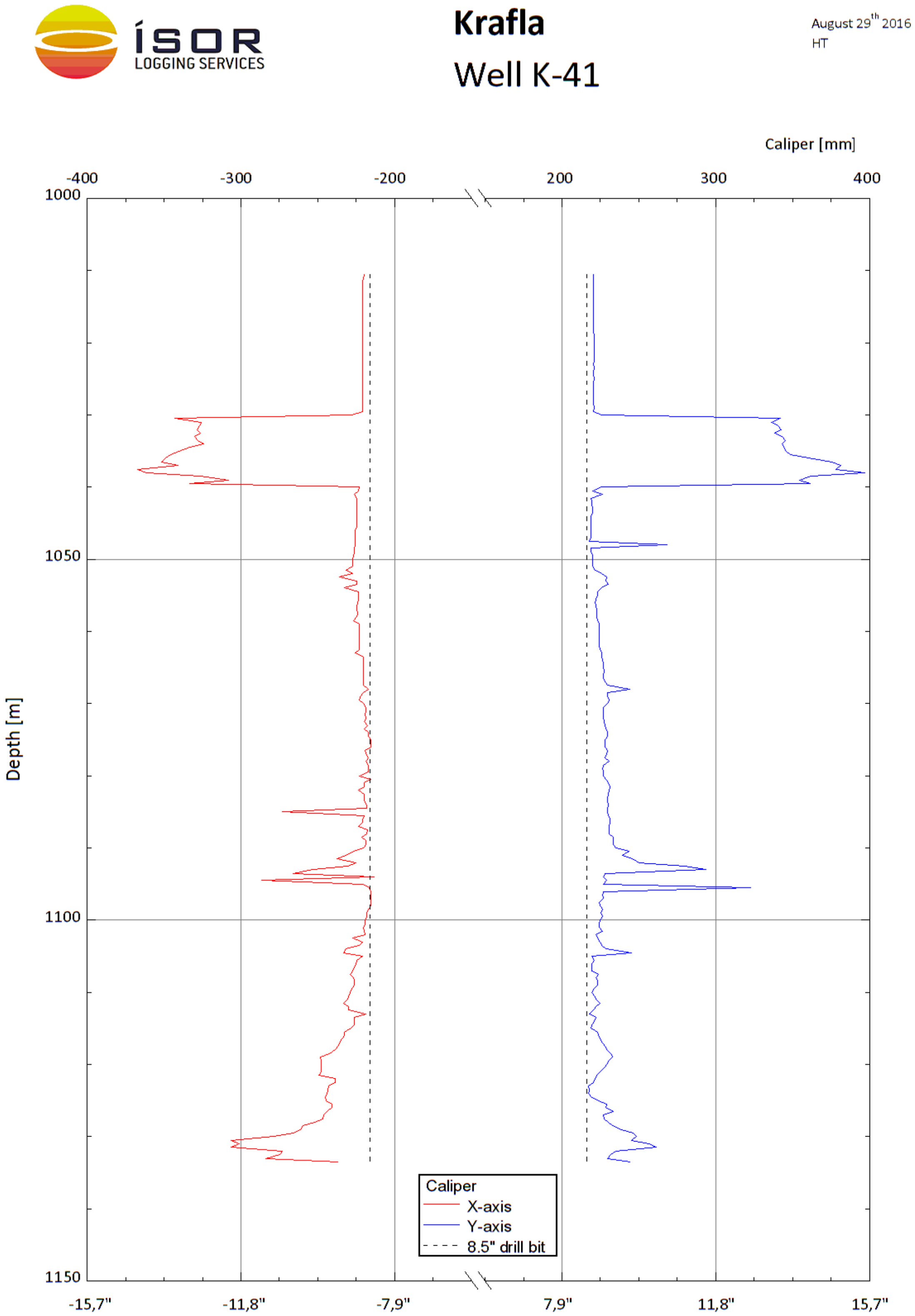


Figure 19. *Caliper log August 21st in well K-41.*

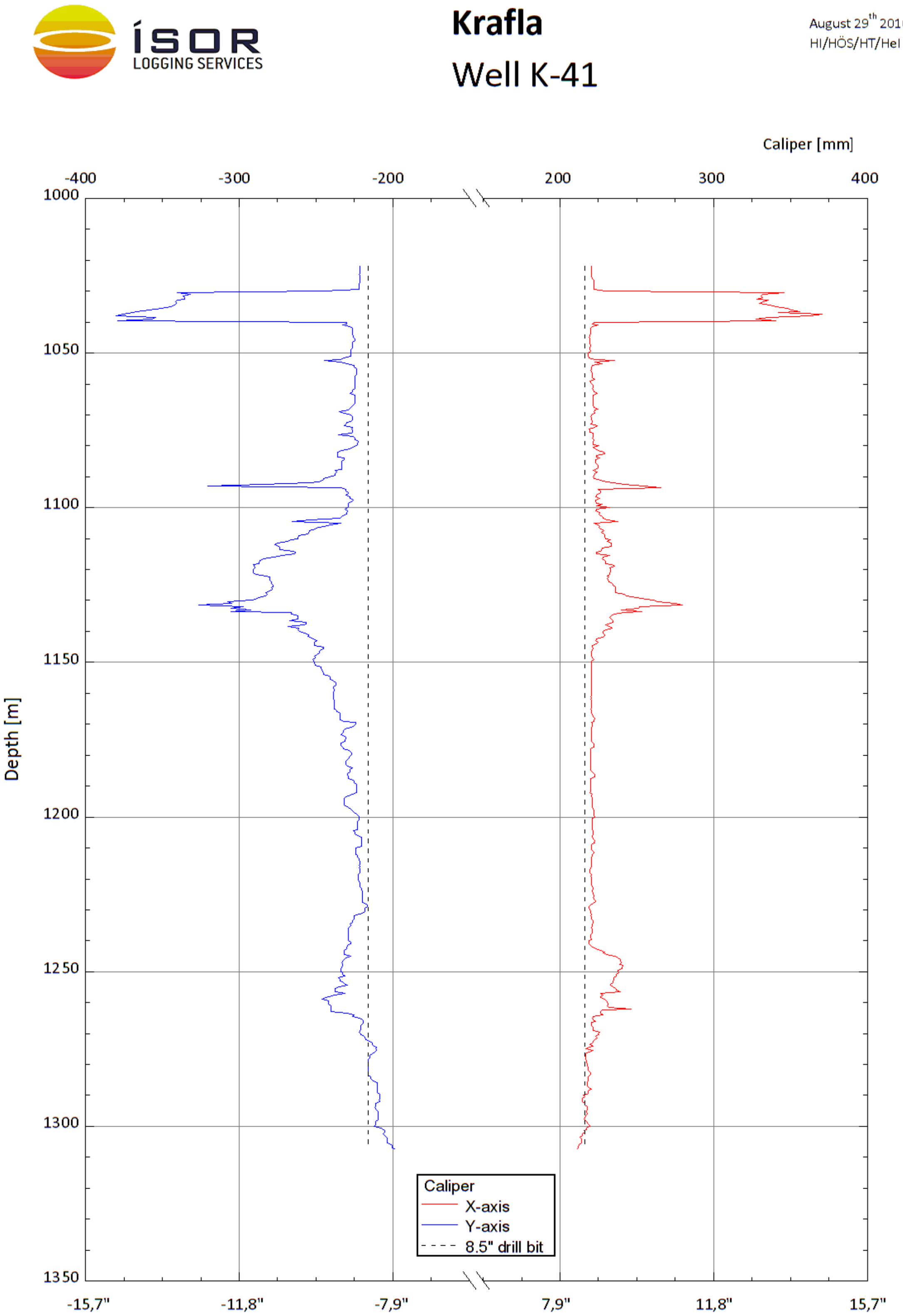


Figure 20. *Caliper log after drilling phase 3 in K-41.*

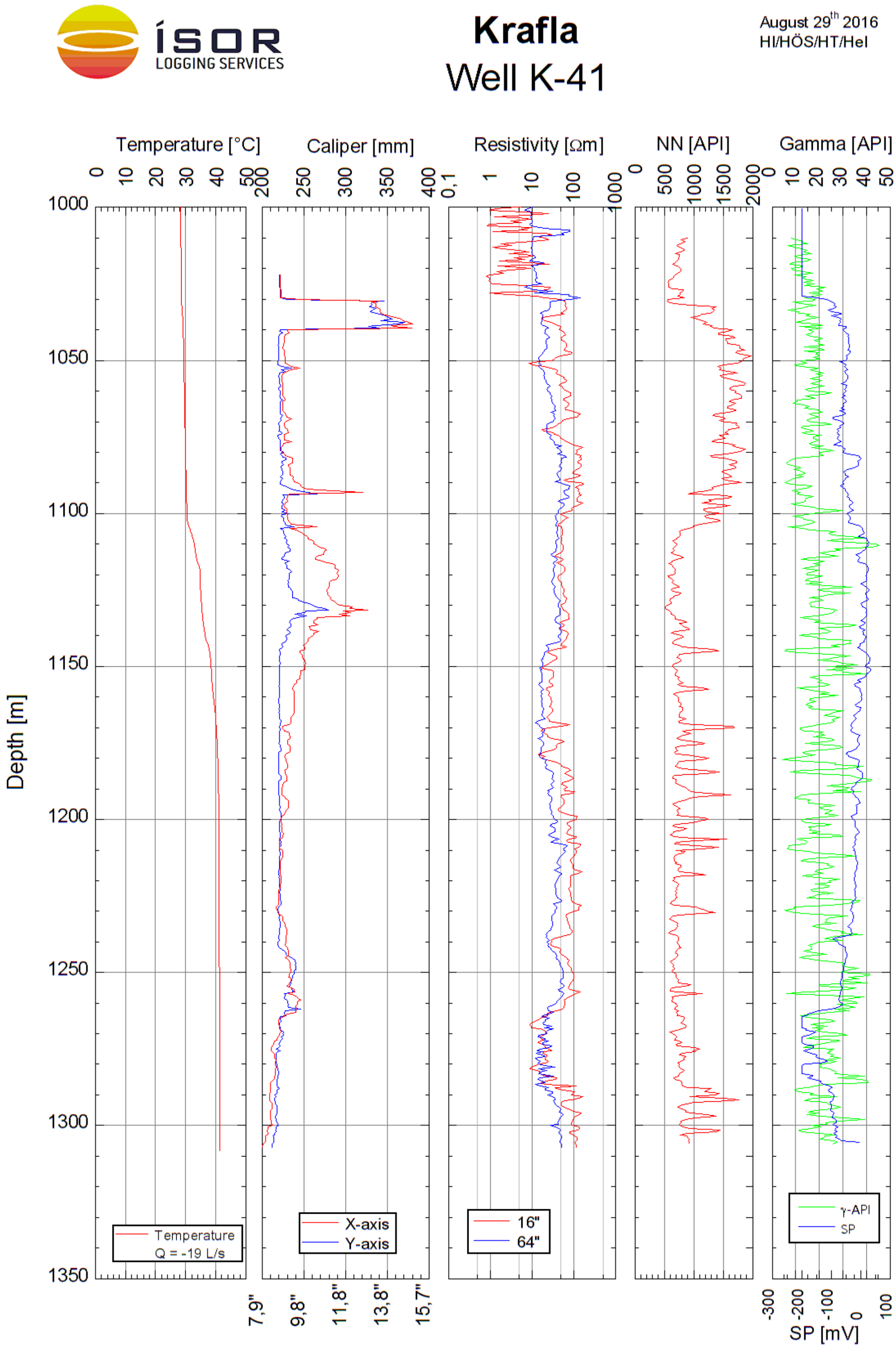


Figure 21. *Geophysical logs after phase 3 of the drilling of well K-41.*

5.3 Multi rate injection test and its analysis

The last phase of the well completion test was the injectivity test which was conducted according to the completion program consisting of multi rate injection. Before the test the well was regarded to be in pressure equilibrium after constant injection of 19.2 L/s while the liner was lowered into the well. The PTS tool was run into hole under 19.2 L/s injection and eventually positions at 1080 m depth during the test. The injectivity test consisted of three steps. An overview of the applied injection rates and the measured pressure response is shown in Figure 22. In Figure 23 the injection rate is plotted against equilibrium pressure at the end of each step. As seen in the figure, data points are well connected with a least squares linear fit with regression consistency of R^2=0.97. The line's slope, 11 (L/s)/bar, represents the well's injectivity index which should be regarded as good permeability. Figure 22 shows that the measured pressure data at 1080 m have a scattering nature of more than 0.1 bar and they indicate a geothermal reservoir with constant pressure boundaries. Moreover, the pressure in each step reaches equilibrium in a relatively short time.

From information of loss of circulation and available temperature profiles it was decided to locate the P/T tool at 1080 m depth for the injectivity test. The injectivity test was performed in following order:

Initial injection rate	19.2 L/s		
Step 1	29.8 L/s	for	02:14:22
Step 2	40.2 L/s	for	01:55:24
Step 3	25.0 L/s	for	01:03:00

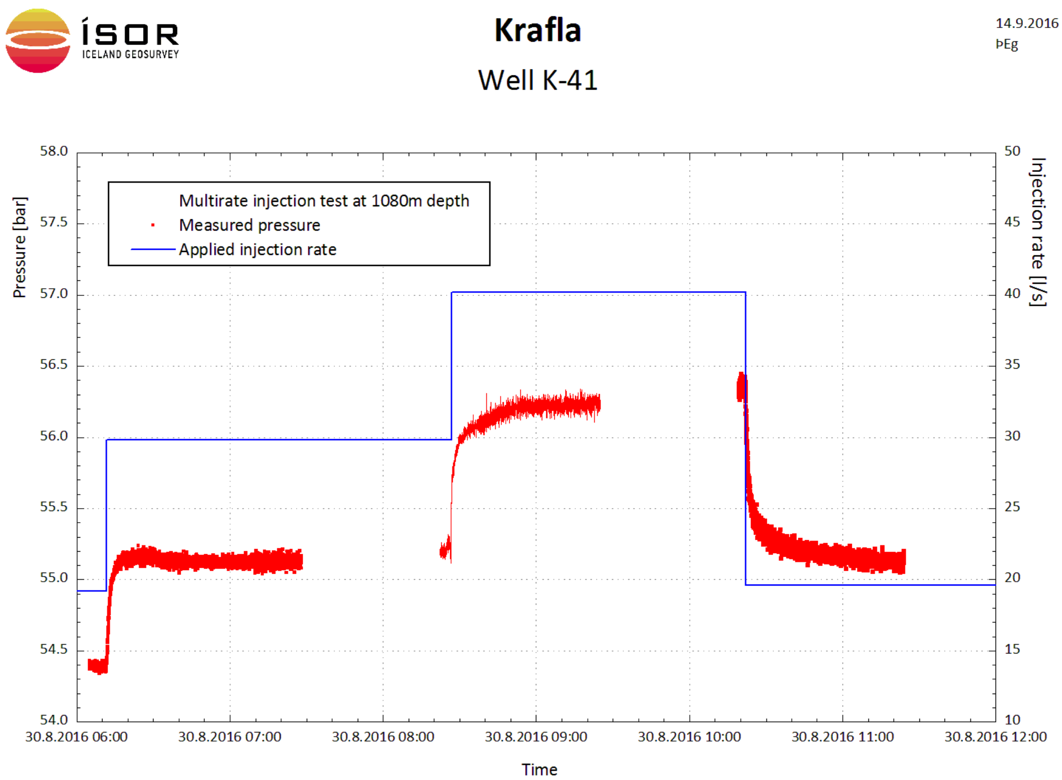


Figure 22. *Injectivity test August 30th. Measured pressure at 1080 m and applied injection rate.*

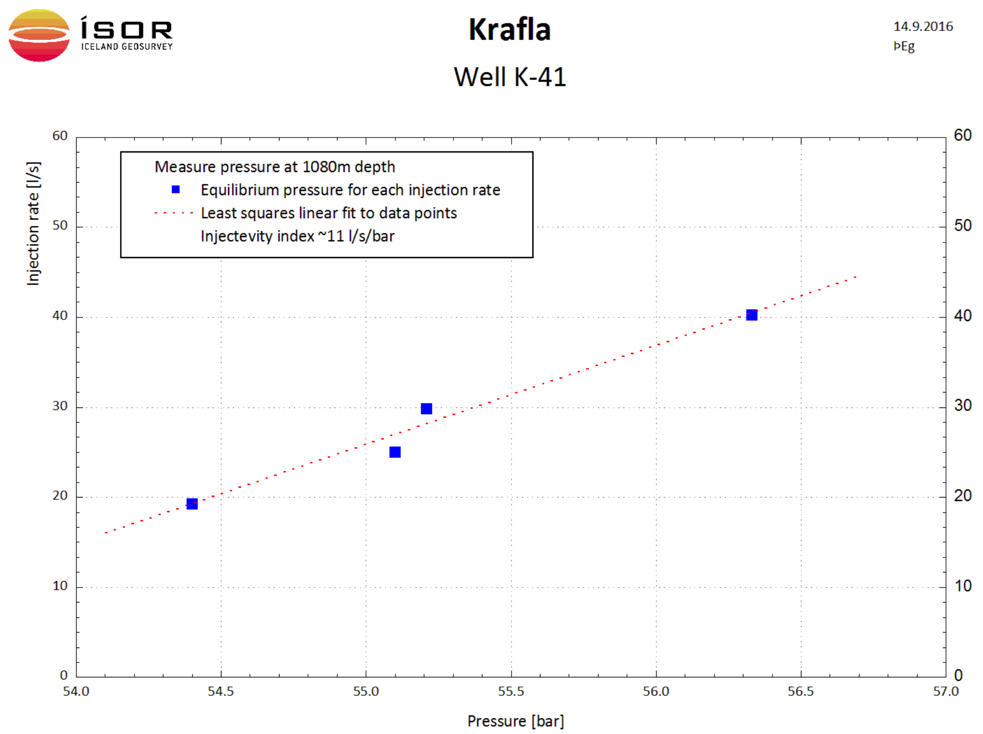


Figure 23. *The injection/pressure steps are correlated, with a constant injection/pressure relation of ~11 (L/s)/bar.*

5.3.1 Well testing analysis and modelling

In an injection test the pressure response is recorded with time after the injection rate is changed suddenly. The pressure response is then compared to the computed response of a model with certain properties that are considered to have similar physical properties as the well and the reservoir it is drilled into. The models at hand depend on various reservoir properties. These model parameters are varied and justified until a good match is obtained between the calculated model response and the actual pressure response measured in the well. The model parameters that give the best fit determine the value of the well and reservoir parameters. This modelling approach is called inverse modelling. This includes some uncertainty but with additional information on the known geology based on cutting analysis and loss zones in the well this uncertainty can be reduced. The computer program, Well Tester (Júlíusson et al., 2008), was used for the modelling of the injection test data from well K-41. Well Tester's algorithm is based on the well-known Theis' approach of the pressure diffusion equation for horizontal, isotropic reservoir and laminar flow that follows Darcy's law (Grant and Bixley, 2011). Non-linear regression analysis is used to determine the reservoir properties of the model that gives the best fit between data points and the model's response to the given change in injection. The results are presented both in tables and figures produced by the program.

5.3.2 Initial parameters

For interpretation of the injection test certain initial parameters for the well and the reservoir are requested. These are; the wellbore radius, accurate values of reservoir temperature, reservoir pressure, rock porosity, fluid dynamic viscosity and compressibility. Well K-41 is cased down to 1021 m in order to prevent diluted water in the formation above the geothermal reservoir to enter the wellbore. According to estimated reservoir temperature and pressure in the neighbouring well K-15, temperature and pressure at 1100 m in well K-41 should be close to 300°C and 80 bar. Other parameters are not necessary for reliable results of the modelling procedure. The reservoir porosity used in the model calculations is 8%. However, the better the parameter determination is, the better is the possibility to obtain accurate values of derived properties such as reservoir thickness and reservoir permeability. Initial parameters used for the data interpretation are listed in Table 11.

Table 11. *An overview of initial wellbore and reservoir parameters used for interpreting the injection test results.*

Property (symbol)	Value	Unit
Estimated reservoir temperature (T_{est})	~300	°C
Estimated reservoir pressure (P_{est})	~80	bar
Wellbore radius (r_w)	0.11	m
Porosity (ϕ)	0.08	-
Dynamic fluid viscosity (μ)	$2.0 \cdot 10^{-5}$	Pa·s
Fluid compressibility (c_w)	$1.9 \cdot 10^{-7}$	Pa^{-1}
Rock compressibility (c_r)	$2.4 \cdot 10^{-11}$	Pa^{-1}
Total compressibility (c_t)	$1.5 \cdot 10^{-8}$	Pa^{-1}

5.3.3 Model type and model properties

Analysing the injection test data seems to indicate that a dual porosity model is the most appropriate one, especially when it comes to fitting the time derivative response. The following model calculations are, therefore, based on a dual porosity model. This means that a secondary permeability, i.e. permeability based on fractures and/or faults in the rock formations, plays an important role in the reservoir mechanism. The well and reservoir model types used for the data analysis are listed in Table 12.

Table 12. *An overview of wellbore and reservoir model type used for the injection test performed in well K-41.*

Well and reservoir model type	
Reservoir	Dual porosity
Boundary	Constant pressure
Well type	Constant skin
Wellbore storage	Constant wellbore storage

The dual porosity model property refers to distinguishing the thermal reservoir into both a rock matrix that stores most of the fluid mass inside the reservoir, and a fracture system through which the reservoir fluid is transferred between different parts of it. The most important property for estimating in what sense the reservoir is dual porosity, i.e. to what extent is the reservoir storage determined by fracture activity, is the storativity ratio

$$\omega = \frac{\phi_f c_{tf}}{\phi_f c_{tf} + \phi_m c_{tm}}$$

where φ denotes porosity and c_t denotes total compressibility. The subscripts *f* and *m* refer to fractures and rock matrix. Note that the storativity ratio, which takes values between 0 and 1, increases as the porosity is more determined by fracture activity. The less this ratio becomes, the more of the reservoir fluid storativity occurs in the rock matrix. Another ratio, the transmissivity ratio, is defined for dual porosity reservoirs as

$$\lambda = \alpha \frac{k_m}{k_f} r_w^2$$

The transmissivity ratio connects the fissure permeability (k_f) to matrix permeability (k_m) and it gets less as the relative fissure permeability is increased. r_w is the wellbore radius and α is a coefficient that relates fissure connection to the rock matrix (Horne, 1995).

5.3.4 Modelling results for the K-41 injection test

In following subchapters, the interpretation results of each injection step are shown with one table and four figures. The table shows values of the well and reservoir properties obtained with the model calculations, i.e. the table lists the actual results of the injection test for the current injection step. The first figure shows the measured pressure and the injection rate during the corresponding injection step. The second figure shows both the pressure change and the logarithmic derivative $\left(\frac{\partial P}{\partial \ln t} = t \cdot \frac{\partial P}{\partial t}\right)$ (Horne, 1995) of the observed pressure on a logarithmic scale for both time and pressure for a dual porosity reservoir. This graph shows how well the observed data are fitted and the logarithmic time derivative indicates how well the model type used for the interpretation suits the observed data. The third figure shows the model fit of the data with a logarithmic time scale and a linear pressure scale and the fourth figure shows on a linear scale how the model response fits the observed pressure on a linear scale.

The obtained model properties of transmissivity and storativity can be used to estimate effective permeability and reservoir thickness for known porosity in the well's vicinity and estimated rock and fluid compressibility (Grant and Bixley, 2011). However, it should be noted that the compressibility values depend on the reservoir state, i.e. temperature and pressure, so the estimated derived parameter values generally depend on properties that are only roughly known. The formulae for the reservoir permeability is $k = \frac{T}{S} \cdot \mu \cdot c_t$ and for reservoir thickness $h = \frac{S}{c_t}$.

The estimated skin effect is an important well property determined from a pressure response at the wellbore's boundary. A negative skin effect is a measure of good permeability between the wellbore wall and the neighbour formation matrix or connecting fissure (Horne, 1995). In case of well damages, possibly caused by cuttings sitting in permeable zones, the calculated skin effect turns into positive values.

As mentioned above, the two ratio reservoir properties, transmissivity ratio and storativity ratio should reflect the dual porosity character in the model. Therefore, they will be discussed for each step of the injection test in order to estimate the validity of choosing the dual porosity model of the interpretation program.

5.3.5 K-41 Injection test: Step 1 (19.2 L/s to ~29.8 L/s)

The first step of the injection test was to change the injection rate from 19.2 L/s to 29.8 L/s. The initial pressure was 54.4 bar and the equilibrium pressure was 55.2 bar which was reached within 25 minutes. Figure 24 shows the pressure measured at 1080 m during the first step change of the multi rate injection test.

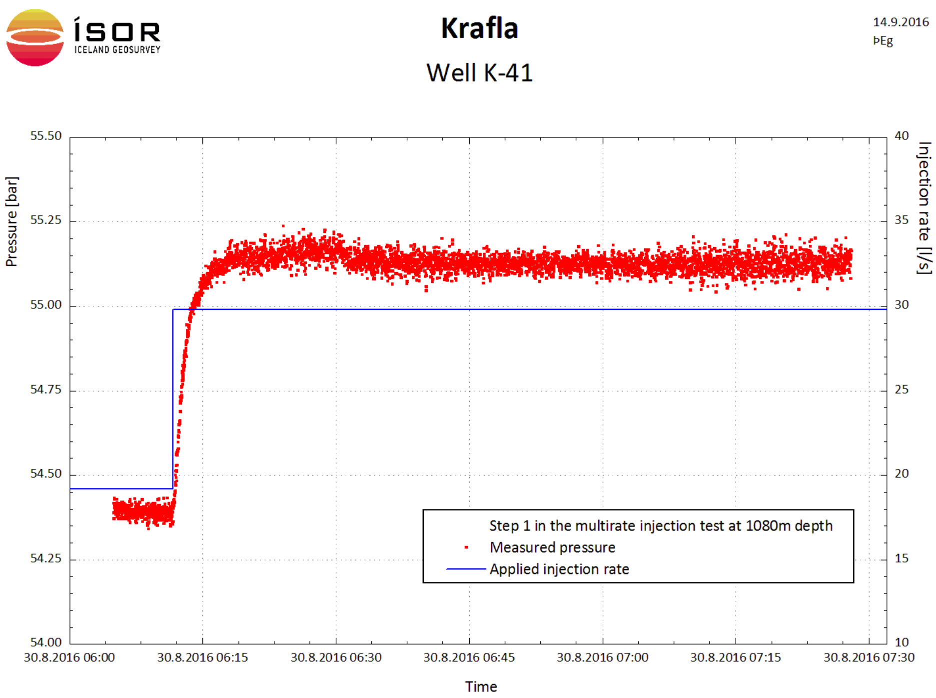


Figure 24. *Pressure response at 1080 m to change in injection rate from 19.2 L/s to 29.8 L/s.*

Table 13. *Modelled well- and reservoir parameters for constant pressures boundaries from the pressure recorded in Step 1 of the injectivity test.*

Reservoir/Well properties	Value	Standard Deviation	Unit
Transmissivity (T)	9.3	0.1	10^{-8} m³/(Pa s)
Storativity (S)	1.78	0.03	10^{-7} m/Pa
Response distance (r_e)	14	1	m
Skin factor (s)	-0.7	-	
Wellbore storage (C)	1.2	$4 \cdot 10^{-3}$	10^{-5} m³/Pa
Transmissivity ratio (λ)	0.88	0.02	10^{-5}
Storativity ratio (ω)	9.3	0.2	10^{-4}
Reservoir Thickness (h)	50-100	-	m
Injectivity Index (II)	14.2	-	(L/s)/bar
Effective Permeability (k)	20-40	-	10^{-15} m²

As seen in Figures 25–27 the obtained parameters for a dual porosity model listed in Table 13 give a good fit to the observed data after the first minute of the test and the model is reliable for calculating the pressure response for any change in injection rate. The scattering in the pressure data are extensively magnified in the time derivative which makes closer interpretation of the model parameters uncertain. That includes that dual porosity character of in the dataset is not obvious since the simulation of time derivative of the pressure has a great variety.

The main reservoir properties, transmissivity and storativity, that govern the model simulation of the obtained pressure data are determined with good accuracy. For this step the skin effect of -0.7 represents a fair coupling of the well to the formation. As said above there is a large scattering in the time derivative data which makes interpretation of the storativity ratio value and the transmissivity ratio value difficult and even meaningless.

From the reservoir properties listed in Table 13 and the reservoir parameters listed in Table 11, the estimated reservoir thickness is $h \approx 50 - 100\ m$ which leads to reservoir permeability of $k \approx 20 - 40\ milliDarcy$. Compared to general permeability of geothermal fields, reservoir permeability of 30 milli-Darcy, is about moderate (Axelsson, 2004).

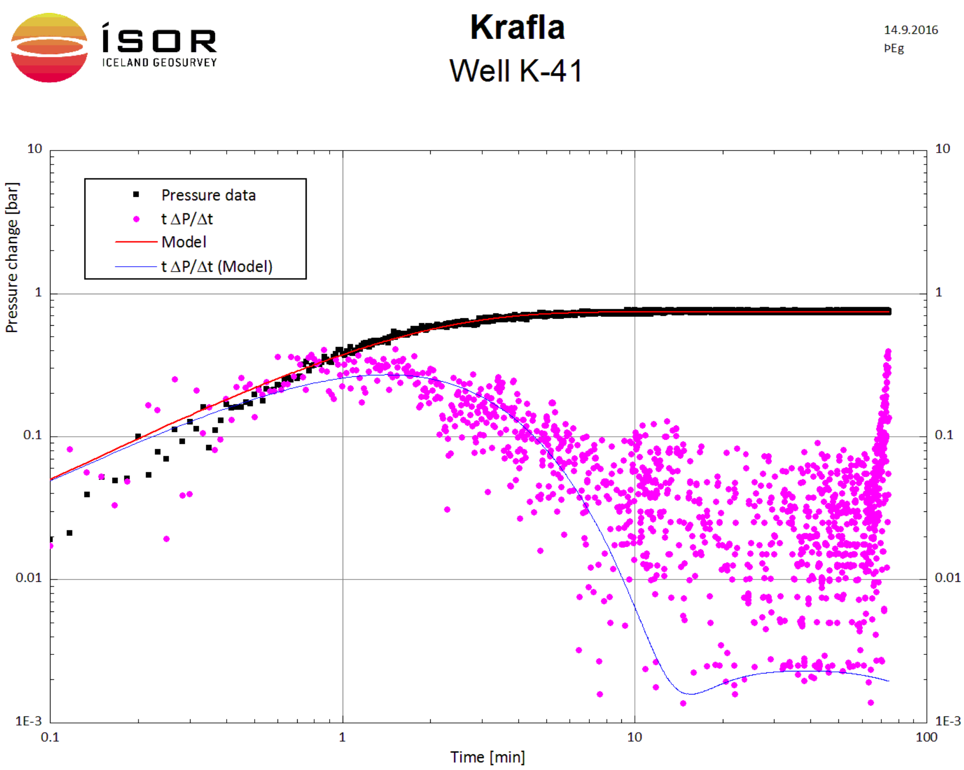


Figure 25. *Modelling results for step 1 on a logarithmic scale for both the pressure change and the time derivative of the pressure data.*

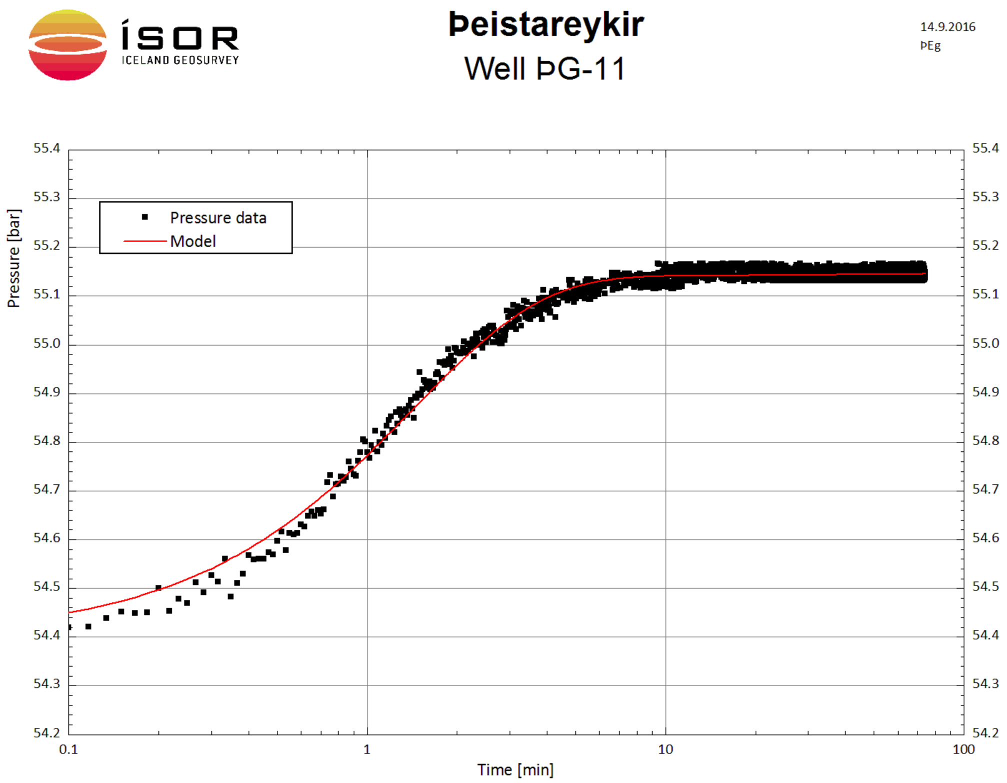


Figure 26. *Modelling results for step 1 on a logarithmic scale for the time and on a linear scale for the pressure data.*

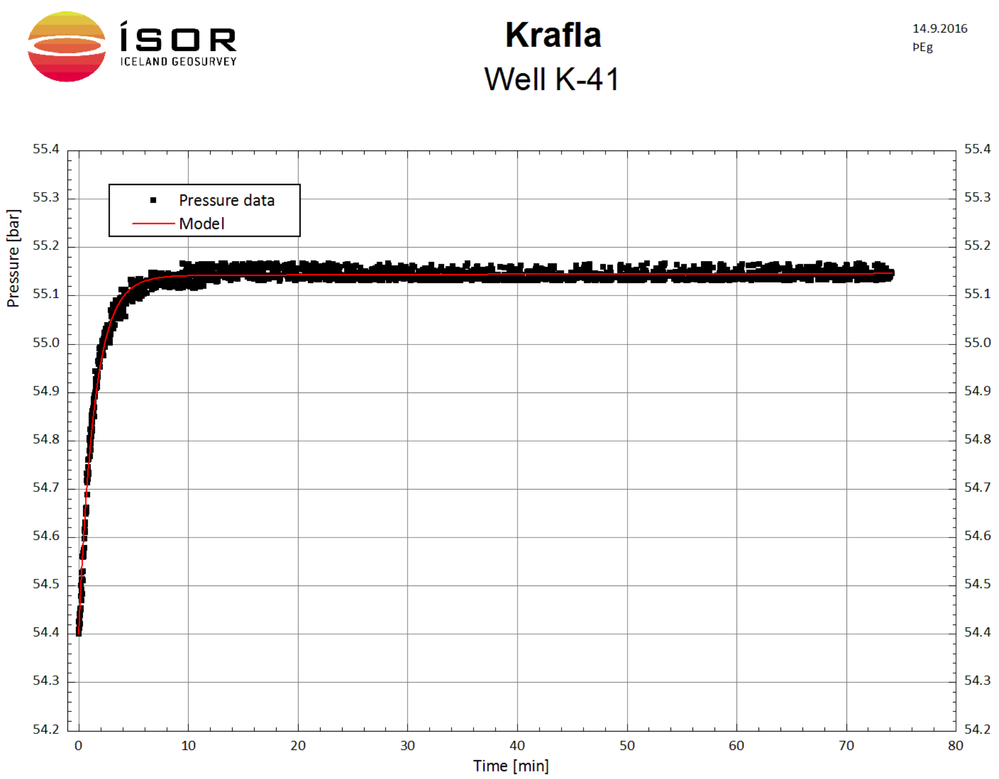


Figure 27. *Modelling results for step 1 on a linear scale for both time and pressure data.*

5.3.6 K-41 Injection test: Step 2 (29.8 L/s to 40.2 L/s)

The second step of the injection test was to change the injection rate from 29.8 L/s to 40.2 L/s. The initial pressure was 55.2 bar and the estimated equilibrium pressure was 56.3 bar which was reached after only about 40 minutes, see Figure 28.

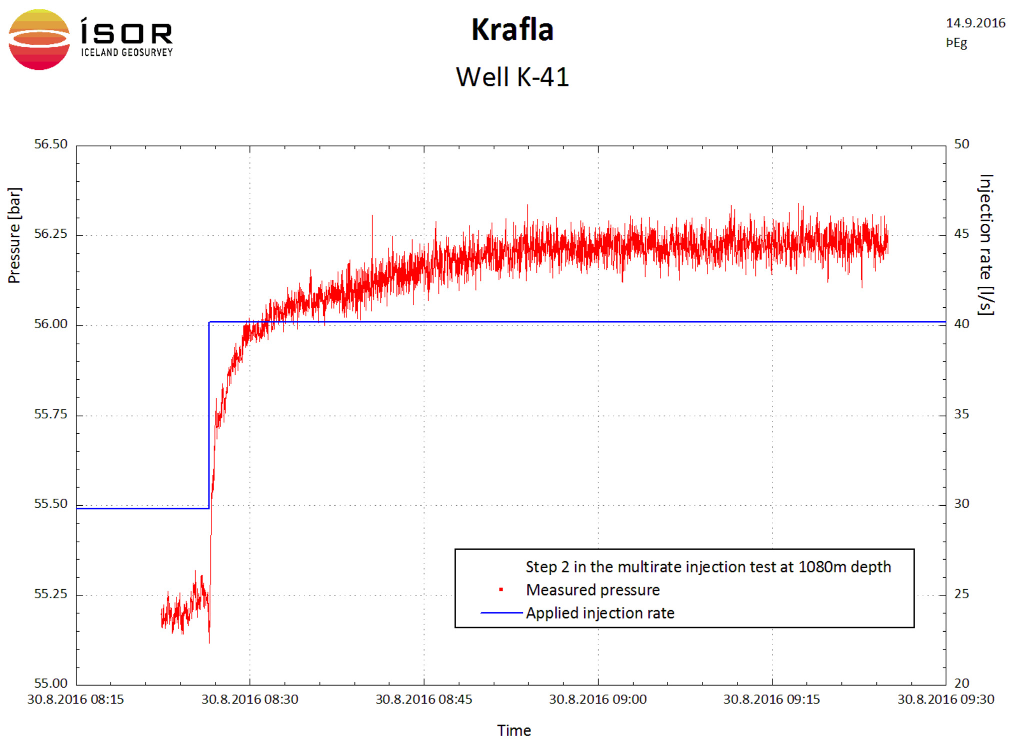


Figure 28. *Pressure response at 1080 m to change in injection rate from 29.8 L/s to 40.2 L/s.*

Table 14. *Modelled well- and reservoir parameters for constant pressures boundaries from the pressure recorded in Step 2 of the injectivity test.*

Parameter	Value	Standard Deviation	Unit
Transmissivity (T)	6.95	0.05	10^{-8} m³/(Pa s)
Storativity (S)	3.90	0.07	10^{-7} m/Pa
Response distance (r_e)	26.9	0.4	m
Skin factor (s)	-1.40	0.02	
Wellbore storage (C)	0.28	0.01	10^{-5} m³/Pa
Transmissivity ratio (λ)	2.0	0.1	10^{-3}
Storativity ratio (ω)	7	1	10^{-5}
Reservoir Thickness (h)	50-100		m
Effective Permeability (k)	15-30		10^{-15} m²
Injectivity Index (II)	10.7		(L/s)/bar

As seen in Figures 29–31 the obtained parameters for a dual porosity model listed in Table 14 give a good fit to the observed data after the first minute of the test and the model is reliable for calculating the pressure response for any change in injection rate. The scattering in the pressure data are extensively magnified in the time derivative which makes closer interpretation of the model parameters uncertain. That includes that dual porosity character of in the dataset is not obvious since the simulation of time derivative of the pressure has a great variety.

The main reservoir properties, transmissivity and storativity, that govern the model simulation of the obtained pressure data are determined with good accuracy. For this step the skin effect of -1.4 represents a fair to good coupling of the well to the formation. As said above there is a large scattering in the time derivative data which makes interpretation of the storativity ratio value and the transmissivity ratio value difficult and even meaningless.

From the reservoir properties listed in Table 14 and the reservoir parameters listed in Table 11, the estimated reservoir thickness is $h \approx 50 - 100\ m$ which leads to reservoir permeability of $k \approx 15 - 30\ milliDarcy$. Compared to general permeability of geothermal fields, reservoir permeability of 30 milli-Darcy, is about moderate (Axelsson, 2004).

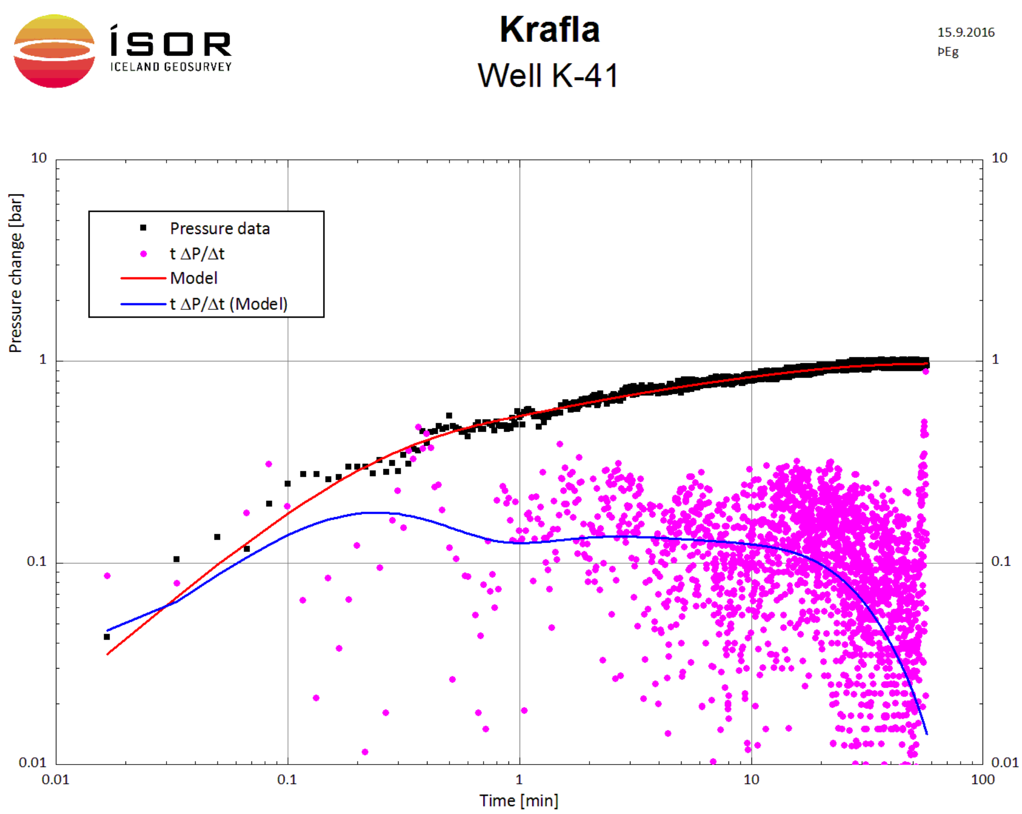


Figure 29. *Modelling results for step 2 on logarithmic scale for both the pressure change and the time derivative of the pressure data.*

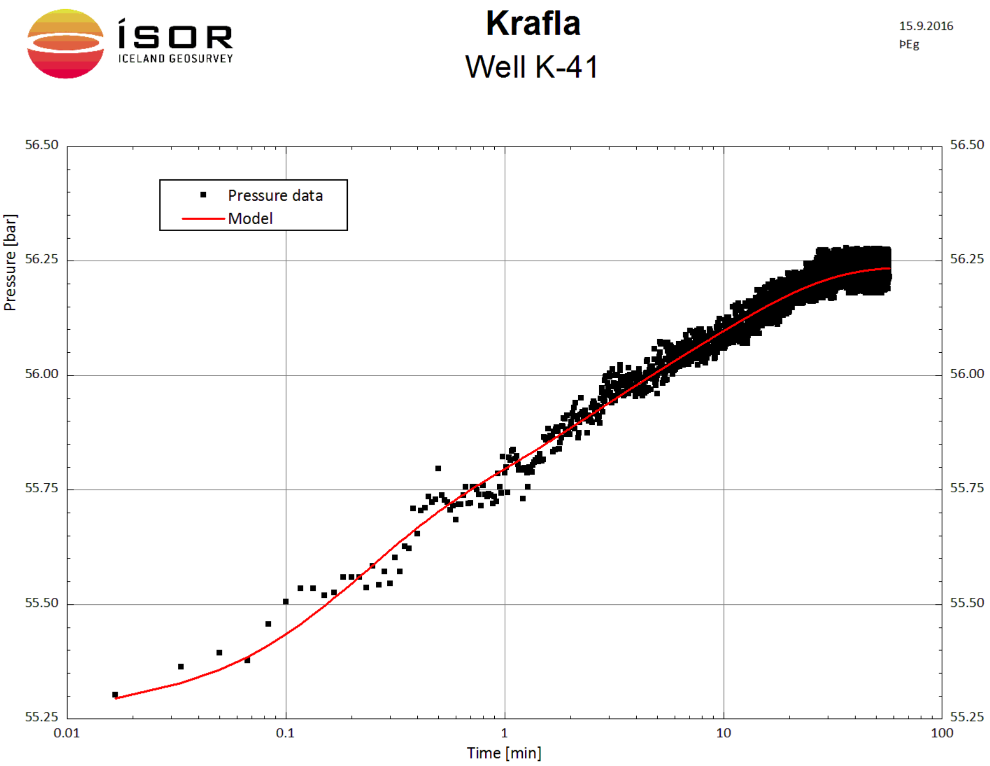


Figure 30. *Modelling results for step 2 on a logarithmic scale for the time and on a linear scale for the pressure data.*

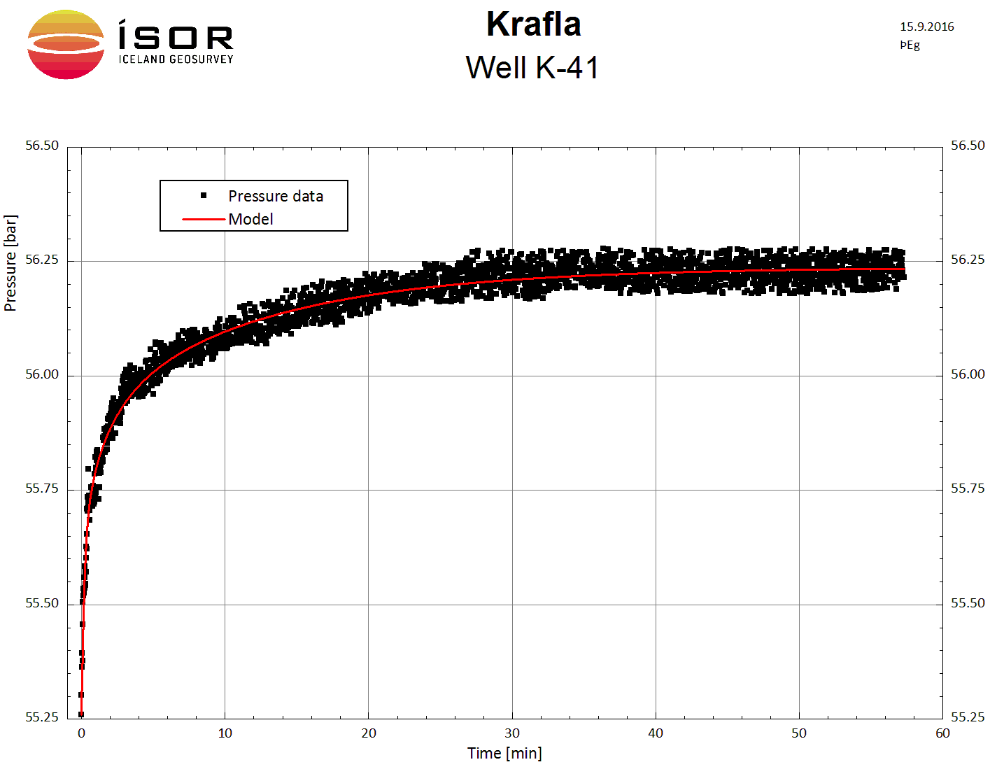


Figure 31. *Modelling results for step 2 on linear scale for both time and pressure data.*

5.3.7 K-41 Injection test: Step 3 (40.2 L/s to 25.0 L/s)

The third step of the injection test was to change the injection rate from 40.2 L/s to 25.0 L/s. The initial pressure was 56.3 bar and the estimated equilibrium pressure was 55.1 bar (Figure 32).

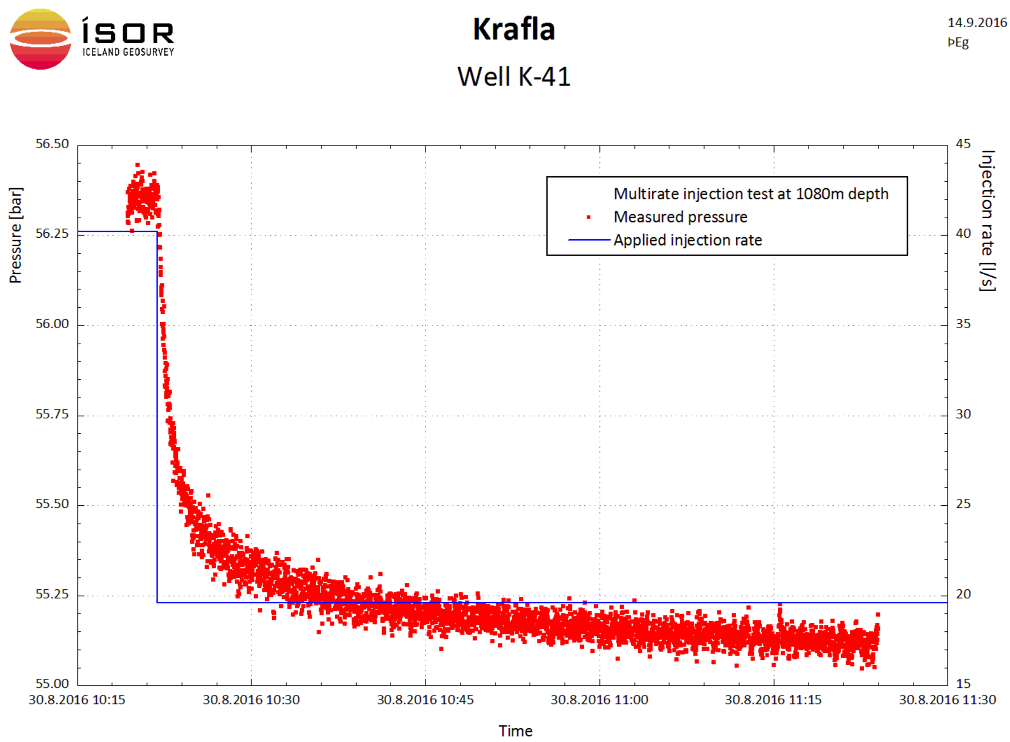


Figure 32. *Pressure response at 1080 m to change in injection rate from 40.2.6 L/s to 25.0 L/s.*

Table 15. *Modelled well- and reservoir parameters for constant pressures boundaries from the pressure recorded in Step 3 of the injectivity test.*

Parameter	Value	Standard Deviation	Unit
Transmissivity (T)	12.00	0.01	10^{-8} m³/(Pa s)
Storativity (S)	2.25	0.03	10^{-7} m/Pa
Response distance (r_e)	63	1	m
Skin factor (s)	-0.10	0.01	
Wellbore storage (C)	0.79	0.05	10^{-5} m³/Pa
Transmissivity ratio (λ)	3.5	0.01	10^{-4}
Storativity ratio (ω)	0.10	0.09	10^{-4}
Reservoir Thickness (h)	50-100		m
Effective Permeability (k)	25-50		10^{-15} m²
Injectivity Index (II)	12.3		(L/s)/bar

As seen in Figures 33–35 the obtained parameters for a dual porosity model listed in Table 15 give a good fit to the observed data after the first minute of the test and the model is reliable for calculating the pressure response for any change in injection rate. The scattering in the pressure data are extensively magnified in the time derivative which makes closer interpretation of the model parameters uncertain. That includes that dual porosity character of in the dataset is not obvious since the simulation of time derivative of the pressure has a great variety.

The main reservoir properties, transmissivity and storativity, that govern the model simulation of the obtained pressure data are determined with good accuracy. For this step the skin effect of -1.4 represents a fair to good coupling of the well to the formation. As mentioned earlier there is a large scattering in the time derivative data which makes interpretation of the storativity ratio value and the transmissivity ratio value difficult and even meaningless.

From the reservoir properties listed in Table 15 and the reservoir parameters listed in Table 11, the estimated reservoir thickness is $h \approx 50 - 100\,m$ which leads to reservoir permeability of $k \approx 25 - 50\,milliDarcy$. Compared to general permeability of geothermal fields, reservoir permeability of 30 milli-Darcy, is about moderate (Axelsson, 2004).

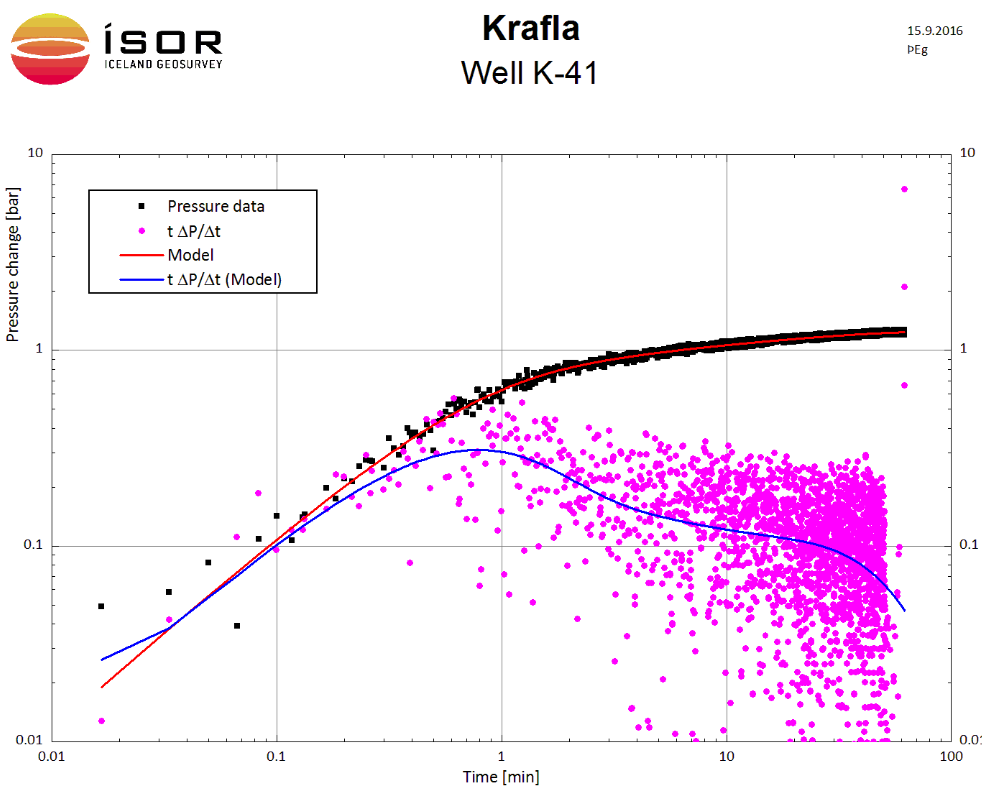


Figure 33. *Modelling results for step 3 on logarithmic scale for both the pressure change and the time derivative of the pressure data.*

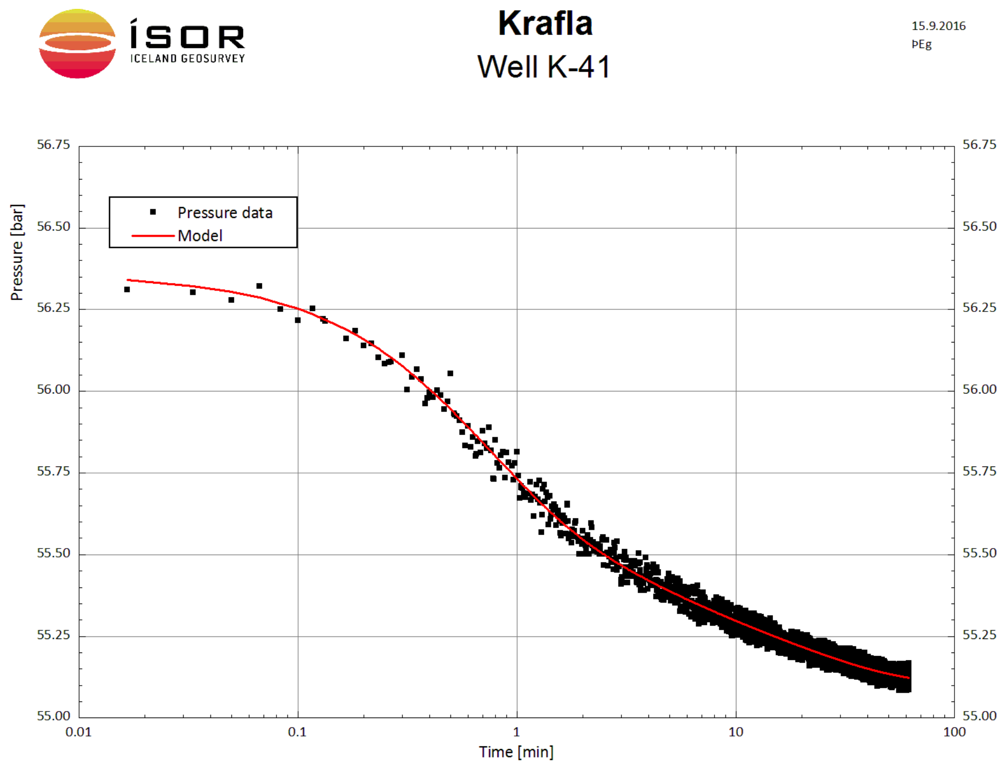


Figure 34. *Modelling results for step 3 on a logarithmic scale for the time and on a linear scale for the pressure data.*

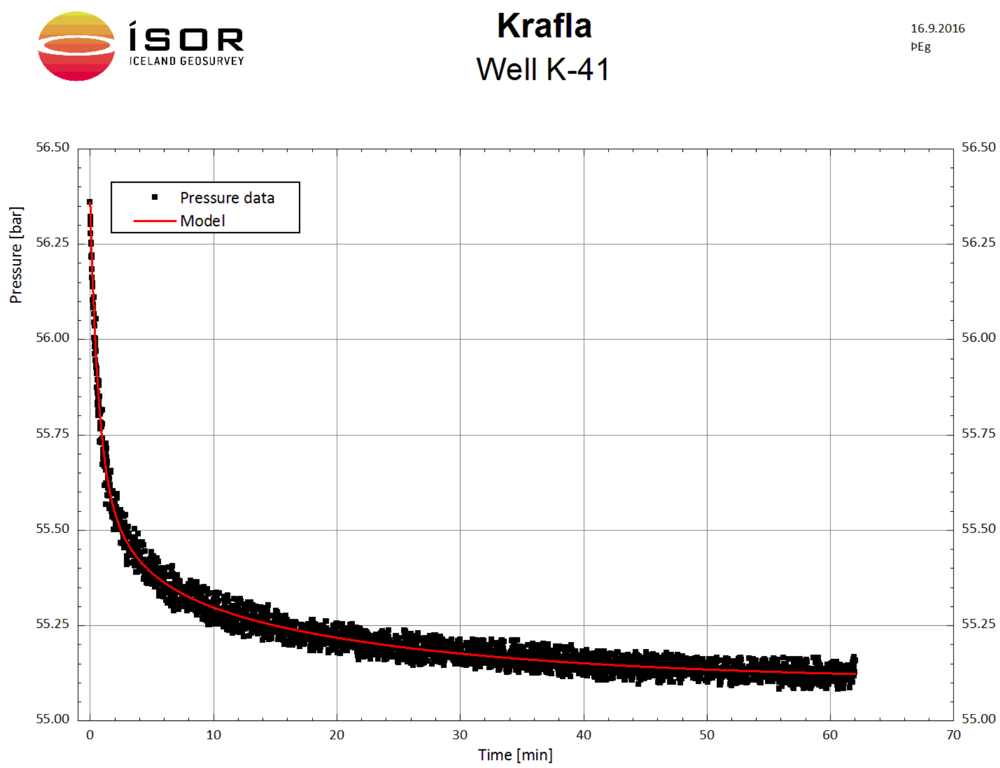


Figure 35. *Modelling results for step 3 on a linear scale for both time and pressure data.*

Table 16. *An overview of the multi rate injection test analysis.*

Reservoir/Well properties	Step 1	Step 2	Step 3
Transmissivity [10^{-8} m³/(Pa s)]	9.3	7.0	12
Storativity [10^{-8} m/Pa]	1.8	3.9	2.3
Response distance [m]	14	27	63
Skin factor [-]	-0.7	-1.4	-0.1
Wellbore storage [10^{-5} m³/Pa]	1.2	0.3	0.8
Transmissivity ratio [10^{-4}]	0.9	20	3.5
Storativity ratio [10^{-4}]	9.3	70	0.1
Reservoir Thickness	50-100	50-100	50-100
Injectivity Index [(L/s)/bar]	14.2	10.7	12.3
Effective Permeability [10^{-15} m²]	20-40	15-30	25-50

The general result of the simple modelling is that for each of the step rate changes, each property is well determined, i.e. low standard deviation. The values of parameters are, however, a bit different for the individual steps. The estimated reservoir thickness is about 50–100 m with a consequent reservoir permeability of 15–50 milli Darcy, which is a moderate up to high value for a geothermal reservoir. The 50–100 m estimate of the reservoir thickness is mainly taken from temperature logs, see Figure 18.

5.4 Flow measurements with spinner log

In combination with the multi rate injection test in well K-41, several flow (spinner) logs were conducted with the PTS tool. An overview of the spinner logs is given in Table 17. Figure 36 shows all the logging runs during the multi rate injection test in the well together with the applied injection rates. As seen, the spinner turns were measured for six, and up to eight, different logging speeds for each of the four injection rates applied before and during the injection test. Figures 37–40 show all the spinner logs viewed in Table 17. For interpretation of the spinner data, flow calculations were evaluated only for the initial injection rate of 19.2 L/s and the maximum flow rate of 40.2 L/s. The main purpose of the spinner logs is to locate permeable zones of the well and determine the fluid quantity lost/gained at each of them. Suspected feed zones detected for the data analysis were at 1120, 1140, 1230 and 1255 m, and a loss zone in the interval below 1270 m to bottom. Thorough analysis of the flow data was then carried out at 1048, 1070, 1225, 1240, 1270 and 1290 m with cross-plots that give a good estimate of the fluid velocity at each location (Grant and Bixley, 2011). The fluid speed at 1048 m depth is regarded to represent the injection into the well (no feed zones higher up in the well). Variation in diameter of the well greatly affects the actual fluid speed at each location and has therefore to be considered in the analysis.

Table 17. *An overview of the spinner logs prior and during the multistep injection test in well K-41.*

Tool speed [m/min]	Depth interval [m]	Time interval	Data file
Injection rate 19.2 L/s:			
45	900-1300	05:06-05:15	Q201608300506.dat
-45	1300-1000	05:28-05:34	Q201608300528.dat
55	1000-1300	05:35-05:41	Q201608300535.dat
-55	1300-1020	05:41-05:46	Q201608300541.dat
65	1020-1300	05:48-05:52	Q201608300548.dat
-65	1300-1020	05:53-05:57	Q201608300553.dat
Injection rate 29.8 L/s:			
45	1080-1300	07:32-07:36	Q201608300732.dat
-45	1300-1000	07:37-07:43	Q201608300737.dat
55	1000-1300	07:44-07:49	Q201608300744.dat
-55	1300-1020	07:50-07:54	Q201608300750.dat
65	1020-1300	07:55-07:59	Q201608300755.dat
-65	1300-1020	08:00-08:03	Q201608300800.dat
Injection rate 40.2 L/s:			
45	1080-1300	09:27-09:32	Q201608300927.dat
-45	1300-1000	09:32-09:38	Q201608300932.dat
55	1000-1300	09:39-09:44	Q201608300939.dat
-55	1300-1020	09:45-09:50	Q201608300945.dat
65	1020-1300	09:50-09:54	Q201608300950.dat
-65	1300-1020	09:55-09:59	Q201608300955.dat
75	1020-1300	09:59-10:03	Q201608300959.dat
-75	1300-1080	10:03-10:07	Q201608301003.dat
Injection rate 25.0 L/s:			
45	1080-1300	11:25-11:29	Q201608301125.dat
-45	1300-1000	11:29-11:36	Q201608301129.dat
55	1000-1300	11:36-11:41	Q201608301136.dat
-55	1300-1020	11:42-11:47	Q201608301142.dat
65	1020-1300	11:47-11:51	Q201608301147.dat
-65	1300-950	11:52-12:00	Q201608301152.dat
-65	950-30	12:00-12:33	Q201608301200.dat

Figure 36. *An overview of the logging runs during the combined multi rate injection test and the flow test together with applied injection rates.*

Cross-plots, where tool speed vs. spinner turns are plotted, are shown in Figures 42–53. As seen in these figures, the fluid speed at each location is determined with a good accuracy which is reflected by the fact that the straight line regression in all cases has the correlation coefficient (Davis, 1973) close to unity ($0.999 < R^2 \leq 1$). As seen on the caliper log in Figure 20 there are irregularities in the wells caliper that must affect the flow pattern of the water in the well. Besides, the spinner log is measured inside the perforated liner and part of the flow occurs in the annulus outside the liner which makes the data interpretation not so unique. The given average fluid velocity in the cross-plots for each location is determined from flow in regular circle cross sectional area as 83% of the maximum flow speed at the center of the well (Grant and Bixley, 2011) which is the first approximation of the fluid flow speed. The cross-plot results are listed in Table 18. The changes from one location to another in the table can be explained as in- or outflow zones between the sites except the difference between 1048 and 1070 m at 19.2 L/s injection. There is no indication in the well data of a loss zone in this interval and the well diameter is similar at both locations. There 40.2 L/s the flow does not change in flow between the 1048 and 1070 m.

Table 18. *Estimated fluid speed in m/min at certain locations during flow measurements according to the cross plots in Figures 42–53.*

Depth	Inj. 19.2 L/s	Inj. 40.2 L/s
1048	53.3	101.5
1070	42.3	100.2
1225	54.4	92.5
1240	46.7	80.6
1270	23.9	45.8
1290	16.3	28.7

According to the temperature logs measured on August 26th and 29th under 19 L/s injection rate , there are feed zones at 1120 m and at 1140 m with inflow of hotter water adding to the injection, see Figure 41. The inflow is not clearly seen in the spinner data, mainly because of the irregular shape of the well in this section, see Figure 20.

In the cross-plot analysis a very consistent relation between the fluid speed and the spinner turns was obtained, i.e. 20.51 RPM increase in propel turns for an increase of 8.3 m/min in average fluid velocity. This was used to calculate the average fluid velocity for the whole profiles with the spinner log. Also, it is known that fluid flow through circular area depends on its velocity and the square of the area, i.e. $Q{\sim}v_{av} \cdot d^2$. This means that changes in $v_{av} \cdot d^2$ represent changes in the flow. Figure 54 shows this term plotted for the depth profiles of the spinner log. The profiles are consistent except for that section (1080–1190 m) in the well where there are irregularities in the caliper log and X- and Y- arms are not consistent which causes ambiguous flow regime. The anomaly seen at 1030–1040 m is probably caused by non-perforated liner pipes that cover the washed out part of the well behind the casing. In this figure, the inflow at the feed zone interval 1100–1120 m and the inflow at 1140 m are possibly seen as anomalies in the flow but cannot be evaluated to exact flow. In Figure 54 loss zones are detected at 1230, 1245, 1255 and 1275 m. The variations below 1290 m is partly due gradually outflow from the well but is also caused by the change in the log speed as the tool is approaching bottom. In temperature logs it is clearly seen that there is a permeable zone at the very bottom of the well, even though it is regarded a small one. The values for $v_{av} \cdot d^2$ on the abscissa axis of Figure 54 is scaled to the 40.2 L/s injection rate at well head and the outflow at each permeable zone should be close to the subsequent flow values.

An overview of interpreted active feed zones of well K-41 based on circulation losses and temperature and spinner logs is given in Table 19 with remarks on how each feed zone is determined.

Table 19. *Feed zones of K-41 based on drilling and well log data.*

Depth [m]	Size	Loss of circulation [L/s]	Remarks on reasoning
1100-1120	Intermediate	17	Seen as inflow in most temperature logs. LOC measured 17 L/s at 1123 m.
1140	Large	>40	Seen as inflow in most temperature logs. When stuck at 1142 m LOC exceeded 40 L/s which was maintained the rest of the drilling.
1230	Intermediate	>40	Seen in spinner logs and in temperature log during heat-up on August 25th when stuck.
1245	Large	>40	Seen in spinner logs.
1255	Small	>40	Seen as out flow in temperature logs when TD at 1259 m. Appears as small feed zone in spinner logs.
1275	Intermediate	>40	Seen in temperature log on August 28th. Intermediate size according to the spinner log.
1305	Small	>40	Latest temperature logs show outflow close to BOH. According to spinner logs this feed zone is small.

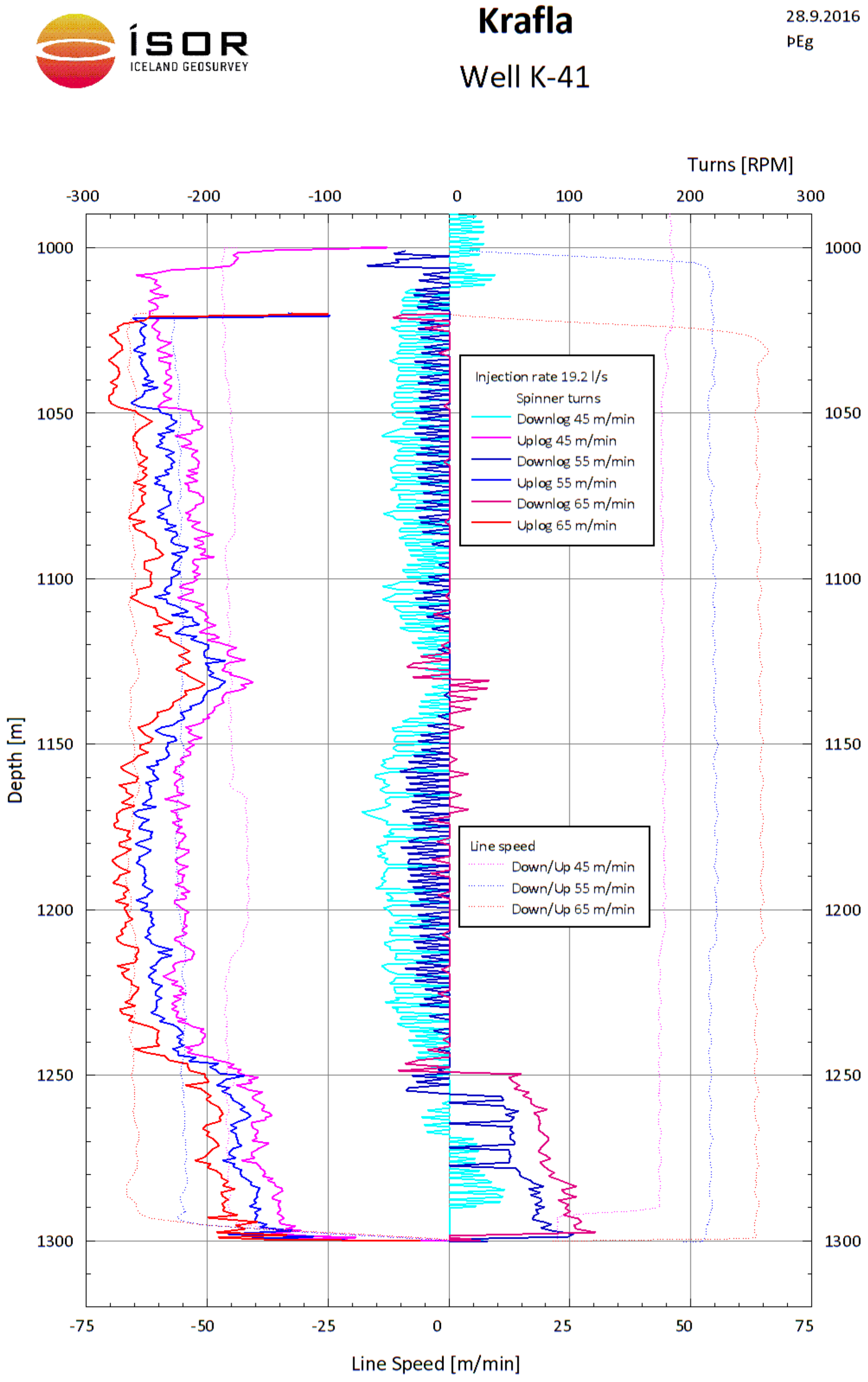


Figure 37. *The spinner logs run with 19.2 L/s injection rate prior to the injection test.*

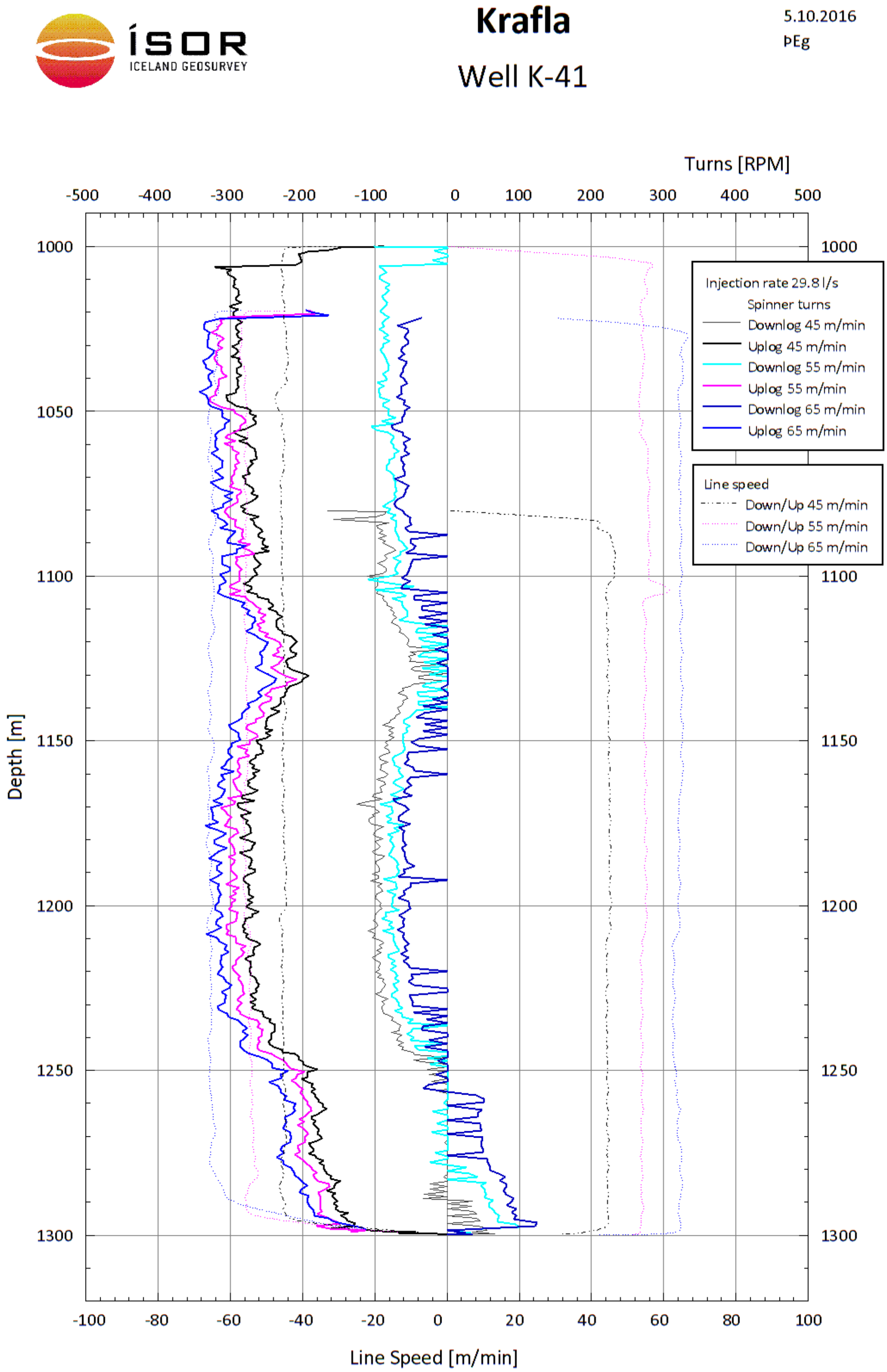


Figure 38. *The spinner logs run during the first step with 29.8 L/s injection rate.*

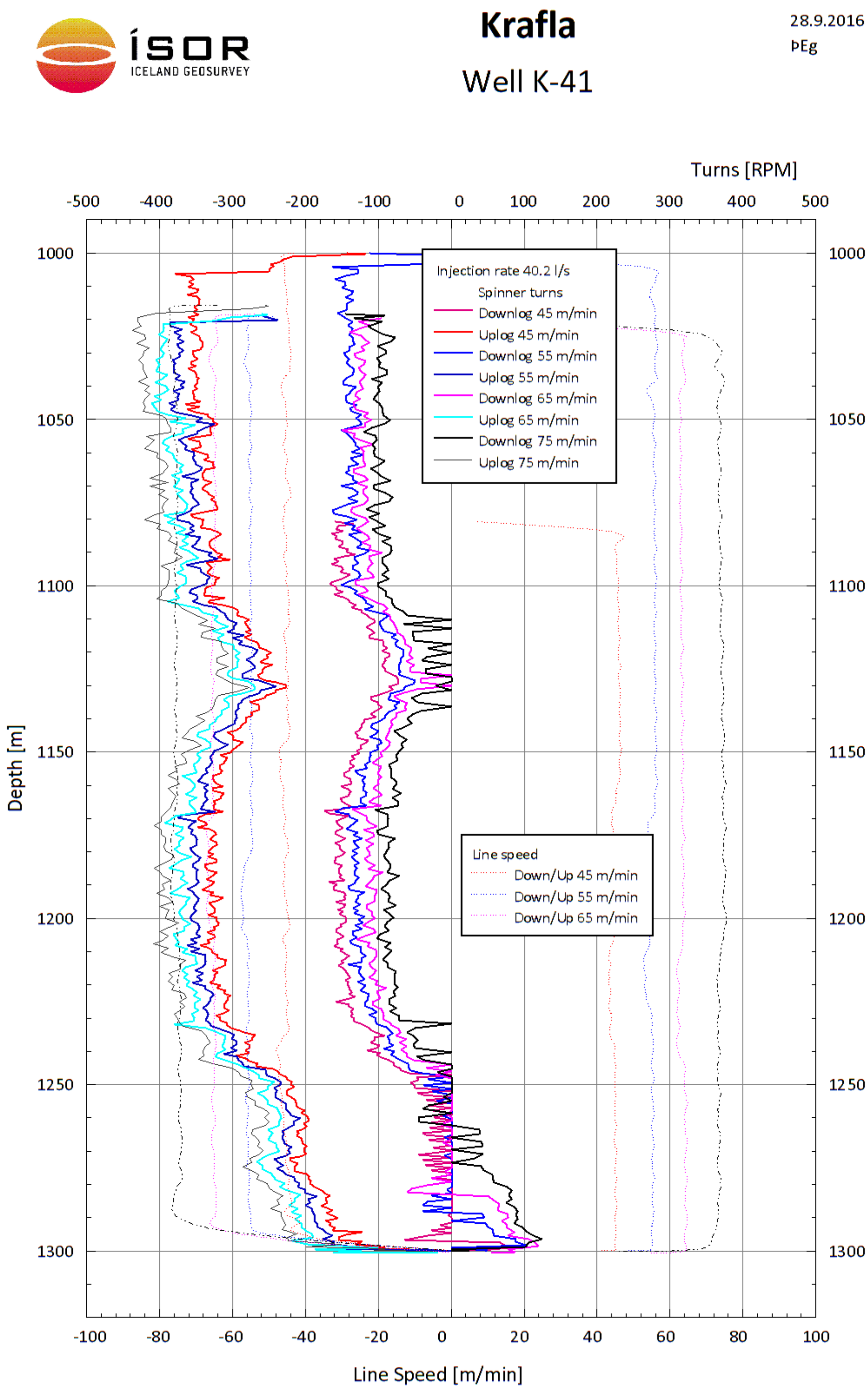


Figure 39. *The spinner logs run during the second step with 40.2 L/s injection rate.*

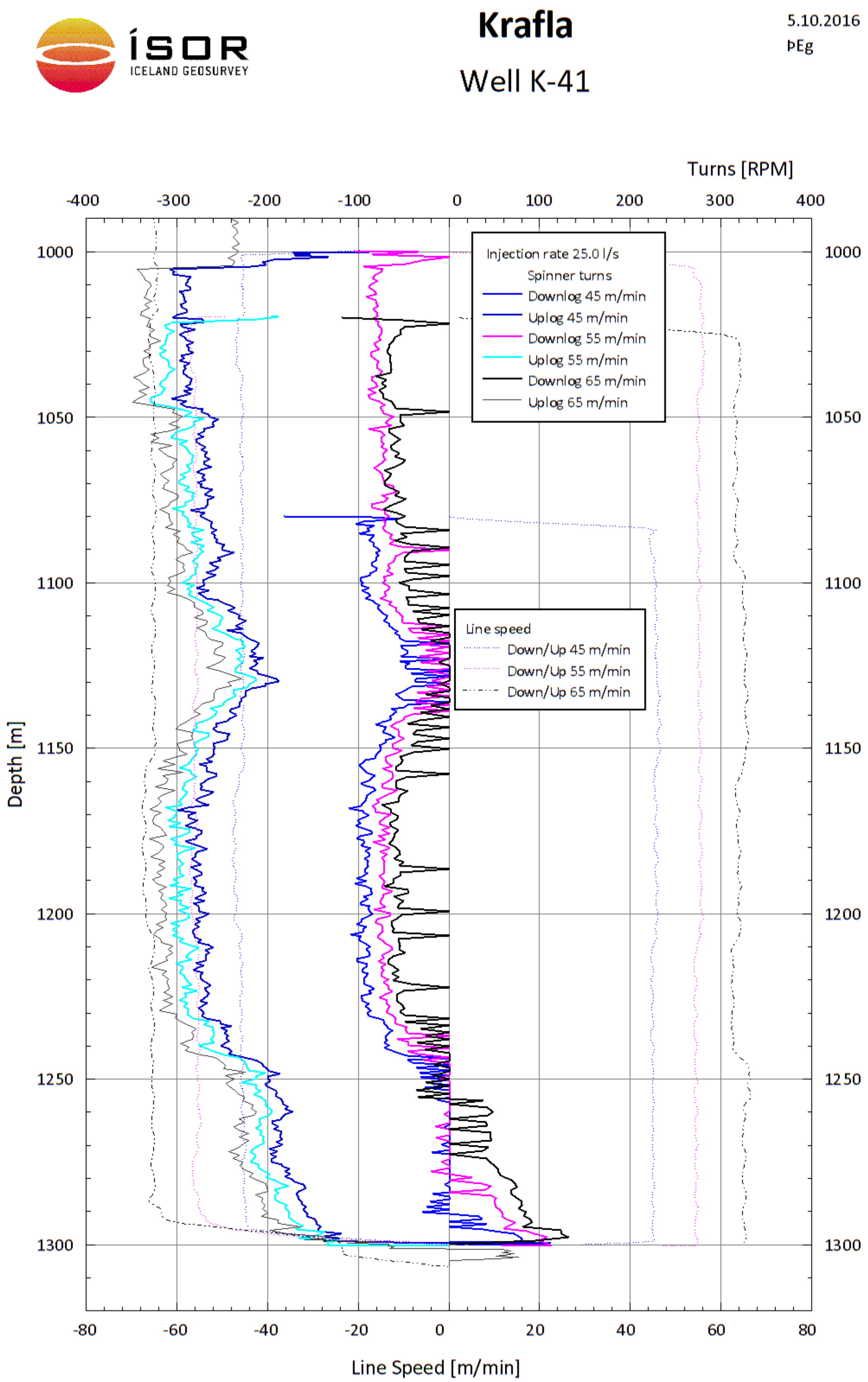


Figure 40. *The spinner logs run during the fall-off step with 25.0 L/s injection rate.*

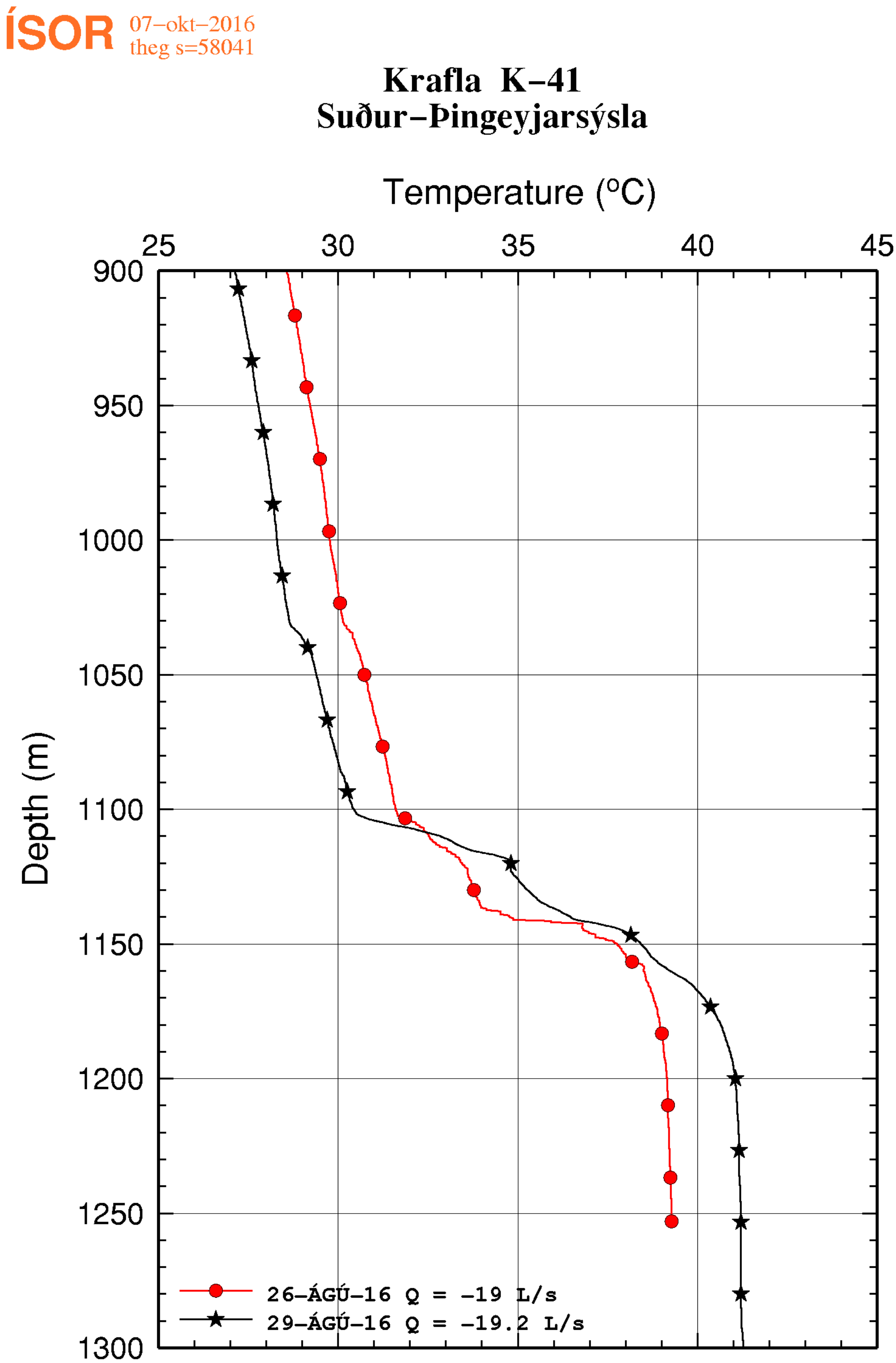


Figure 41. *Temperature logs showing permeable zones from 1100 m.*

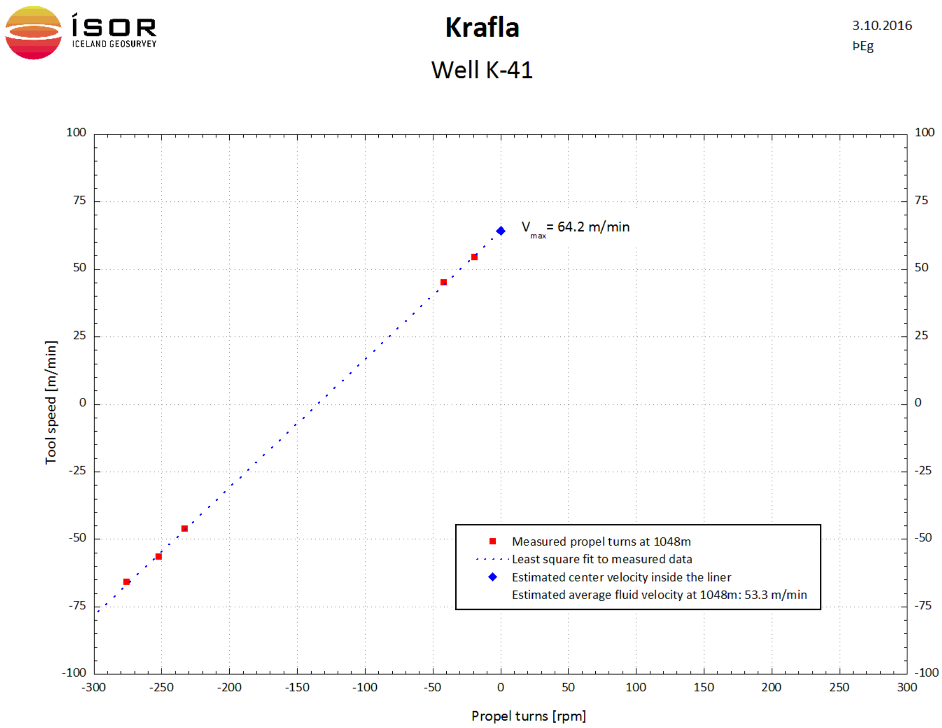


Figure 42. *Cross-plot at 1048 m under 19.2 L/s injection rate gives an average fluid velocity ~53 m/min (83% of V_{max}).*

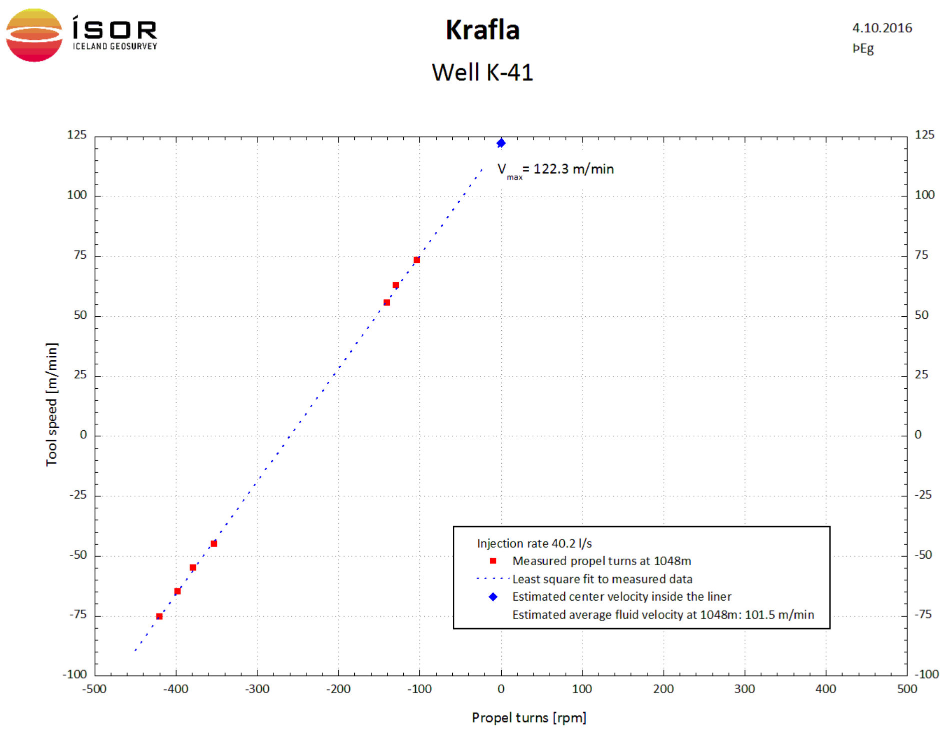


Figure 43. *Cross-plot at 1048 m under 40.2 L/s injection rate gives an average fluid velocity ~102 m/min (83% of V_{max}).*

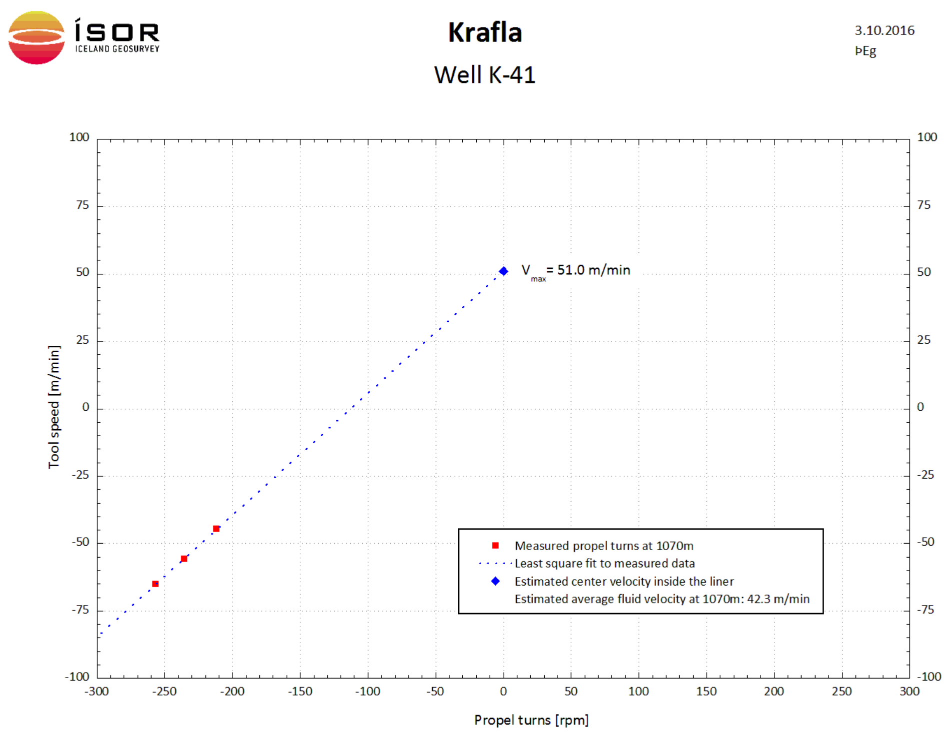


Figure 44. *Cross-plot at 1070 m under 19.2 L/s injection rate gives an average fluid velocity ~42 m/min (83% of V_{max}).*

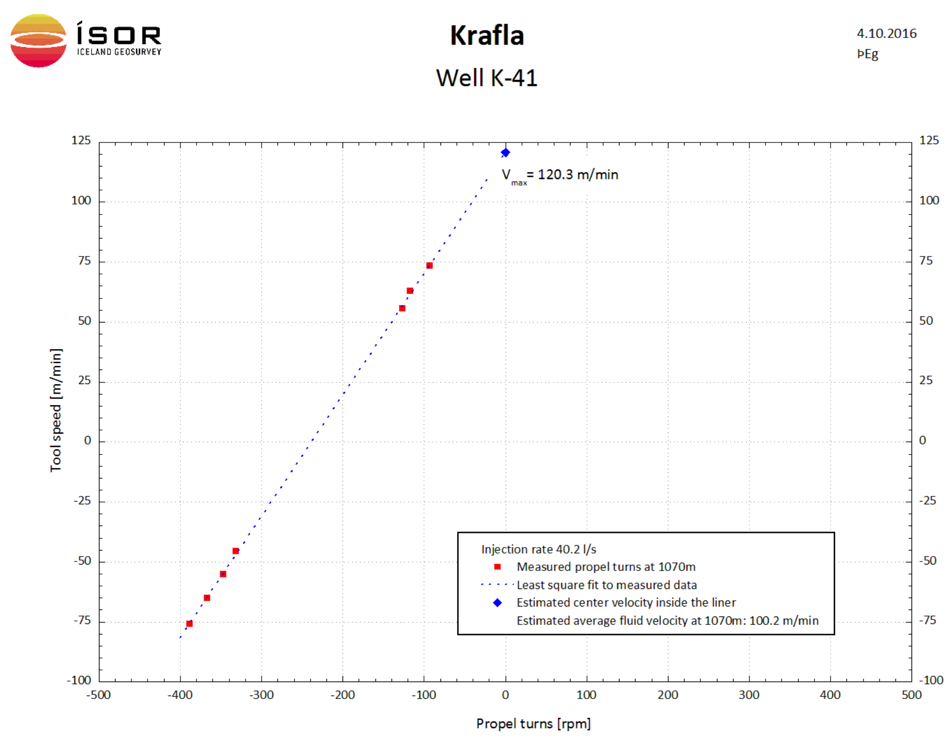


Figure 45. *Cross-plot at 1070 m under 40.2 L/s injection rate gives an average fluid velocity ~100 m/min (83% of V_{max}).*

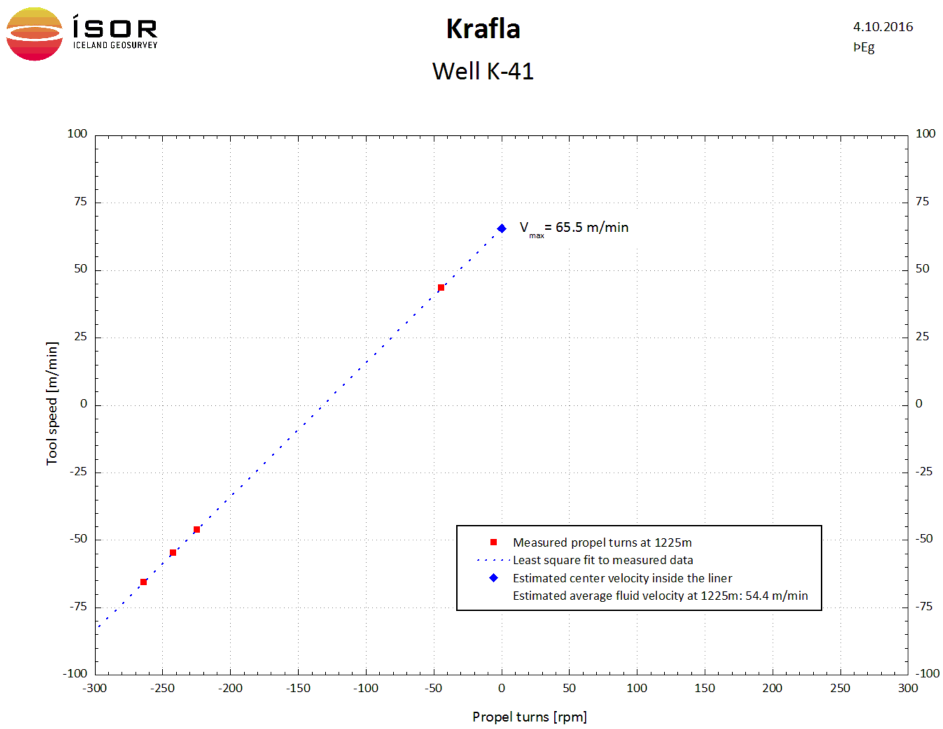


Figure 46. *Cross-plot at 1225 m under 19.2 L/s injection rate gives an average fluid velocity ~54 m/min (83% of V_{max}).*

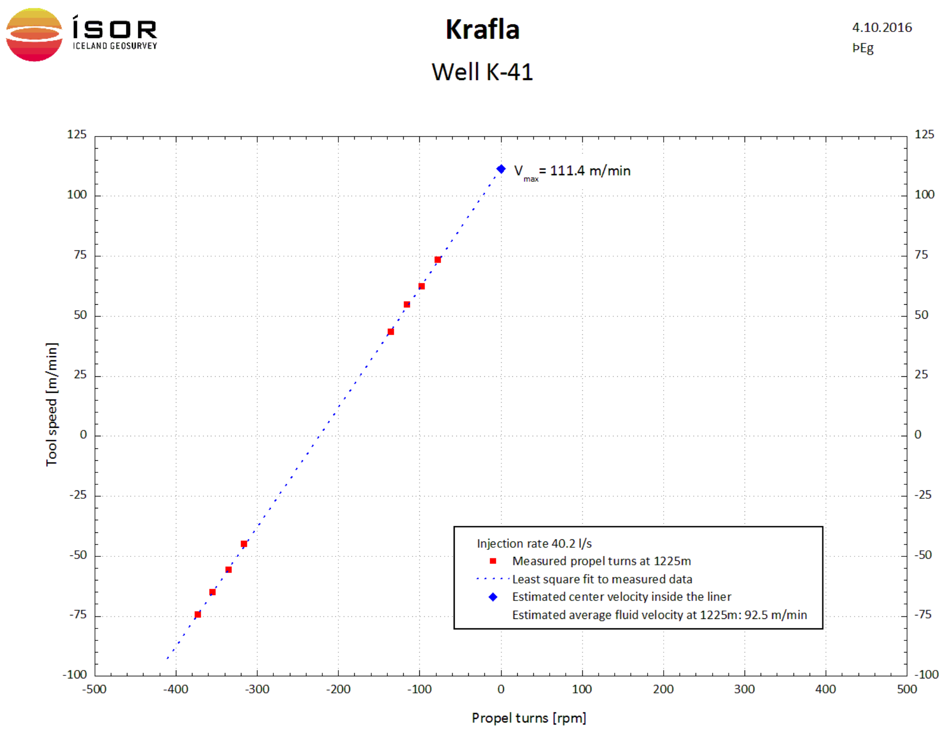


Figure 47. *Cross-plot at 1225 m under 40.2 L/s injection rate gives an average fluid velocity ~93 m/min (83% of V_{max}).*

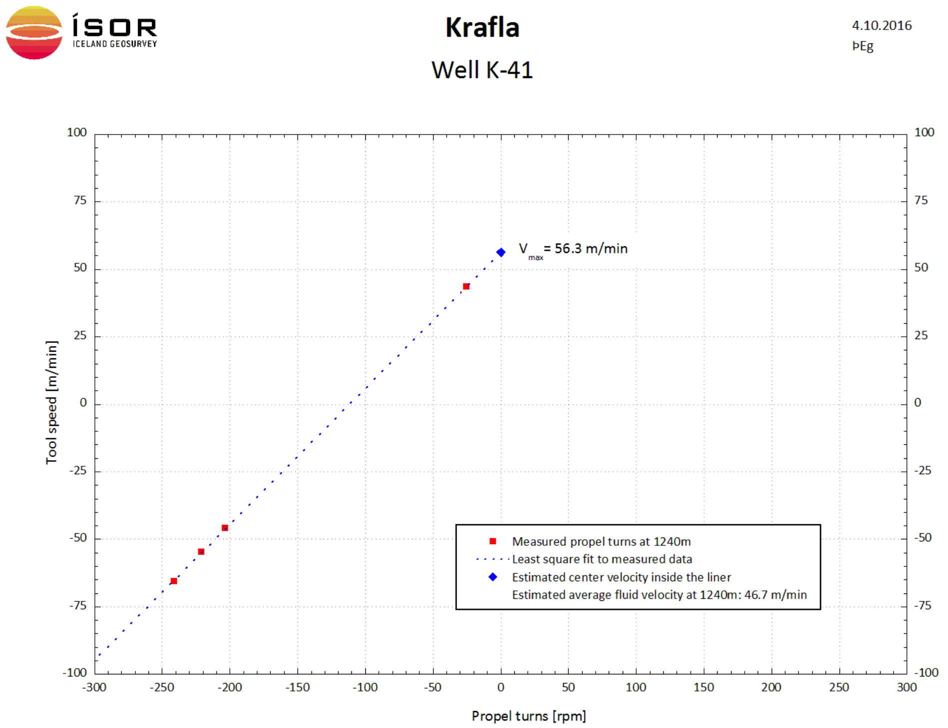


Figure 48. *Cross-plot at 1240 m under 19.2 L/s injection rate gives an average fluid velocity ~48 m/min (83% of V_{max}).*

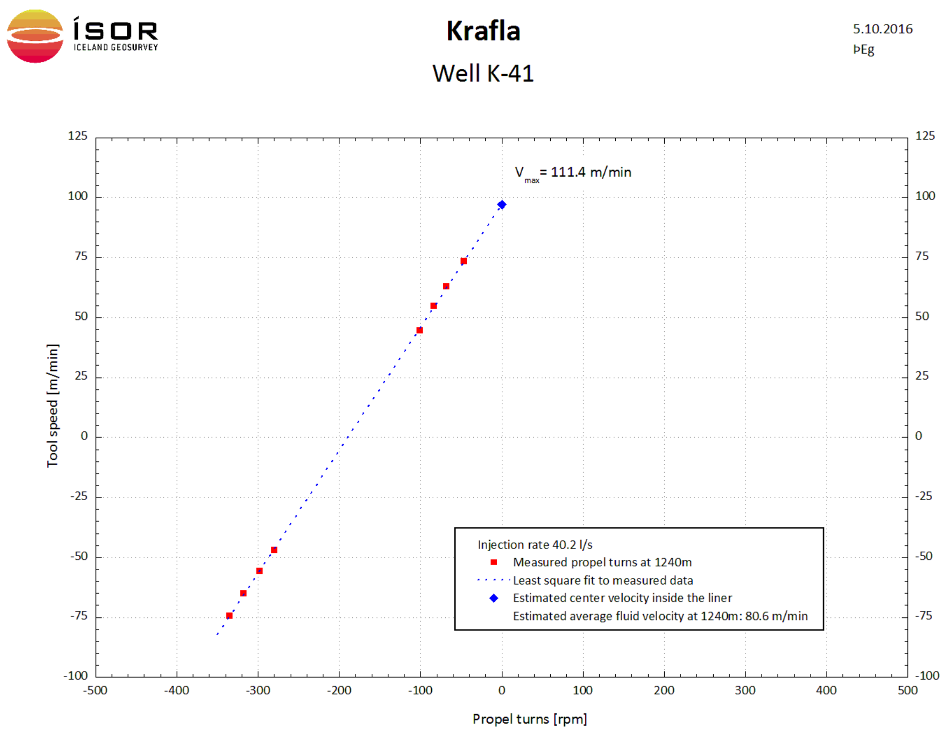


Figure 49. *Cross-plot at 1240 m under 40.2 L/s injection rate gives an average fluid velocity ~81 m/min (83% of V_{max}).*

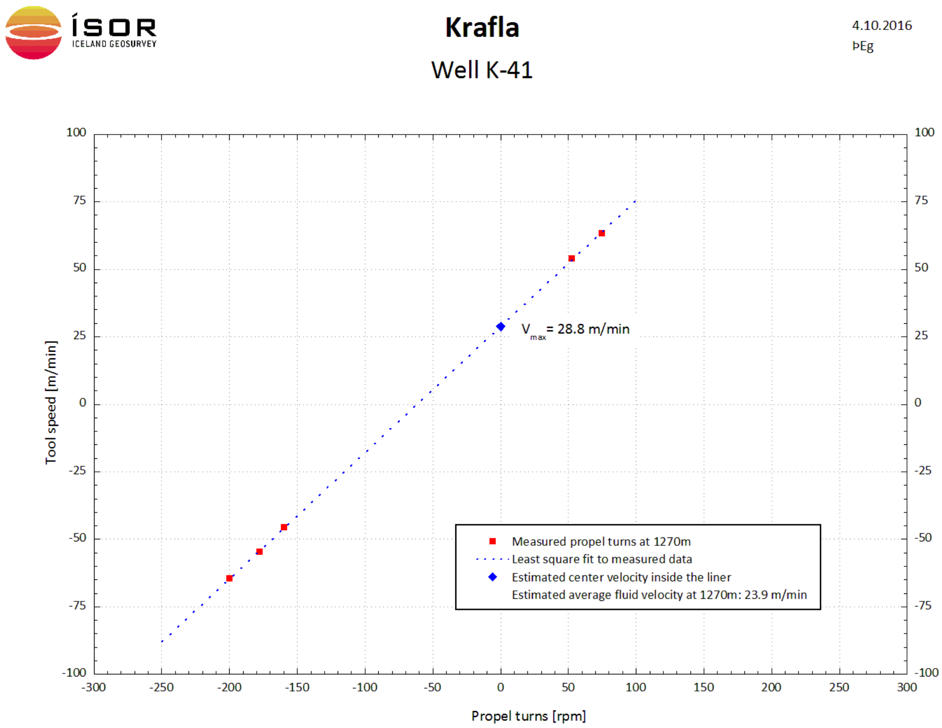


Figure 50. *Cross-plot at 1270 m under 19.2 L/s injection rate gives an average fluid velocity ~24 m/min (83% of V_{max}).*

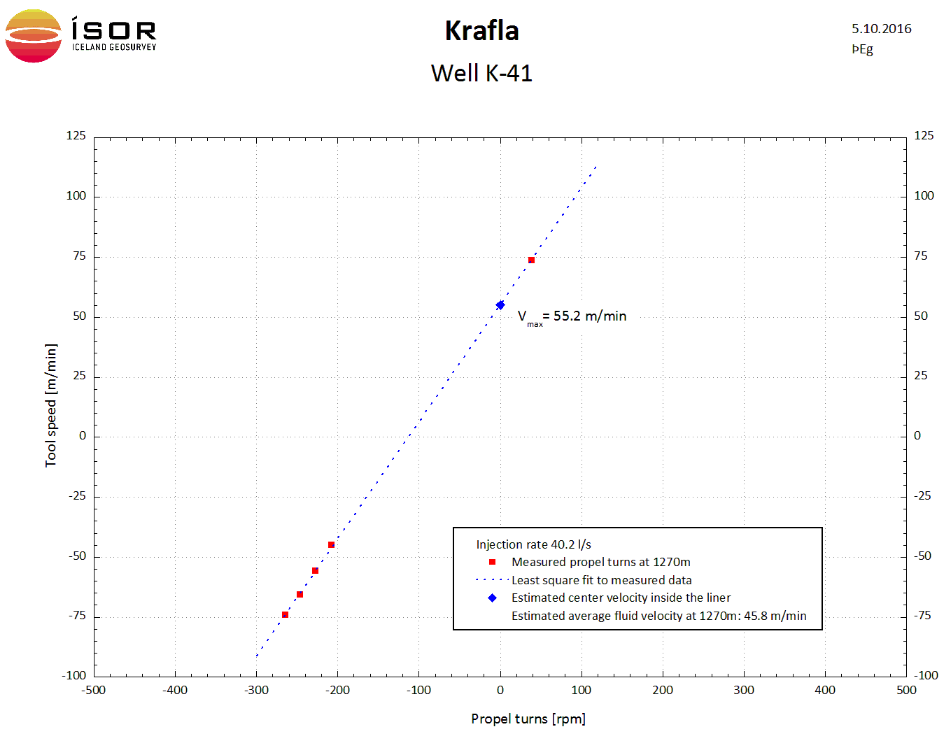


Figure 51. *Cross-plot at 1270 m under 40.2 L/s injection rate gives an average fluid velocity ~46 m/min.*

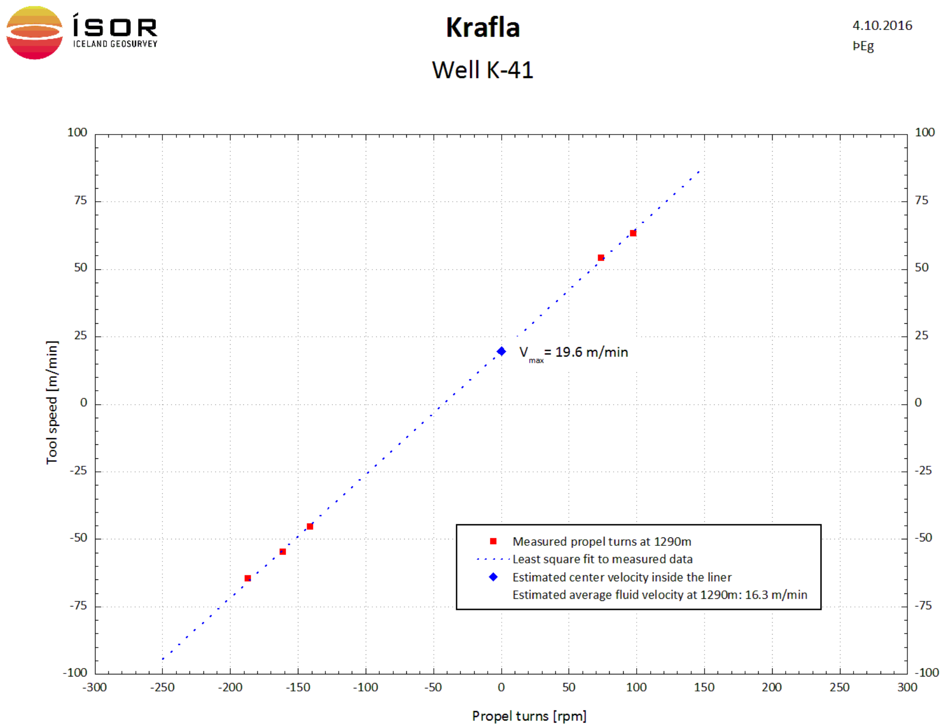


Figure 52. *Cross-plot at 1290 m under 19.2 L/s injection rate gives an average fluid velocity ~16 m/min (83% of V_{max}).*

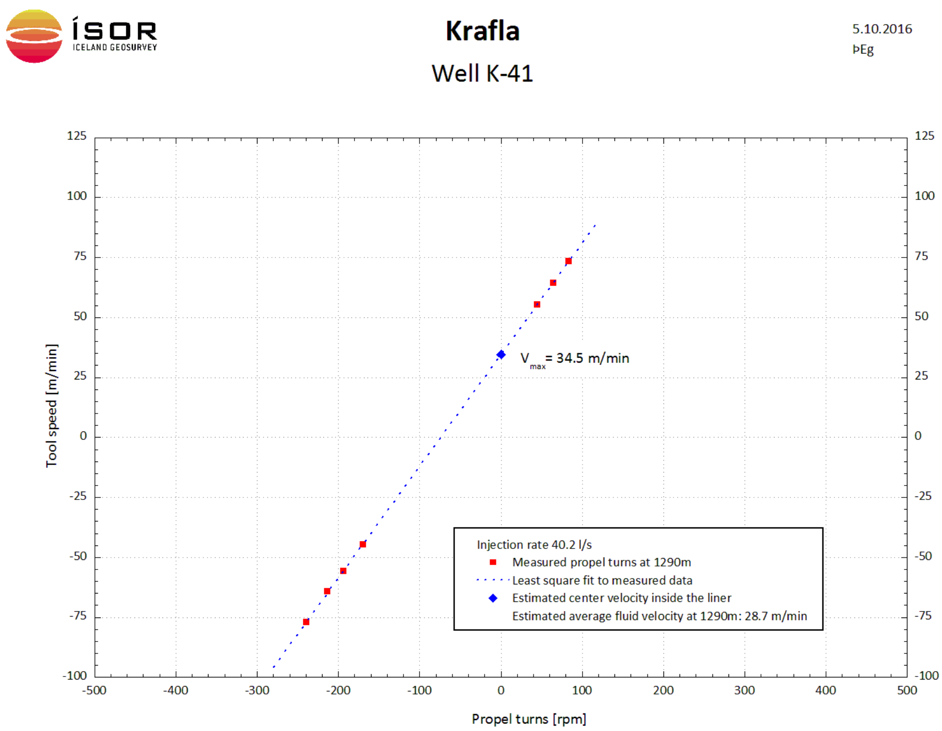


Figure 53. *Cross-plot at 1290 m under 40.2 L/s injection rate gives an average fluid velocity ~29 m/min (83% of V_{max}).*

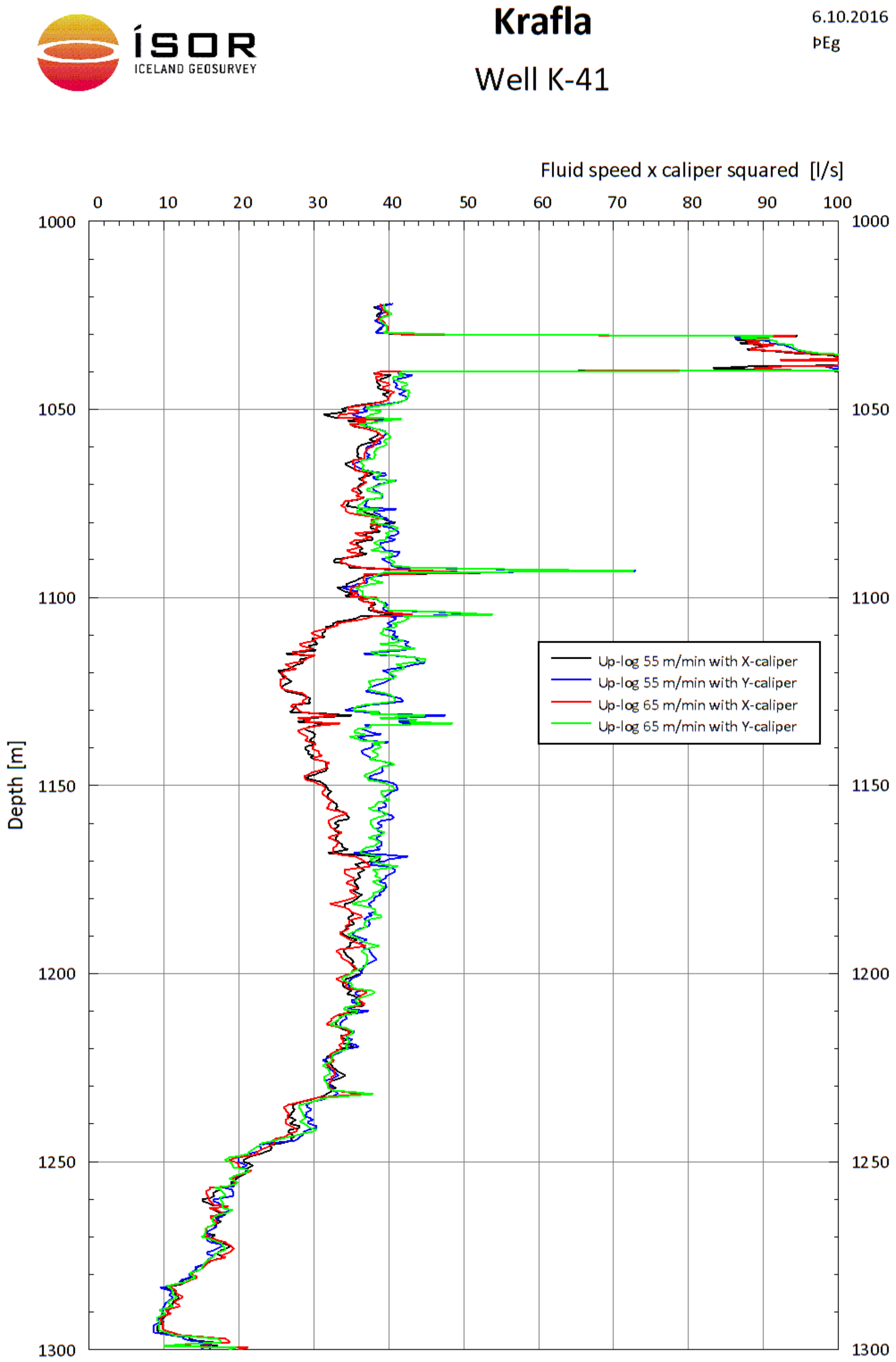


Figure 54. *Comparison of the spinner data with 40.2 L/s injection on wellhead and the estimated fluid speed normalized to the square of the well diameter.*

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Appendix:
Daily reports

	# K-41	Wednesday 17th of August 2016 Workday #29 of Sleipnir

Krafla	**Report for Workday #29** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	RSÁ (E-mail: rsa@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1040 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1036,1	Depth at 8:00.	1040 m	Drilling time:	0 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	- L/s	Average ROP:	0 m/hr.

Drilling operation

After ÍSOR's CBL logging, the flow-line was taken down and the casing was cut off at the expansion sleeve. A new expansion sleeve and a master valve were installed before connecting the kill-line and flow-line. Phase 2 is now finished. Currently a new BHA is being run in hole.

Comparison of lithology of well K-41 with KJ-32 and KJ-33 for phase 2 can be seen in figure 1. In well K-41 basalt (glassy and fine-coarse grained) can be seen at 290-500 m. Below that the basalts are replaced with breccia down to ~700 m where basalts and tuff take over down to 1040 m (current depth). Below 940 m the well´s bedrock is dominantly intrusive basalts. This is in reasonably good agreement to the other wells on the same pad.

Laumontite occurs at 404 m and it appears in few samples below that depth. Epidote can be seen in a short interval at 408-410 m. Then it disappears but comes again into the system at 638 m where it can be found in most samples after that down to 1040 m, indicating more than 230 °C. Wairakite (200-300 °C) appears at 546 m and wollastonite at 976 m (more than 300 °C). However, at 996 m, calcite was found over epidote (Figure 2), which may indicate influx of cooler carbonate rich fluid.

Figure 3 shows a comparison with KJ-32 and KJ-33 for the next few hundred meters.

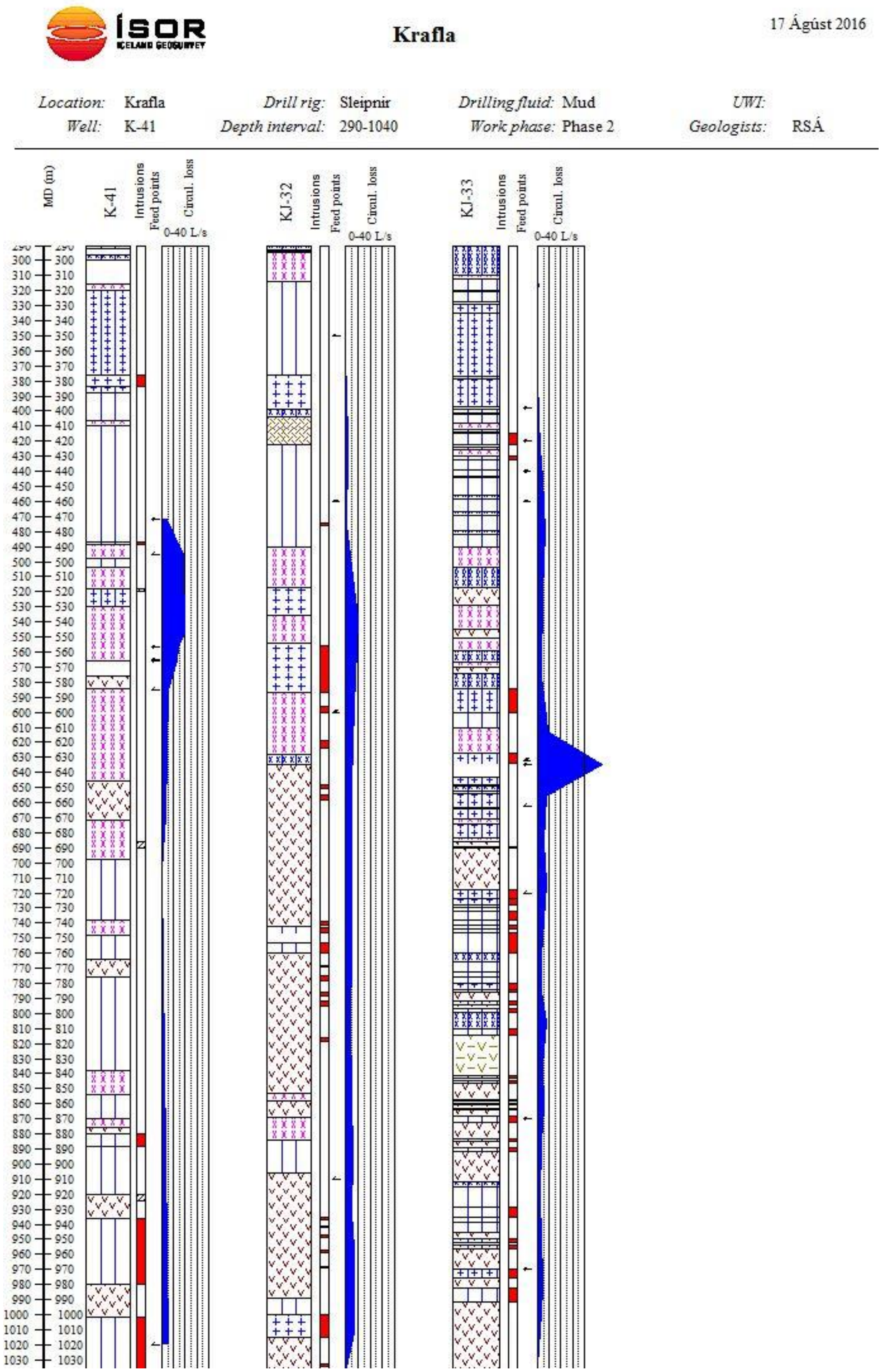


Figure 1. *Comparison of well K-41 with wells KJ-32 and KJ-33 for phase 2.*

Figure 2. *Calcite found over epidote at 996 m. The bubbles form when hydrochloric acid is added to the sample and* CO_2 *is released.*

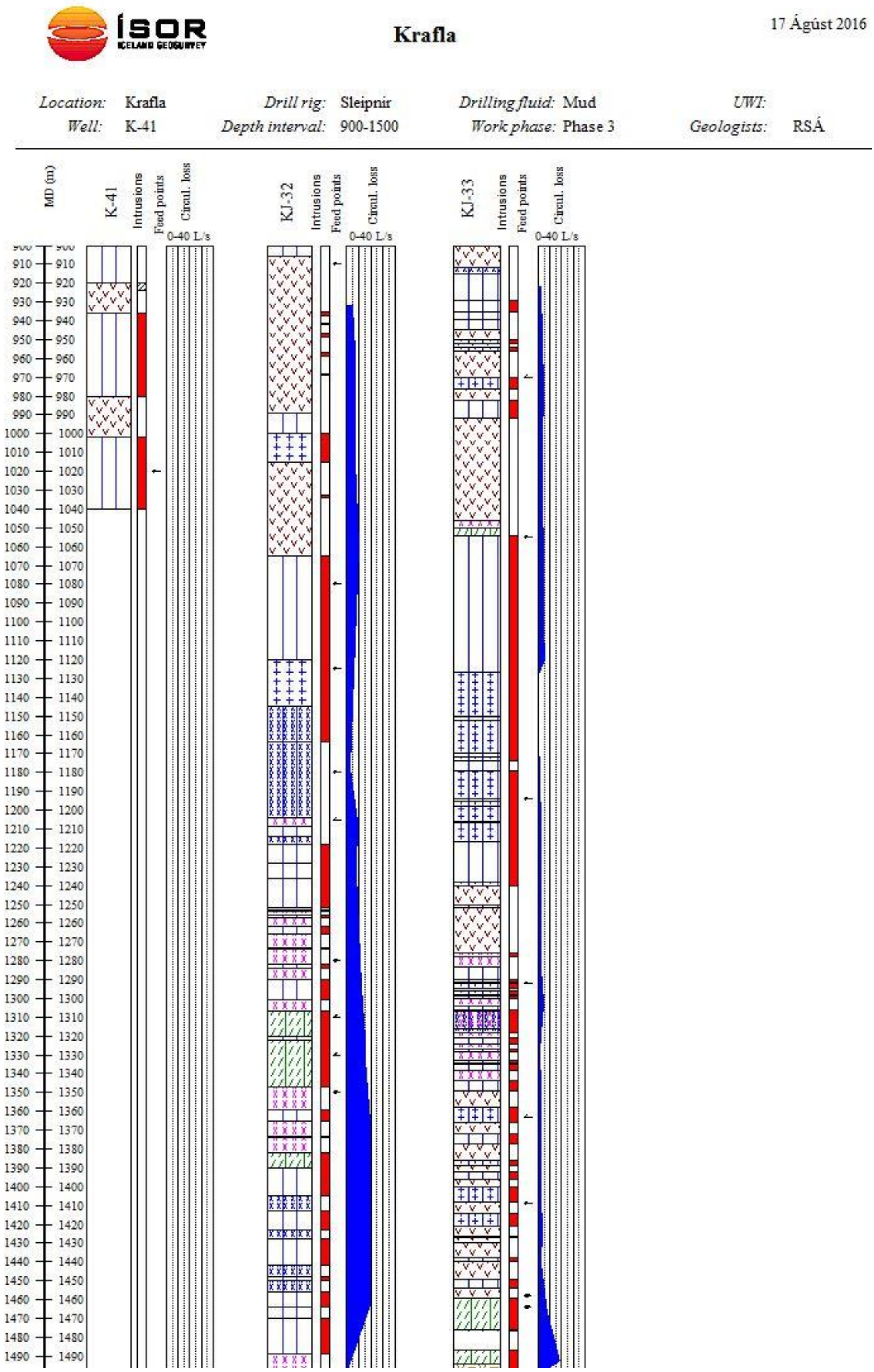


Figure 3. *Comparison of K-41 with KJ-32 and KJ-33 for phase 3.*

Skýringar við jarðlagasnið og bergummyndun

Berggerðir

- Hraunlagakargi
- Basalttúff
- Basaltbreksía
- Glerjað basalt
- Fín-meðalkorna basalt
- Meðal-grófkorna basalt
- Grófkorna basalt
- Ísúrt túff
- Ísúr breksía
- Ísúrt dul-meðalkorna berg
- Ísúrt grófkorna berg
- Súrt túff
- Súr breksía
- Súrt dul-meðalkorna berg
- Súrt grófkorna berg
- Jökulberg
- Millilag
- Túffríkt set
- Eðjusteinn
- Sandsteinn
- Möl og steinar
- Svarf vantar

Ummyndunarbelti

- Ferskt belti
- Sme-zeol belti
- Blandlagsbelti
- Klórít belti
- Kló-epid belti
- Epid-amfíb belti

Innskot

- Innskot
- Hugsanlegt innskot

Ummyndunarstig

- Engin ummyndun
- Lítil ummyndun
- Meðal ummyndun
- Mikil ummyndun

Vatnsæðar

Sym. nr.	
7	Lítil æð
8	Meðal æð
9	Stór æð

Greining ummyndunarsteinda

Sym. nr.	
1	Svarfgreining örugg
2	Svarfgreining óviss
3	Þunnsneiðargreining örugg
4	Þunnsneiðargreining óviss
5	Röntgengreining örugg
6	Röntgengreining óviss

ÍSOR ICELAND GEOSURVEY	K-41	Thursday 18th of August 2016 Workday #30 of Sleipnir

Krafla	**Report for Workday #30** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	RSÁ (E-mail: rsa@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1047 m	Hole made last 24 hrs. :	8 m
Last casing depth:	1031	Depth at 8:00.	1123 m	Drilling time:	1.25 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	17 L/s	Average ROP:	6.4 m/hr.

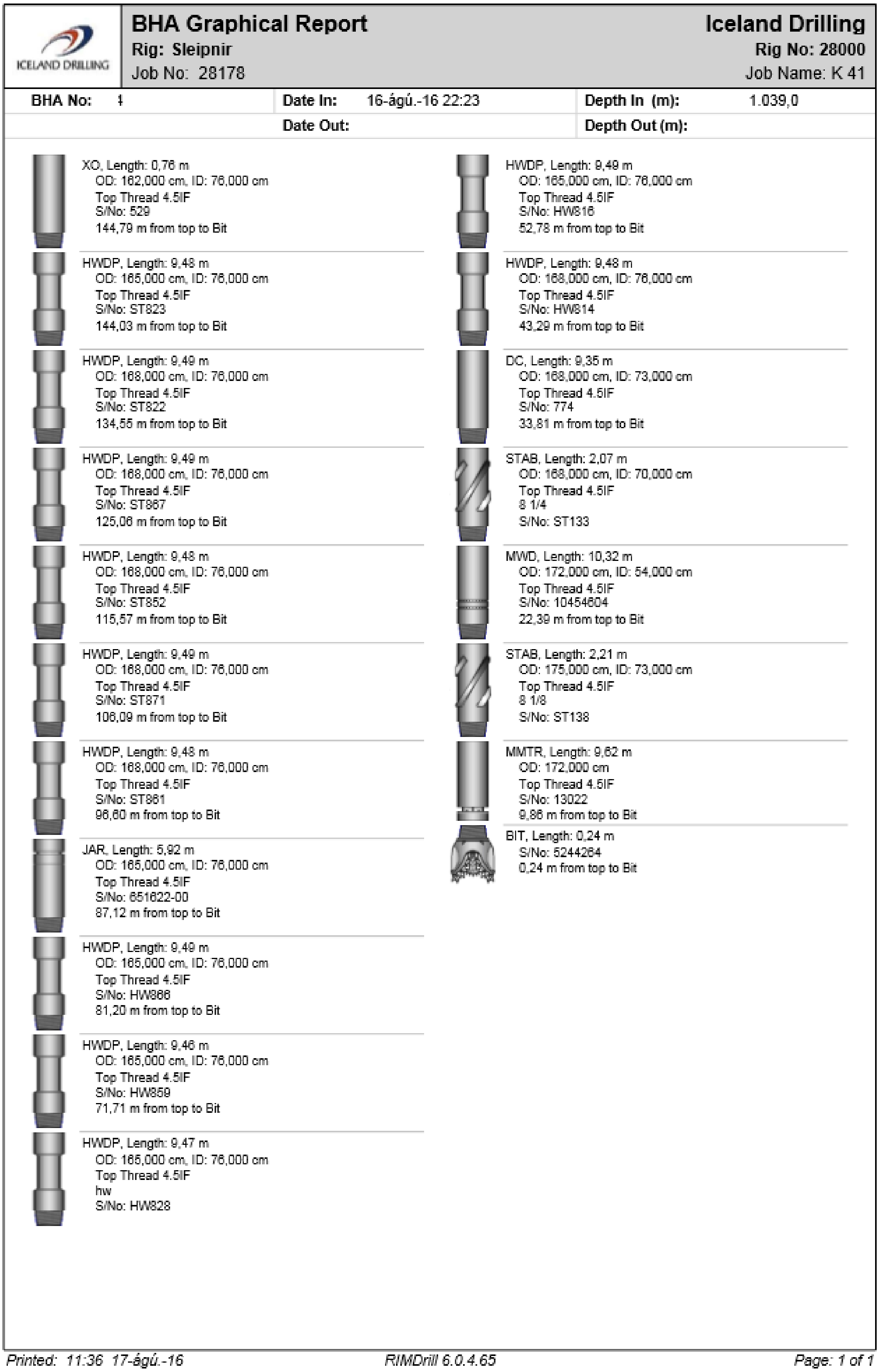
Drilling operation

The BOP stack was pressure tested shortly after midnight and the motor was tested at around 03:00. A new BHA (Figure 1) was RIH. Before noon yesterday, a short maintenance break was required due to problems with the power tong took, before finishing RIH. The float collar was tagged at 1009 m and the shoe at 1031 m.

Drilling into formation commenced at 18:30 yesterday. When a depth of 1046 m (MD) was reached the well was circulated for an hour before a gyro survey was carried out by ÍSOR´s logging engineers. The results from yesterday´s gyro can be seen in Table 1 and Figure 2. When the gyro was finished, drilling into formation continued and current depth at 8:00 this morning is 1123 m MD (Figure 3). At 6:30 this morning no LOC had been observed but while drilling into formation LOC was 17 L/s at 8:00 at 1123 m MD.

Table 1. *Gyro survey for well K-41 carried out 17th of August.*

MD	Inclination	True Az.
803.01	35.09	72.89
830.00	35.32	73.53
860.00	35.74	73.78
890	35.74	74.58
920	35.11	73.54
950	35.25	74.81
980	34.93	71.78
1005	34.49	74.08



ICELAND DRILLING	**BHA Graphical Report** **Rig: Sleipnir** Job No: 28178	**Iceland Drilling** **Rig No: 28000** Job Name: K 41

BHA No:	1	**Date In:**	16-ágú.-16 22:23	**Depth In (m):**	1.039,0
		Date Out:		**Depth Out (m):**	

XO, Length: 0,76 m
OD: 162,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: 529
144,79 m from top to Bit

HWDP, Length: 9,48 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST823
144,03 m from top to Bit

HWDP, Length: 9,49 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST822
134,55 m from top to Bit

HWDP, Length: 9,49 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST867
125,06 m from top to Bit

HWDP, Length: 9,48 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST852
115,57 m from top to Bit

HWDP, Length: 9,49 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST871
106,09 m from top to Bit

HWDP, Length: 9,48 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: ST861
96,60 m from top to Bit

JAR, Length: 5,92 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: 651622-00
87,12 m from top to Bit

HWDP, Length: 9,49 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW866
81,20 m from top to Bit

HWDP, Length: 9,46 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW859
71,71 m from top to Bit

HWDP, Length: 9,47 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
hw
S/No: HW828

HWDP, Length: 9,49 m
OD: 165,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW816
52,78 m from top to Bit

HWDP, Length: 9,48 m
OD: 168,000 cm, ID: 76,000 cm
Top Thread 4.5IF
S/No: HW814
43,29 m from top to Bit

DC, Length: 9,35 m
OD: 168,000 cm, ID: 73,000 cm
Top Thread 4.5IF
S/No: 774
33,81 m from top to Bit

STAB, Length: 2,07 m
OD: 168,000 cm, ID: 70,000 cm
Top Thread 4.5IF
8 1/4
S/No: ST133

MWD, Length: 10,32 m
OD: 172,000 cm, ID: 54,000 cm
Top Thread 4.5IF
S/No: 10454604
22,39 m from top to Bit

STAB, Length: 2,21 m
OD: 175,000 cm, ID: 73,000 cm
Top Thread 4.5IF
8 1/8
S/No: ST138

MMTR, Length: 9,62 m
OD: 172,000 cm
Top Thread 4.5IF
S/No: 13022
9,86 m from top to Bit

BIT, Length: 0,24 m
S/No: 5244264
0,24 m from top to Bit

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Figure 1. *BHA for well K-41, RIH August 17th.*

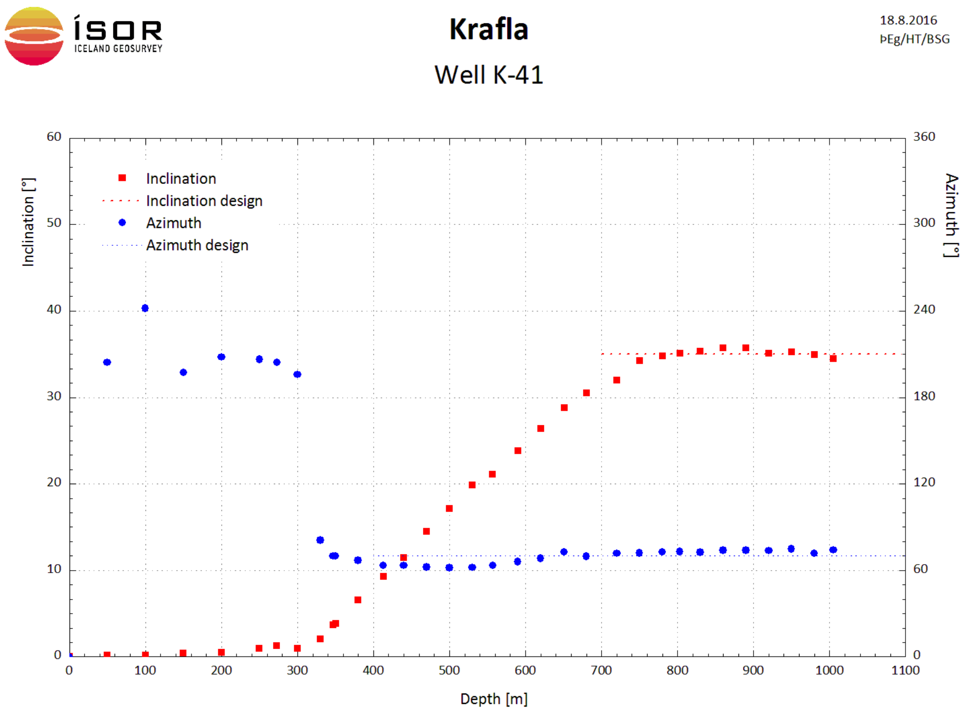

Figure 2. *Gyro survey for well K-41*

Figure 3. *Easy view image from drilling during the night after the gyro survey.*

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ÍSOR ICELAND GEOSURVEY	K-41	Friday 19th of August 2016 Workday #31 of Sleipnir

Krafla	**Report for Workday #31** Preliminary results	Phase 3 (7" perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	RSÁ, ÞEg (E-mail: rsa@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1142 m	Hole made last 24 hrs. :	95 m
Last casing depth:	1031	Depth at 8:00.	1142 m	Drilling time:	11 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	>40 L/s	Average ROP:	8,6 m/hr.

Drilling operation

Drilling was ongoing from midnight until 10:00 where a total of 95 m were drilled with 7-8 ton WOB, pressure of 92-96 bar, torque of 820-860 daNm and 40 L/s pumping (Figure 1). Polymer pills were injected after drilling each single.

No circulation losses were observed at 1039-1123 m. At 1123 m LOC was 17 L/s at 35 L/s pumping. After drilling down to 1142 m a circulation loss measure was conducted showing 22 L/s loss. During circulation, before inserting the next drill pipe, mud pressure dropped and the drill string got stuck resulting in higher torque. Figures 2 and 3 show drill parameters, mud-pressure, flow through stand-pipe, torque and depth the hours before and after. As seen in figures 1-3 the ROP during drilling is high and the circulation time between drill pipes is long. As the drill string got stuck none of the injected water returned to surface because of the blocked flow path. According to the drill parameters shown in Figures 2 and 3 the drill string got stuck during circulation at ~09:57.

During drilling through 1116 m WOB decreased from 8 tons to 3 tons and for some reason the injection rate was decreased from 40 L/s to 35 L/s with consequent drop in mud pressure. Cutting analysis shows brecciated and less altered lithology above 1116 m (Figure 4). At that depth the lithology changes abruptly to more altered tuff or breccia. The cuttings became smaller, more altered and oxidized.

Currently the string is still stuck and attempts to get it unstuck using an air compressor are being carried out.

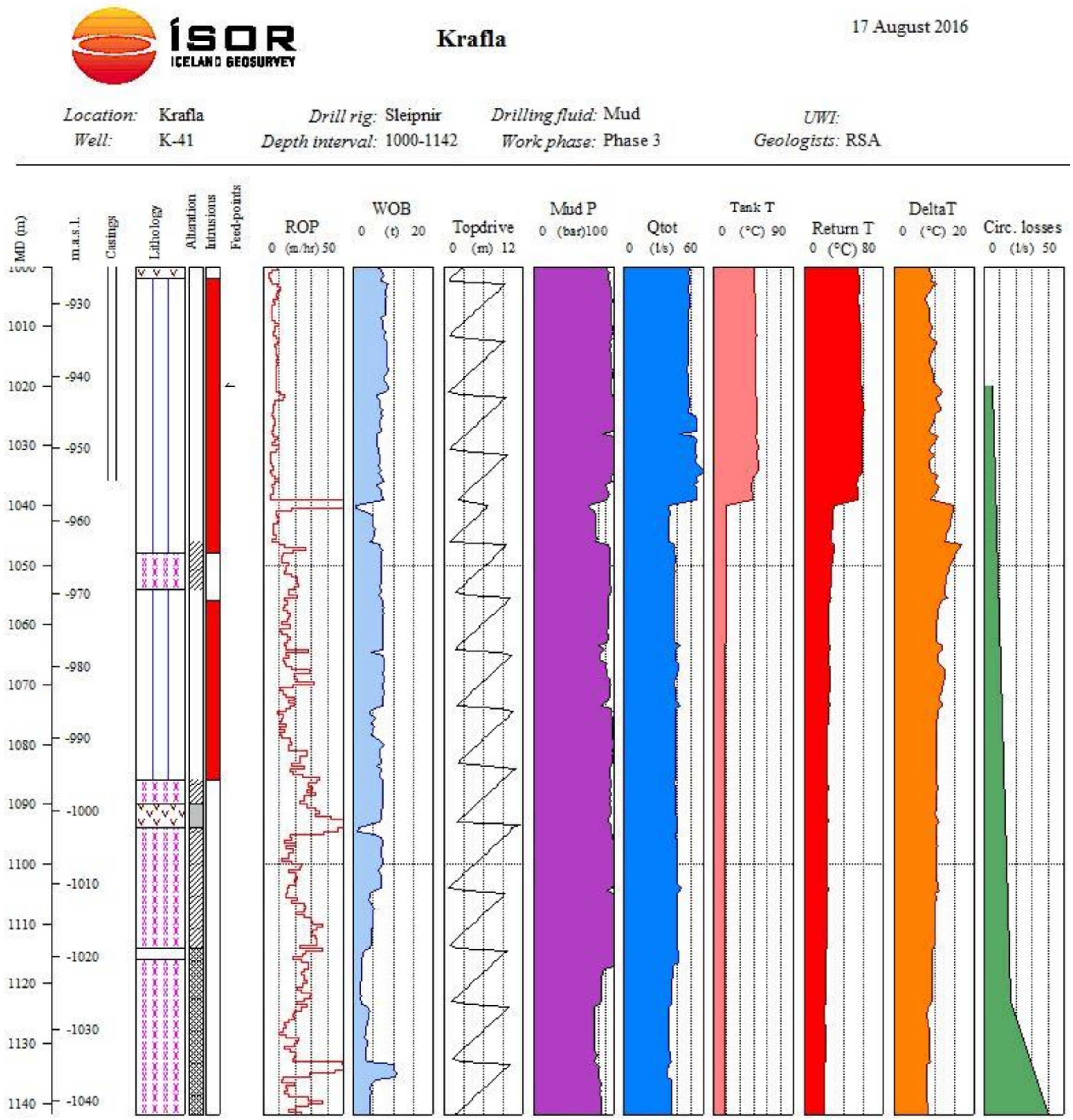

Figure 1. *Drilling parameters and lithology for 1000-1142 m MD.*

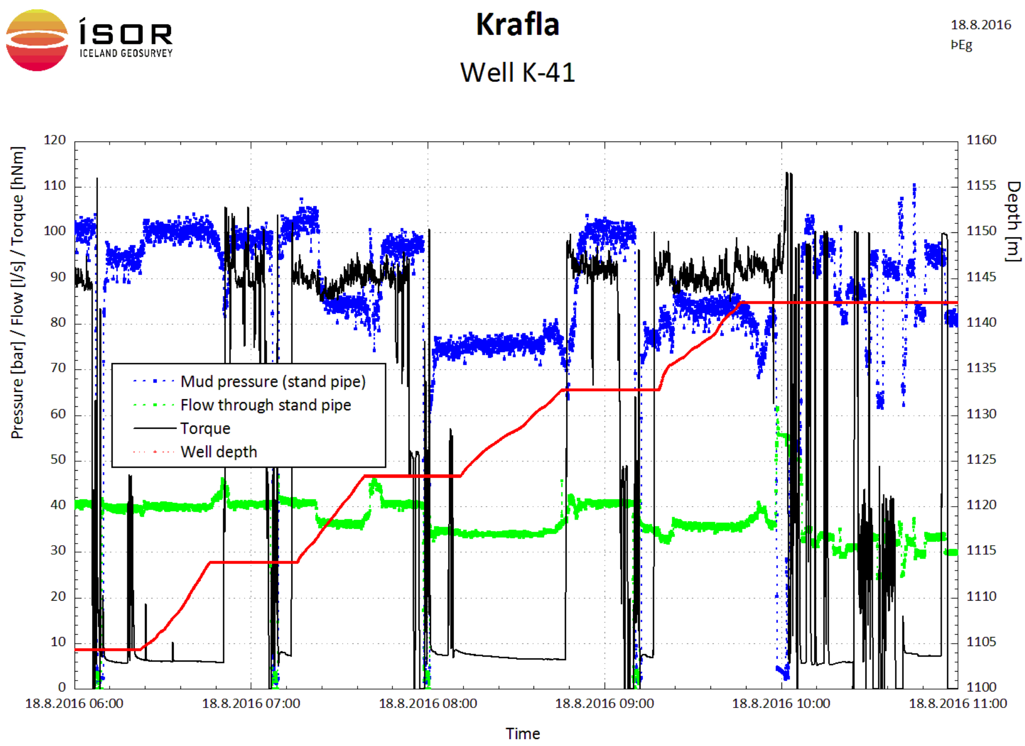

Figure 2. *Drill parameters Mud pressure, flow through stand-pipe, torque and depth of well the hours before the drill string got stuck.*

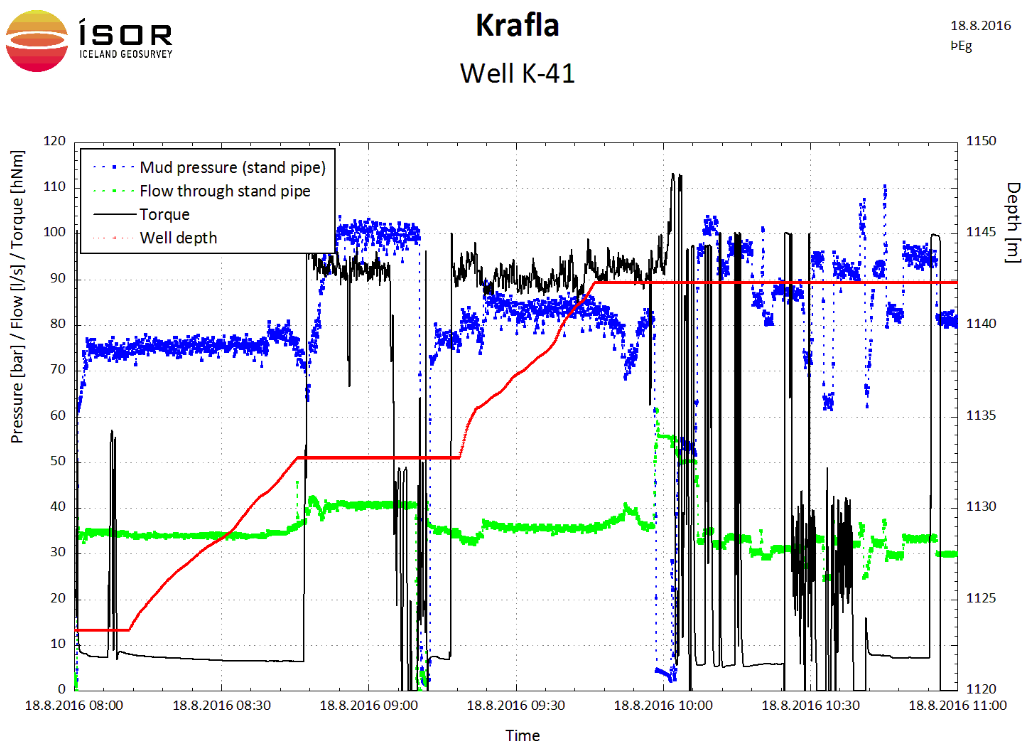

Figure 3. *Same as Figure 1 zoomed in time around the moment the drill string got stuck.*

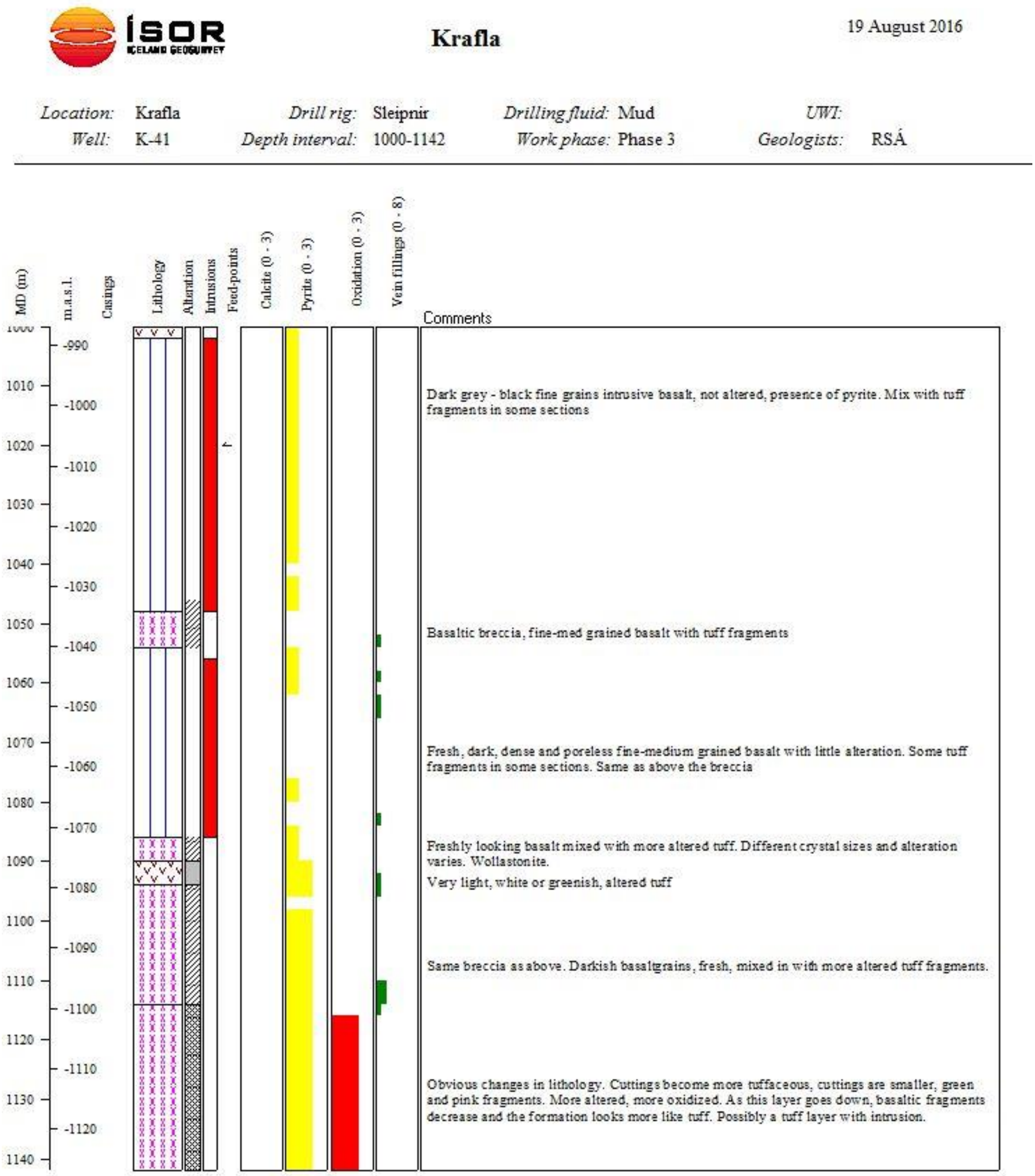

Figure 4. *Lithology from 1000-1142 m where the drill string got stuck.*

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ÍSOR ICELAND GEOSURVEY	# K-41	Saturday 20th of August 2016 Workday #32 of Sleipnir

Krafla	**Report for Workday #32** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	RSÁ (E-mail: rsa@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1142 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1031	Depth at 8:00.	1142 m	Drilling time:	0 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	>40 L/s	Average ROP:	- m/hr

Drilling operation

Before midnight August 18th an air compressor arrived on site and was connected to standpipe. In order to get the string unstuck, air, water and polymer pills have been injected into the well, as well as jarring every now and then. Some movement of the string has been observed.

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ÍSOR ICELAND GEOSURVEY	K-41	Sunday 21th of August 2016 Workday #33 of Sleipnir

Krafla	**Report for Workday #33** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	BG/SvSv MT HI (E-mail: bg@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1142 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1031	Depth at 8:00.	1142 m	Drilling time:	0 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	>40 L/s	Average ROP:	- m/hr

Drilling operation

After trying to get unstuck for almost 48 hrs. the string finally got loose at noon (12:00) yesterday. The crew then proceeded to POOH.

Last night the logging engineers ran a temperature log, X-Y log and a mini-injection test. The purpose was to locate aquifers, estimate the shape of the well-bore in particular to look for signs of cave-ins and to get a rudimentary injectivity index for the well in its present condition.

The logging engineers arrived at the rig around 21:30 last night. Logging started at 22:55 and was completed around 05:00 this morning. The results of the logging are shown in Figs. 1 to 4.

After the logging was complete an early morning "ad-hoc" phone-meeting was called to discuss the next steps in the well. After perusing the data, a decision was made to continue drilling with a "locked" BHA but without motor and MWD. A BHA similar or identical to the BHA used recently in well ÞG-11.

Early this morning the crew started to RIH with an 8½" bit and a "locked" BHA. However, RIH had to be postponed due to maintenance work on the jib.

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Figure 1. *Temperature log RIH during 19 L/s injection and total LOC. The probe stopped at 1135 m indicating ~ 7 m bottom fill. All injected fluid seems to exit the well somewhere below 1135 m.*

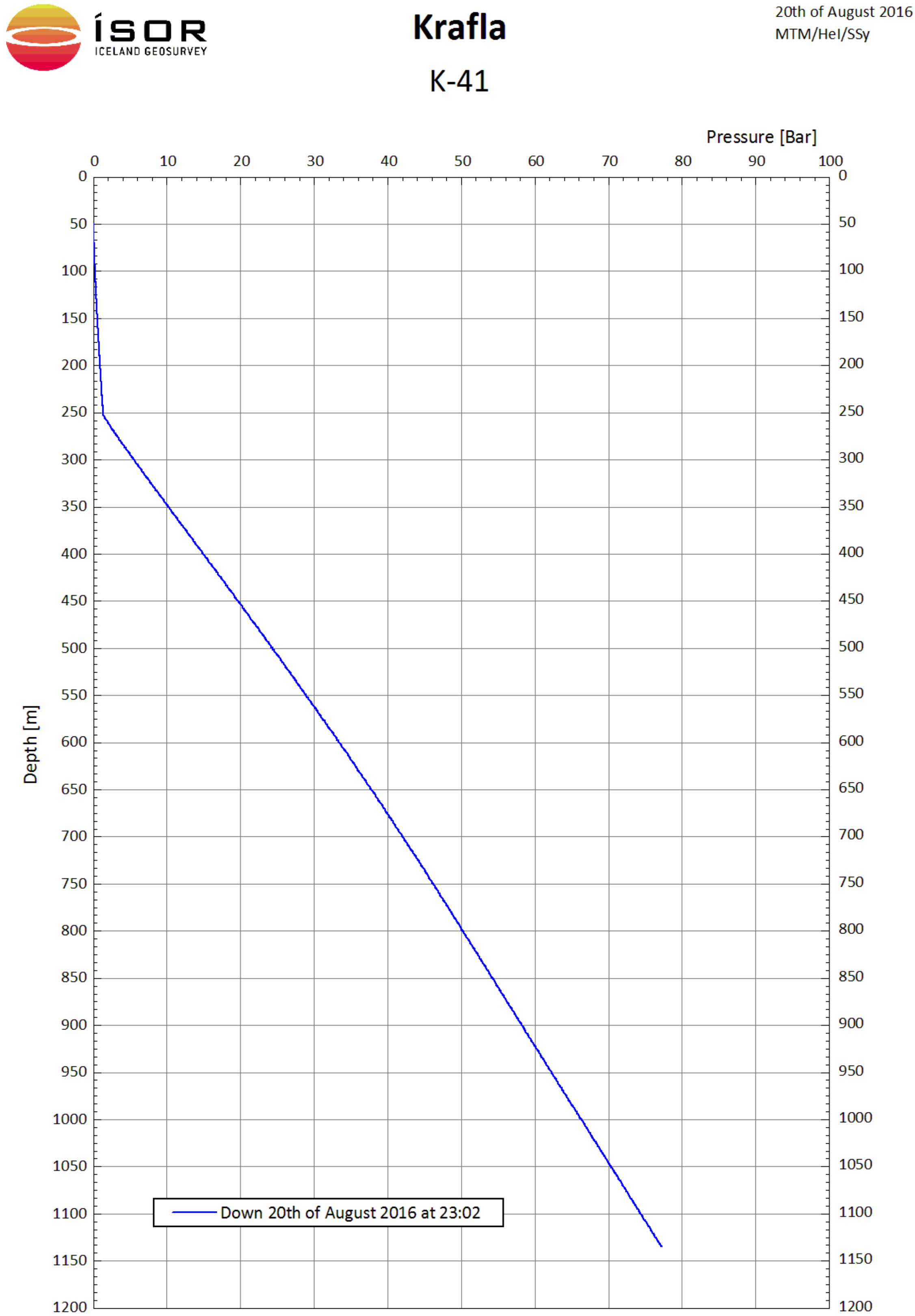

Figure 2. *Pressure profile logged (down) with a TP-tool. Injection was 19 L/s water table at 250 m and bottom tagged at 1135 m (MD).*

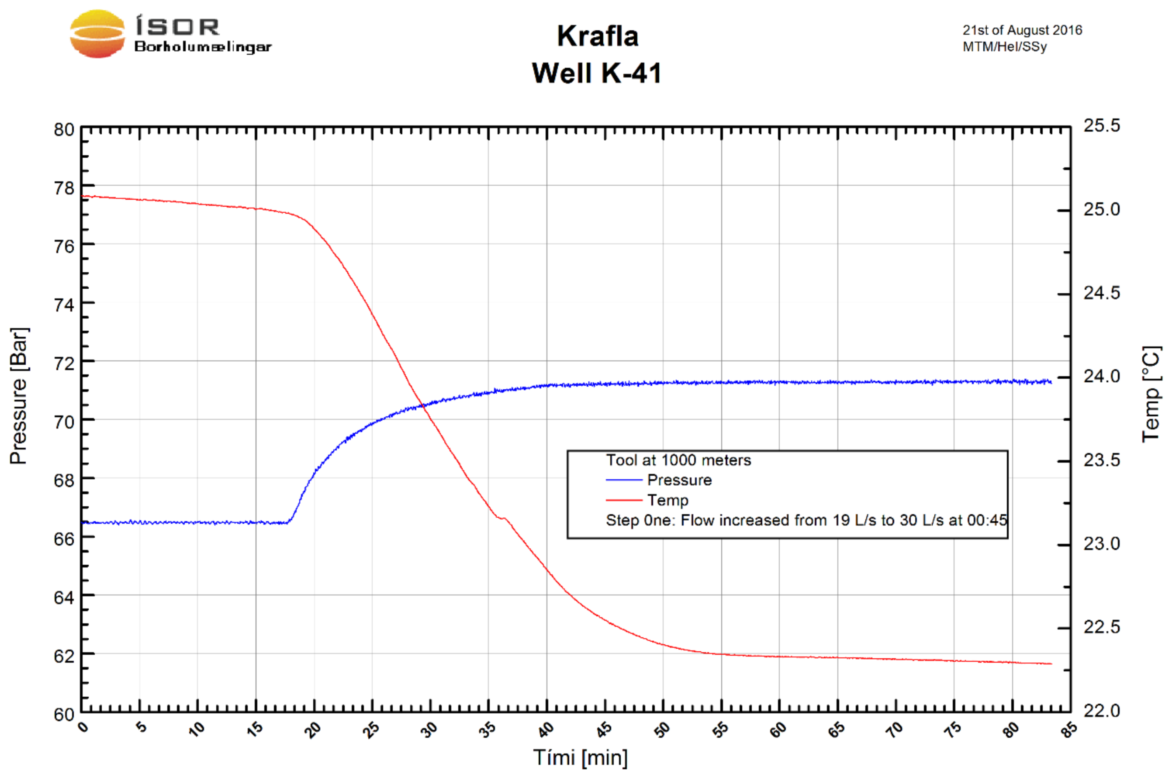

Figure 3. *Results of a short injection test. During POOH and subsequent logging injection rate was 19 L/s. Injection was increased to 30 L/s (@18 minutes) resulting in a pressure increase of ~4,8 bar. The rudimentary injection index obtained from this short test is 2,3 (L/s/bar).*

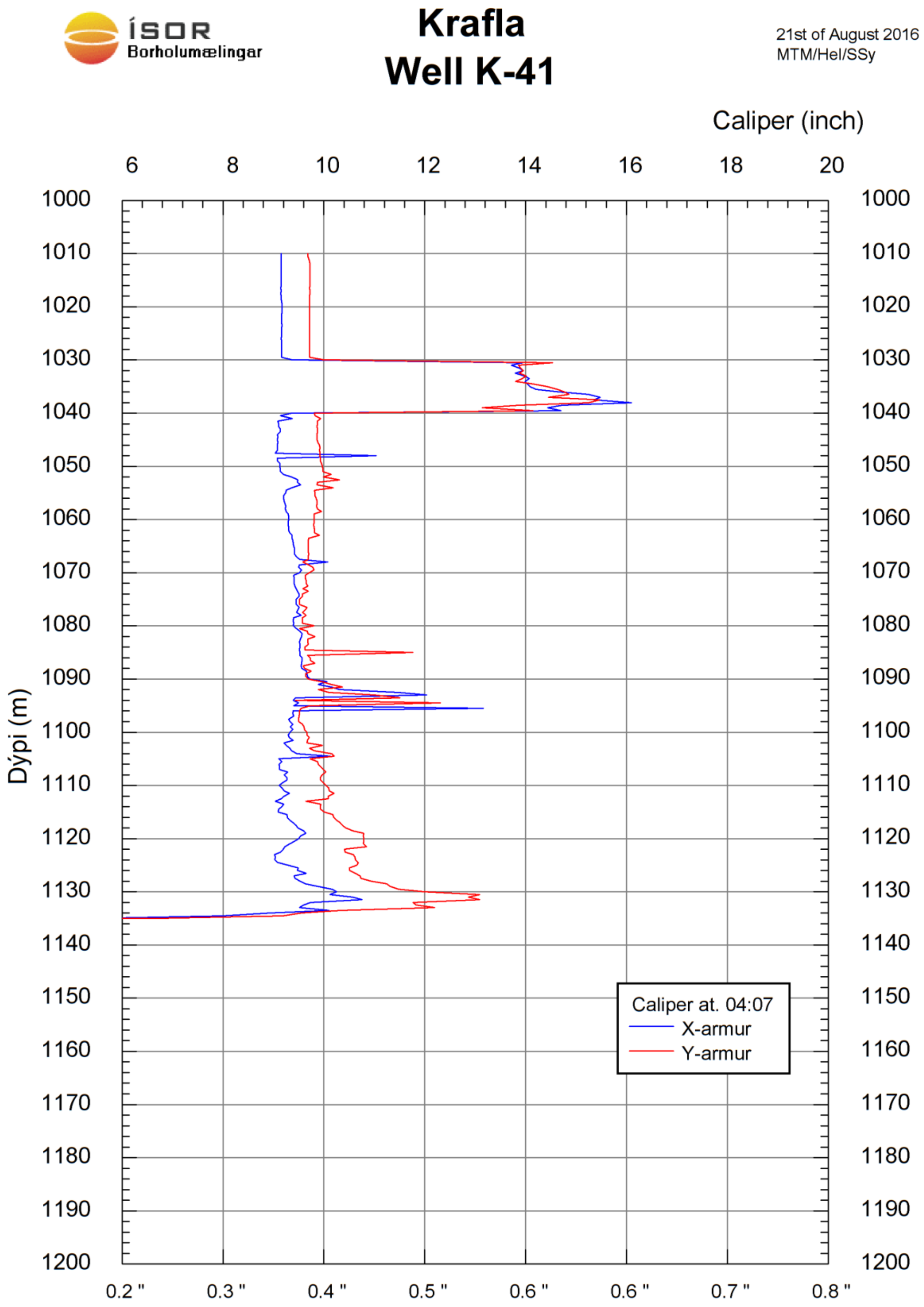

Figure 4. *Results of caliper log. The bottom part of the last section drilled with the 12 ½" bit can be seen from 1030 to 1040 m. A minor washout occurs between 1090 and 1100 m. Below that the eccentricity of the well seems to increase towards the bottom were a washout can be seen around 1130 m depth.*

Krafla	**Report for Workday #34** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	BG/SvSv MTM HeI (E-mail: bg@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1142 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1031	Depth at 8:00.	1142 m	Drilling time:	0 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	>40 L/s	Average ROP:	- m/hr

Drilling operation

RIH started after logging was completed yesterday morning. During RIH the jib was damaged and had to be replaced. RIH commenced again around 16:00 yesterday afternoon. Last night some maintenance work on the top-drive was carried out. A decision was then made to replace the Jar in the BHA so the crew POOH to replace the Jar. This morning the crew is RIH again, however, further maintenance on the top-drive is required. At this point in time it is not clear when drilling will resume. A drawing of the BHA is given in Fig. 1.

Figure 2. shows the actual path of well K-41 projected onto an aerial photograph of the area. The red line shows the actual well path as recorded by gyro-logs to 1005 m (MD). The yellow line indicates the extrapolated well path to 1150 m based on gyro-data down to 1005 m. Also shown is the location of well KJ-15 on the same pad as K-41, and the well heads and actual well paths for wells KJ-32 and KJ-33 who also share a well-pad with K-41. Trajectories for wells KJ-30, KJ-36, KJ-37 and KJ-38 are also shown.

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ICELAND DRILLING

BHA Graphical Report

Rig: Sleipnir

Job No: 28178

Iceland Drilling

Rig No: 28000

Job Name: K 41

BHA No:	5	**Date In:**	21-ágú.-16 10:49	**Depth In (m):**	1.142,0
		Date Out:		**Depth Out (m):**	

XO, Length: 0,76 m
OD: 16,200 cm, ID: 7,600 cm
Top Thread 4.0IF
S/No: 529
147,11 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST823
146,35 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST822
136,87 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST867
127,38 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST852
117,89 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST871
108,41 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: ST861
98,92 m from top to Bit

JAR, Length: 6,00 m
OD: 16,700 cm, ID: 7,000 cm
Top Thread 4.5IF
Heildarborun 140 klstÓðinn
S/No: 474-651442

HWDP, Length: 9,49 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW866
83,44 m from top to Bit

HWDP, Length: 9,46 m
OD: 16,700 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW859
73,95 m from top to Bit

HWDP, Length: 9,47 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW828
64,49 m from top to Bit

HWDP, Length: 9,49 m
OD: 16,500 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW816
55,02 m from top to Bit

HWDP, Length: 9,48 m
OD: 16,800 cm, ID: 7,600 cm
Top Thread 4.5IF
S/No: HW814
45,53 m from top to Bit

DC, Length: 9,40 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: 565
36,05 m from top to Bit

DC, Length: 9,45 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: 633
26,65 m from top to Bit

DC, Length: 9,35 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: 744
17,20 m from top to Bit

STAB, Length: 2,07 m
OD: 16,800 cm, ID: 7,000 cm
Top Thread 4.5IF
S/No: ST133
7,85 m from top to Bit

PC, Length: 3,33 m
OD: 16,800 cm, ID: 7,300 cm
Top Thread 4.5EF
S/No: 732
5,78 m from top to Bit

BSTAB, Length: 2,21 m
OD: 17,200 cm, ID: 7,300 cm
Top Thread 4.5IF
S/No: ST006
2,45 m from top to Bit

BIT, Length: 0,24 m
Top Thread 4.5REG
S/No: 5261478
0,24 m from top to Bit

Printed: 07:43 22-ágú.-16 *RIMDrill 6.0.4.65* *Page: 1 of 1*

Figure 1. The *BHA that is being RIH after the stuck-pipe event at 1142 m. The motor and MWD tool have been removed.*

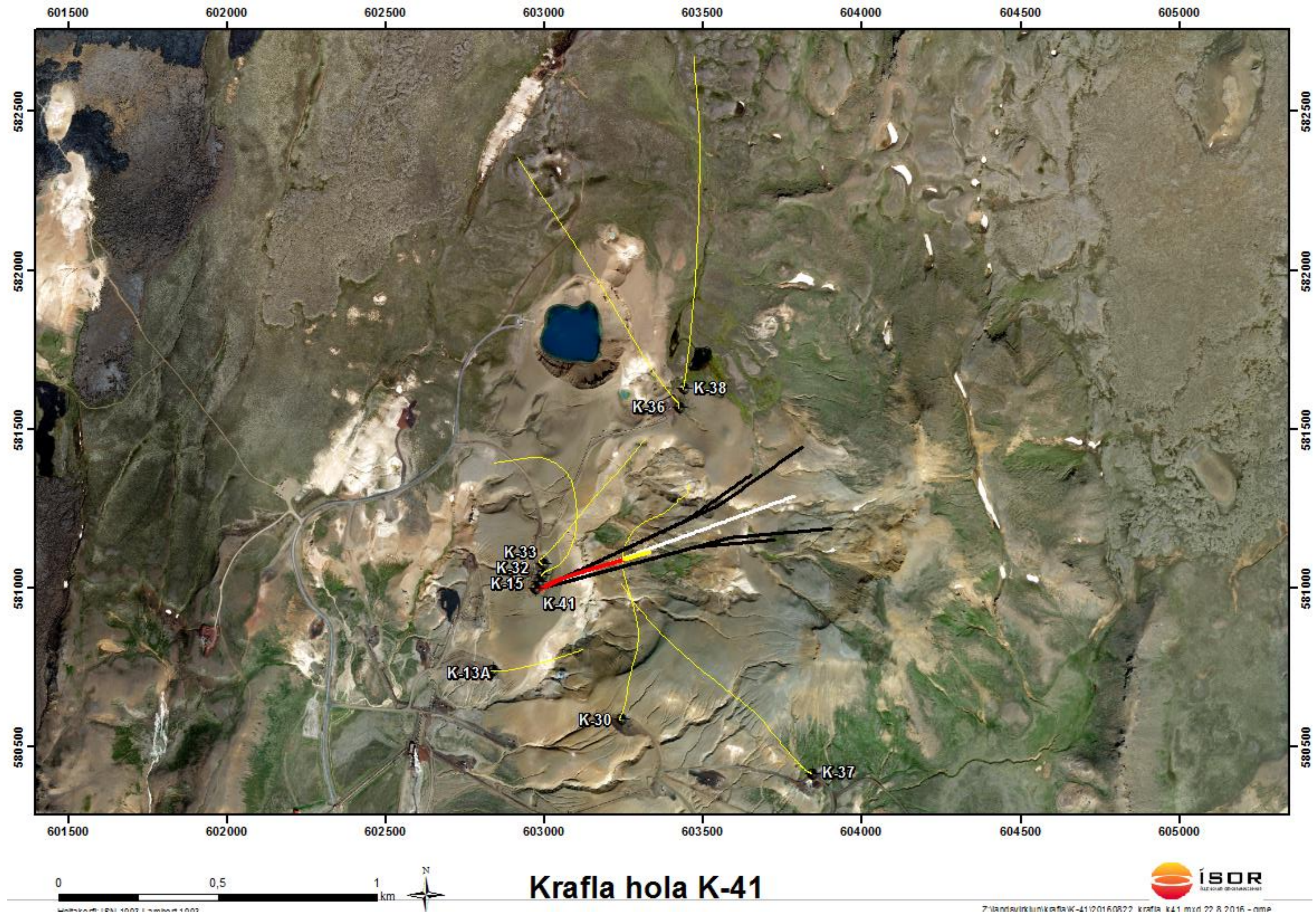

Figure 2. Actual well path for K-41 based on gyro (red) and extrapolated path (yellow) to 1150 m (MD).

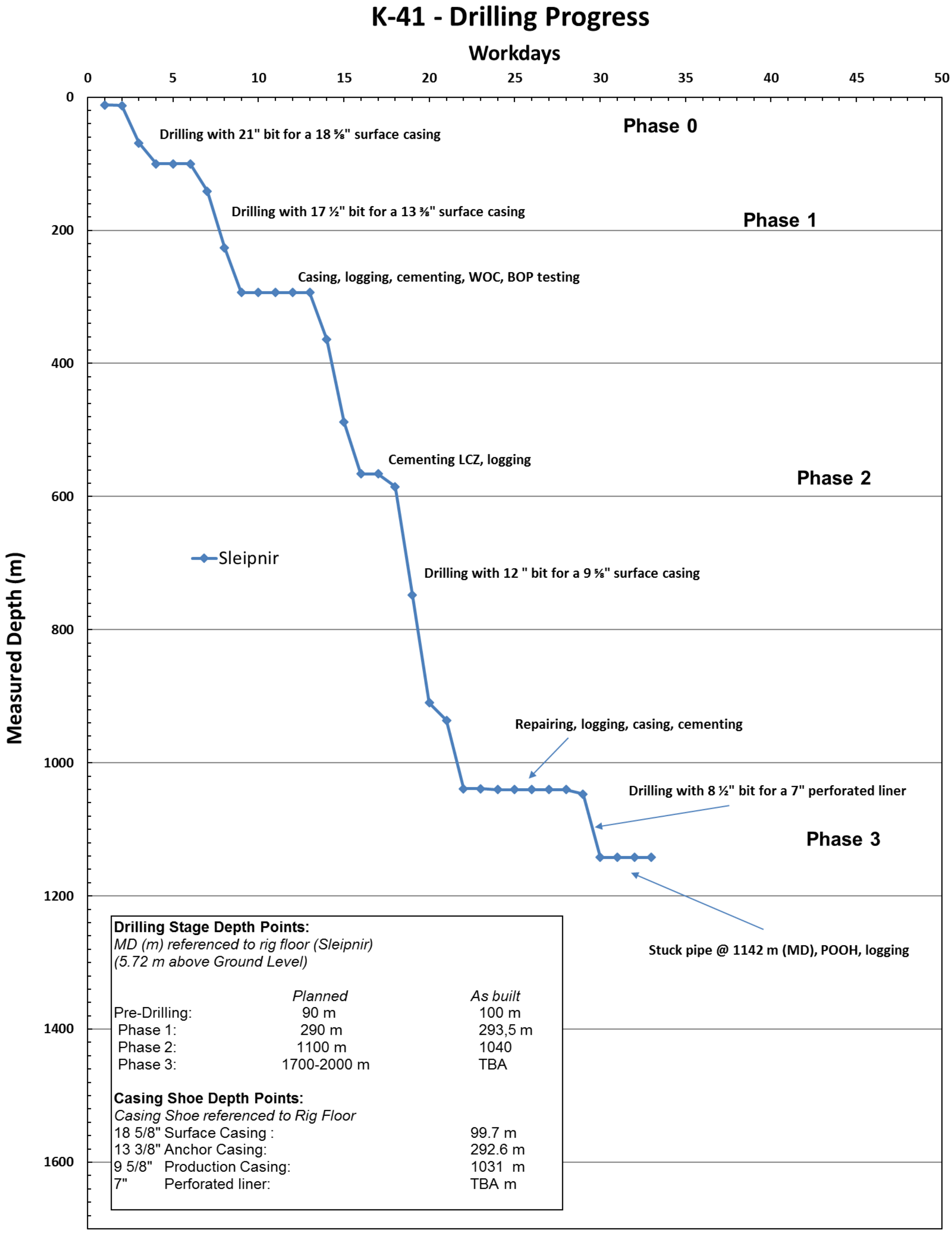

Figure 3. *Progress of drilling in K-41*

ÍSOR ICELAND GEOSURVEY	K-41	Tuesday 23rd of August 2016 Workday #35 of Sleipnir

Krafla	**Report for Workday #35** Preliminary results	Phase 3 (7" perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	BG RSÁ/SvSv MTM HeI (E-mail: bg@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1211 m	Hole made last 24 hrs. :	69 m
Last casing depth:	1031	Depth at 8:00.	1259 m	Drilling time:	10,5 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	>40 L/s	Average ROP:	6,6 m/hr

Drilling operation

Drilling in formation commenced shortly before 13:30 yesterday afternoon. Over the next three hours the well was drilled to 1163 m depth (MD). Yesterday's drilling is summarized in Fig. 1. Injection of polymer pills can clearly be seen once during drilling of each single and again at the end of each single. Torque increases gradually (purple). The significantly lower stand-pipe pressure (red) during drilling of the last single (Fig. 1) is probably related to slightly lower pumping rates (blue).

However, the slow climb of the stand-pipe pressure on the first single this morning (Fig. 2) may indicate that further loss zones have been intersected by the well. In addition, the stand pipe pressure was quite high during drilling around 1240 m at 5 o'clock this morning compared to the stand-pipe pressure recorded on the next single at around 6 o'clock (~1250 m) with similar injection rates.

After inserting the next single, the pipe was stuck (Fig.3).

Geology

The rudimentary (and very preliminary) injectivity index obtained last Sunday morning is compared to properly determined injectivity indexes from other wells in Krafla in Table 1. In Fig.4 LOC for K-41 is plotted against true depth in the well. LOC form other wells in the area is displayed for comparison. These are preliminary results and should be taken with "a grain of salt" or two.

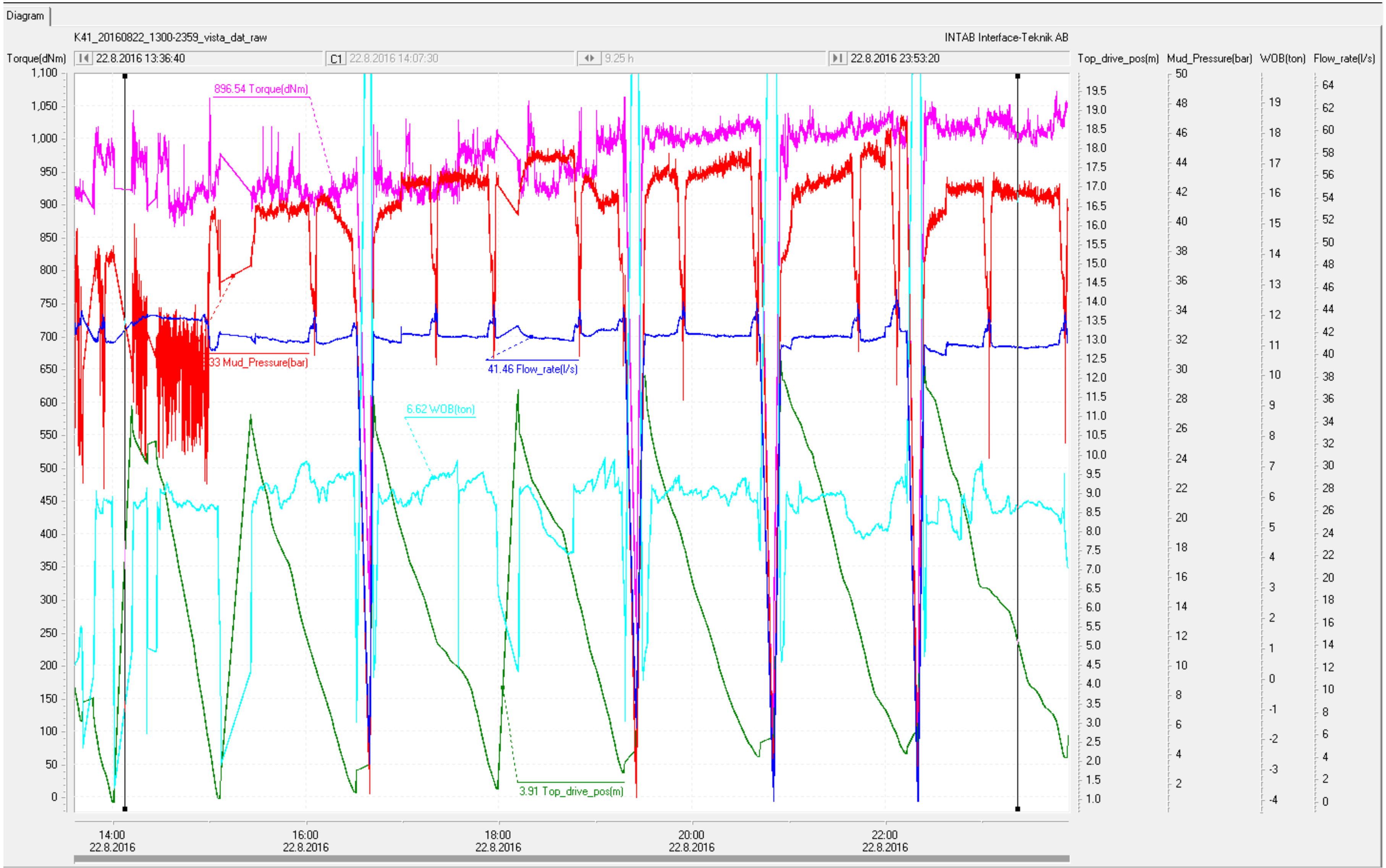

Figure 1. *Key parameters in yesterday drilling.*

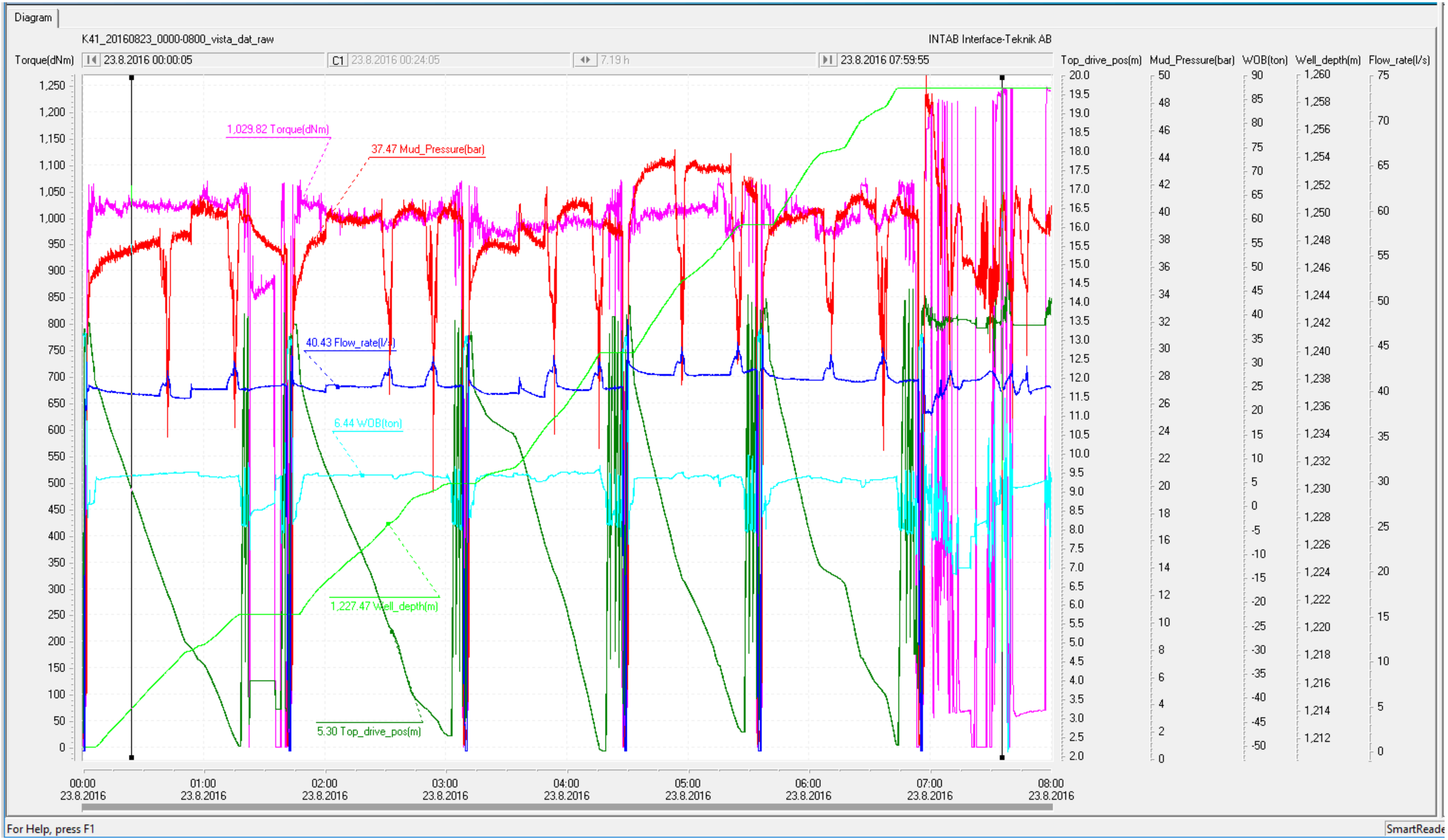

Figure 2. *Key parameters during this morning's drilling.*

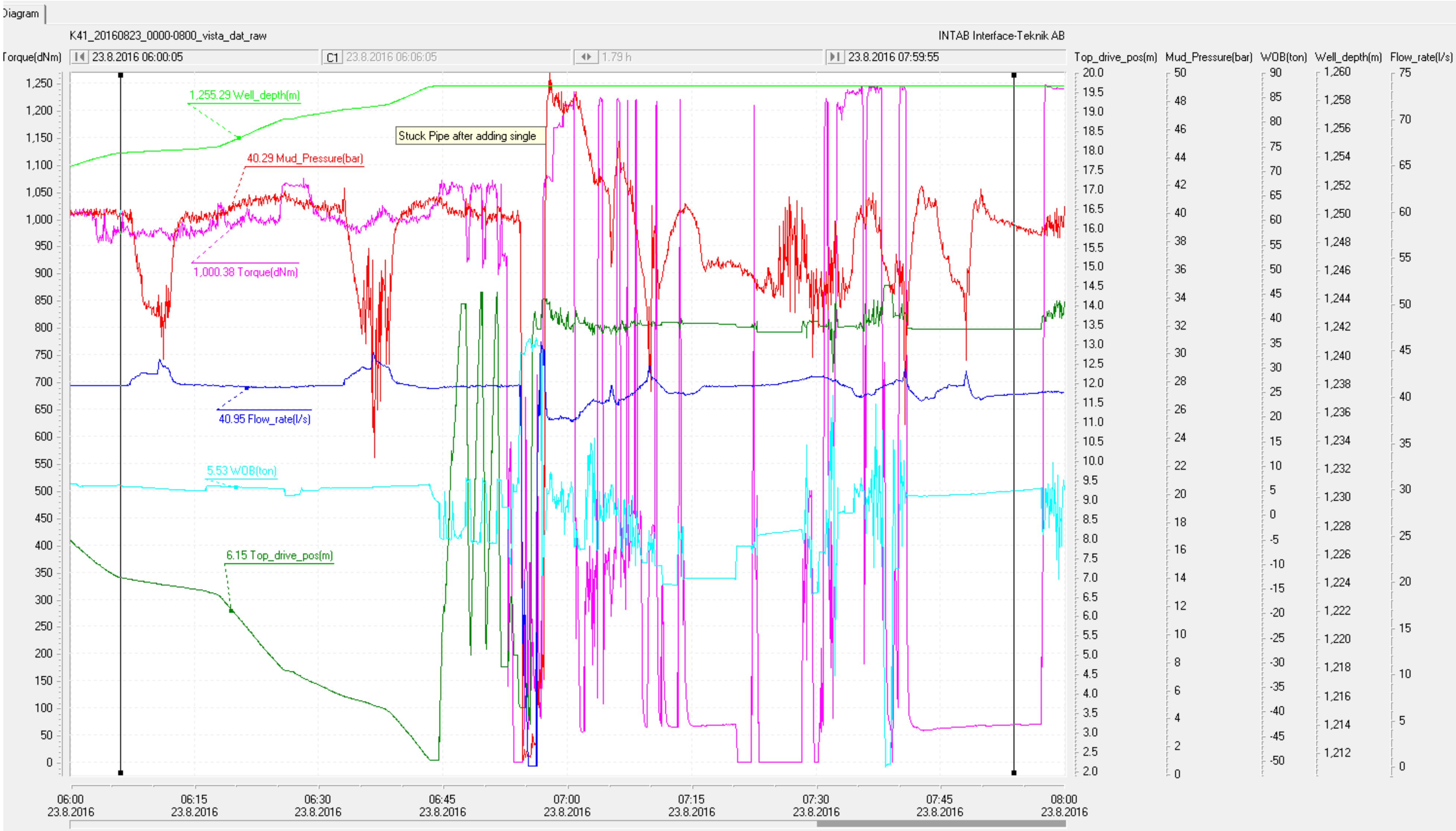

Figure 3. *Key parameters during this morning´s "stuck-pipe" event.*

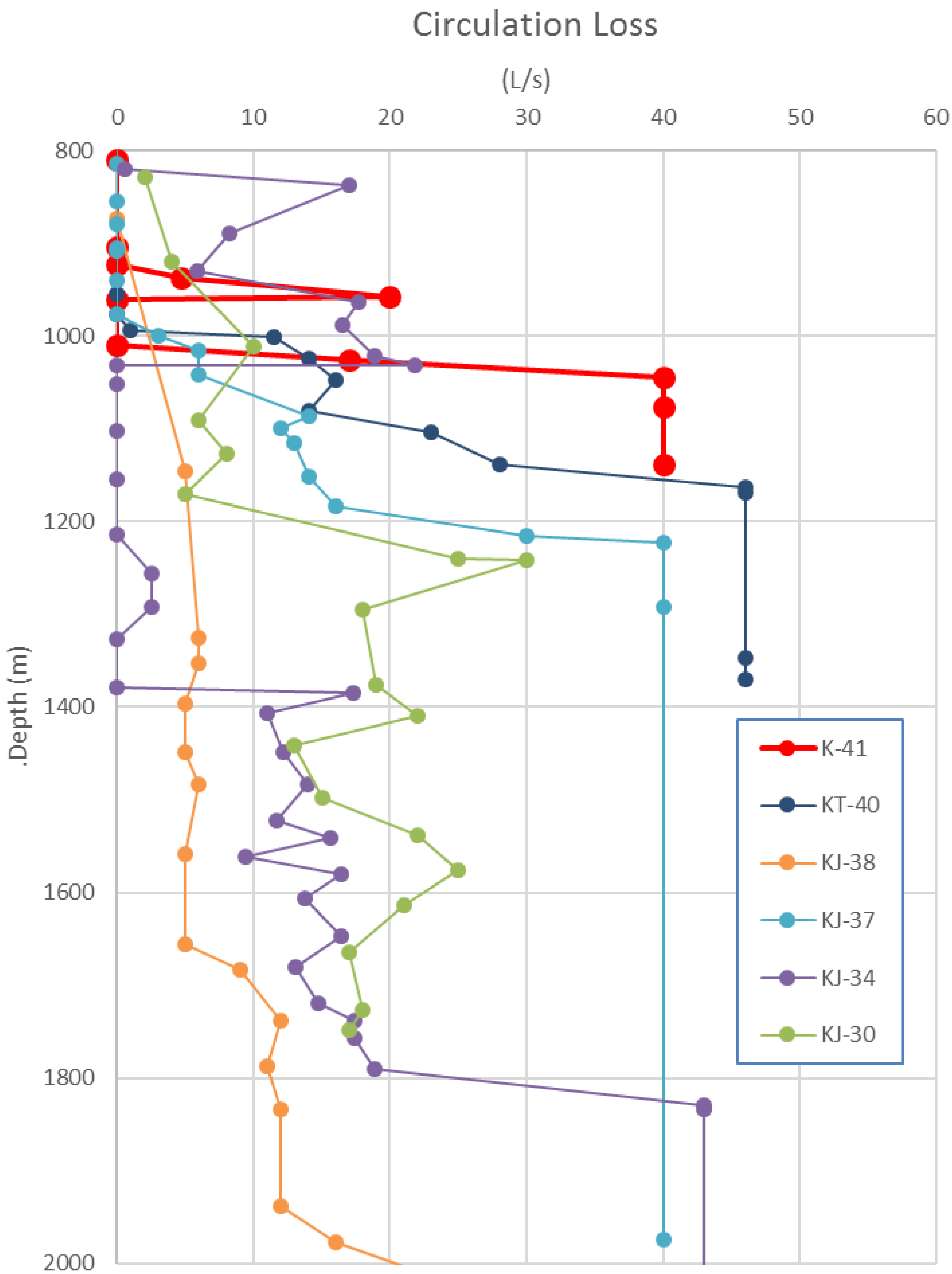

Figure 4. *Circulation loss as a function of true depth in K-41 compared to circulation losses in selected wells in Krafla.*

Table 1. *Injectivity index values for several wells at Krafla. The values are as listed by Anette K. Mortensen et al. 2009a except for K-40 which is from Anette K. Mortensen et al. 2009b.*

Well	Well ID	Date	I-Index [*L/s/bar*]
K-13A	58113	26.09.1989	3,0
K-30	58030	26.07.1997	1,0
K-31	58031	07.10.1997	4,6
K-32	58032	14.09.1998	3,0
K-33	58033	08.08.1999	3,5
K-34	58034	09.09.1999	5,5
K-35	58035	05.07.2007	3,0
K-36	58036	18.11.2007	11
K-37	58037	18.01.2008	3,7
K-38	58038	20.07.2008	3,0
K-39	58039	31.10.2008	6,6
K-40	58040	28.08.2009	16
K-41	58041	21.08.2016	(2,3)

References:

Anette K. Mortensen, Ásgrímur Guðmundsson, Benedikt Steingrímsson, Freysteinn Sigmundsson, Guðni Axelsson, Halldór Ármannsson, Héðinn Björnsson, Kristján Ágústsson, Kristján Sæmundsson, Magnús Ólafsson, Ragna Karlsdóttir, Sæunn Halldórsdóttir and Trausti Hauksson (2009a). *Jarðhitakerfið í Kröflu. Samantekt rannsókna á jarðhitakerfinu og endurskoðað hugmyndalíkan.* ÍSOR-2009/057, 206 pp.

Anette K. Mortensen, Magnús Á. Sigurgeirsson, Þorsteinn Egilson, Guðmundur Heiðar Guðfinnsson, Hörður Tryggvason, Ragnar B. Jónsson and Sveinbjörn Sveinbjörnsson (2009b). *Krafla – Hola KT-40. 3. áfangi: Jarðlagagreining og mælingar.* ÍSOR-2009/070, 54 pp.

Borvakt

	K-41	Wednesday 24th of August 2016 Workday #36 of Sleipnir
Krafla	**Report for Workday #36** Preliminary results	Phase 3 (7" perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	RSÁ/SvSv, MTM, HeI (E-mail: rsa@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1259 m	Hole made last 24 hrs. :	48 m
Last casing depth:	1031	Depth at 8:00.	1259 m	Drilling time:	6,75 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	>40 L/s	Average ROP:	7,1 m/hr

Drilling operation

Drilling continued with WOB 6,5 tons, 40 L/s and a total loss of circulation. At 1259 m, the string got stuck when adding a new single. At first, some movement of the string was possible, but soon it got completely stuck.

As can be seen in Figure 1, the string got stuck soon before 07:00. At ~4:30 yesterday morning, the flow rate was increased from 40 L/s to 41 L/s and at the same time, the stand pipe pressure increased. The flow rate and the stand pipe pressure remained at this level for the next single (~1240-1249 m). As the next single was put in, the flow rate remained the same but the stand pipe pressure dropped slightly, indicating a change in flow from the well to the formation including addition of a possible loss zone. The reader is encouraged to compare the flowrate and stand-pipe pressure at the tail end of the single ending at 1240 m depth (between 4:00 and 4:15) with the same parameters during drilling of the last single (~1249-1259). The location of this potential loss zone can however not be determined accurately.

This single was finished and the well was reamed without any problems. When putting in the next single the string got stuck. The last single was then removed again before starting to try to get the string unstuck. Operations to get the string unstuck have been ongoing since yesterday morning.

The Jar has not been working and therefore it is considered likely that the fill is sitting above the Jar. Currently a temperature log is being carried out by ÍSOR´s logging engineers in order to locate the fill and estimate its size (Figure 2).

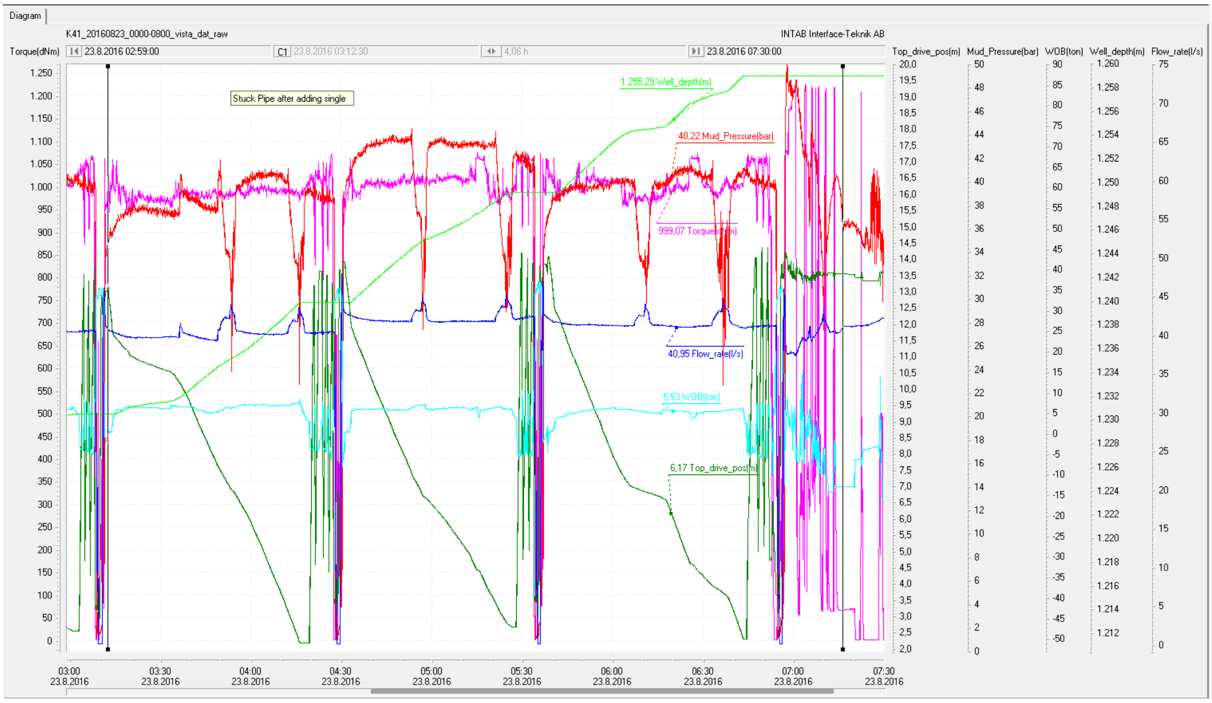

Figure 1. *The string got stuck at 07:00 at 1259 m MD.*

Figure 2. *ÍSOR´s logging engineers on site, logging temperature.*

Borvakt

ÍSOR ICELAND GEOSURVEY	K-41	Thursday 25th of August 2016 Workday #37 of Sleipnir

Krafla	**Report for Workday #37** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	RSÁ/SSy, MTM, HeI (E-mail: rsa@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1259 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1031	Depth at 8:00.	1259 m	Drilling time:	0 hrs.
Drilling fluid:	Mud	Circulation losses at 8:00	>40 L/s	Average ROP:	- m/hr

Drilling operation

After being stuck for 24 hours a decision was made to let the well heat up and do a temperature survey. ÍSOR´s logging engineers arrived on site and started logging at 9:30. After difficulties with logging using a temperature probe, a K-10 was RIH to log temperature and pressure (Figure 1). The drill bit is at 1252 m, the second stabilizer is 7,85 m above (at 1244 m) and the jar is located 89,44 m above the drill bit or at 1162,5 m. The temperature log indicates that the drill string is stuck from ~1210-1244 m and is sitting on top of the upper stabilizer. The last BHA can be found in Daily geology report 34. It also shows that the well has not heated up significantly and is still cold at the bottom. Therefore, it was decided to let it heat up overnight and do a second temperature log, which is currently being carried out.

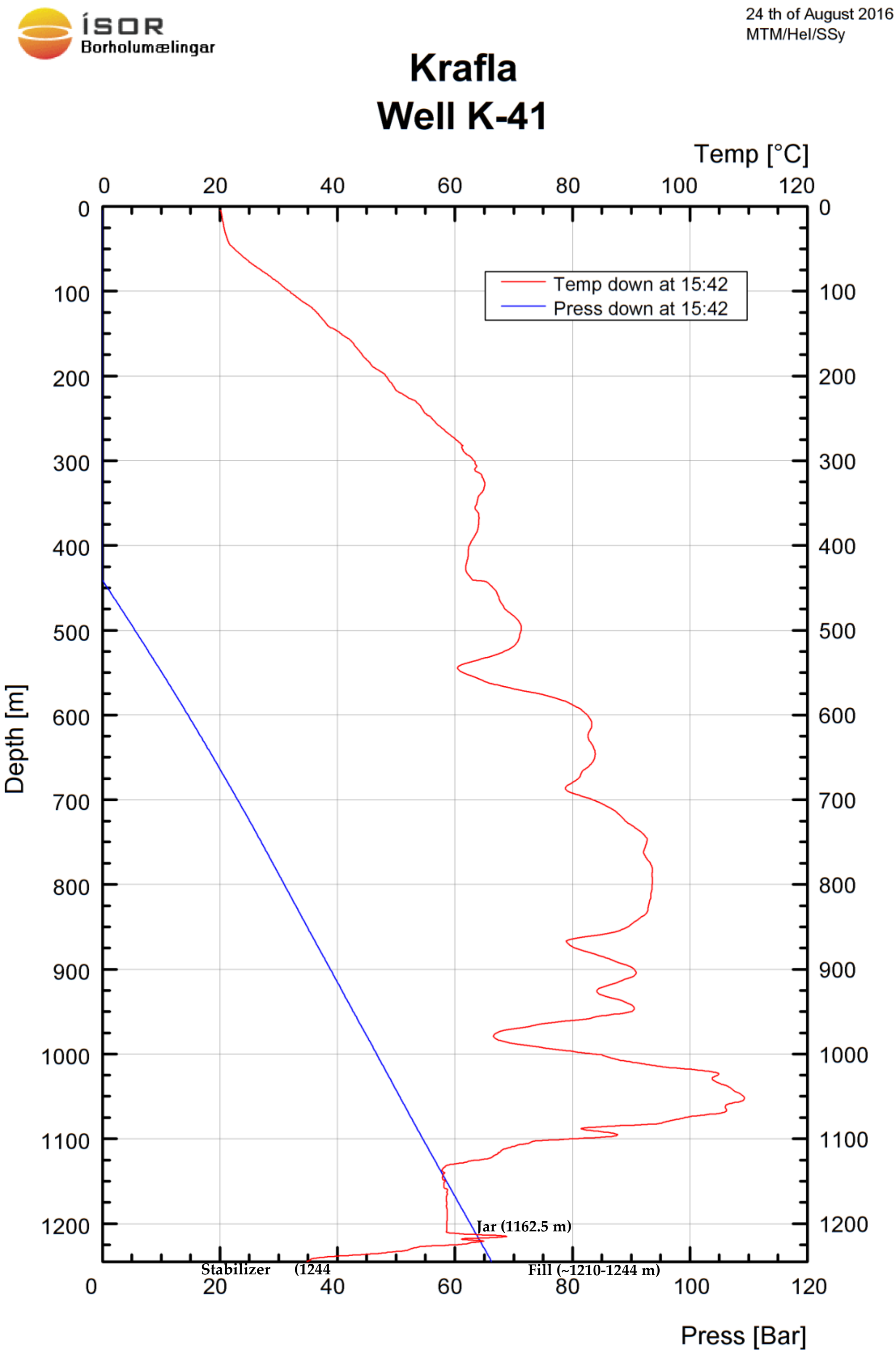

Figure 1. *Temperature logged down. Drill bit is at 1252 m and the fill is likely to be at ~1210-1248 m, sitting on top of a stabilizer.*

Borvakt

Krafla	**Report for Workday #38** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	RSÁ/SSy, MTM, HeI (E-mail: rsa@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1259 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1031	Depth at 8:00.	1259 m	Drilling time:	0 hrs.
Drilling fluid:	Water	Circulation losses at 8:00	>40 L/s	Average ROP:	- m/hr

Drilling operation

After being stuck for 48 hours a second temperature log was carried out by ÍSOR´s logging engineers yesterday morning (Figures 1 and 2). This log showed the well was around 30°C hotter than 24 hours before, and was now up to 140°C. The hottest part of the well was located above the fill. 1000 L of cold water were pumped down the well at 19 L/s in order to push the heat pulse down to the fill and heat it up more. Then the pumps were shut off and the driller started jarring and trying to rotate the string at the same time. This worked and the string started rotating at 14:30. For the next few hours the drill bit moved slowly up. When pumping at 25 L/s, the pressure went up to 2,3 bar. At 20:30 the string got unstuck and POOH started. Pumping on kill-line started at 23:15 with 19 L/s. The bit was up to 1020 m at midnight. This morning at around 4:30 a breakdown in the hydraulic system occurred and a hydraulic hose needs to be replaced.

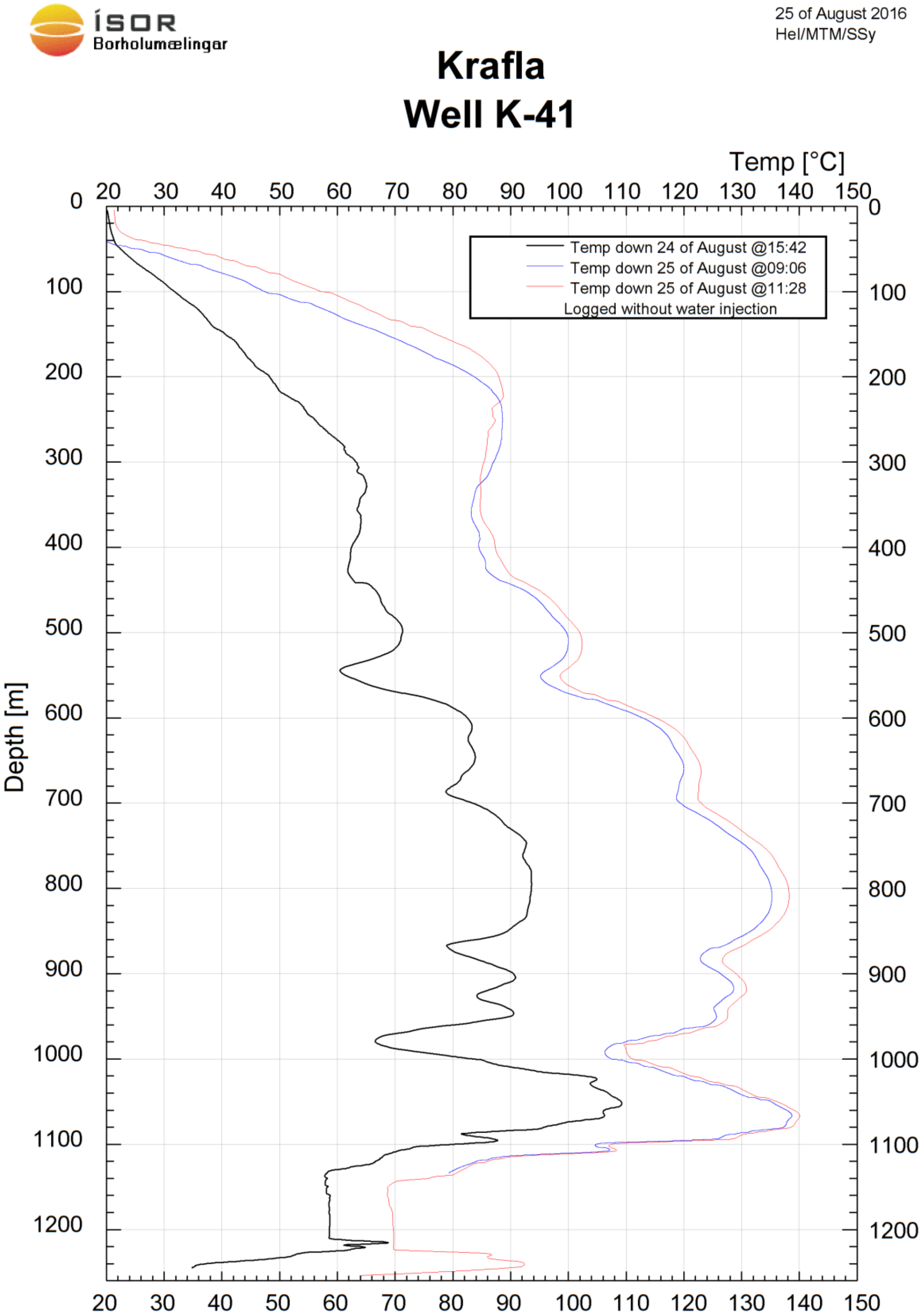

Figure 1. *Temperature logged down 25th of august. Drill bit was at 1252 m and the fill was likely to be at ~1210-1248 m, sitting on top of a stabilizer.*

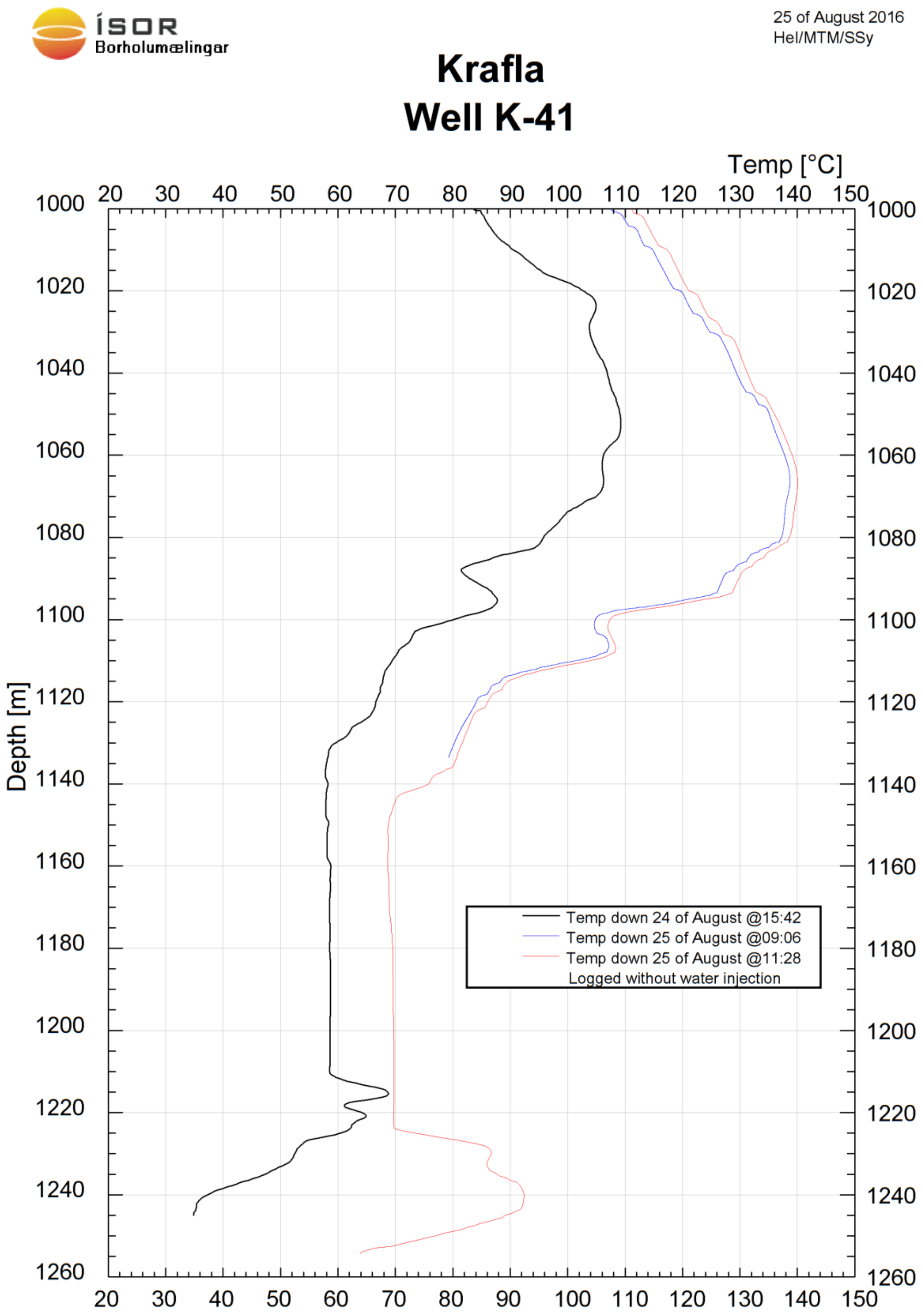

Figure 2. *Drill string was likely to be stuck at 1222-1242 m MD.*

Borvakt

	K-41	Saturday 27th of August 2016 Workday #39 of Sleipnir
Krafla	**Report for Workday #39** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	BG/HeI, HI, HÖS (E-mail: bg@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1259 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1031	Depth at 8:00.	1259 m	Drilling time:	0 hrs.
Drilling fluid:	Water	Circulation losses at 8:00	>40 L/s	Average ROP:	- m/hr

Drilling operation

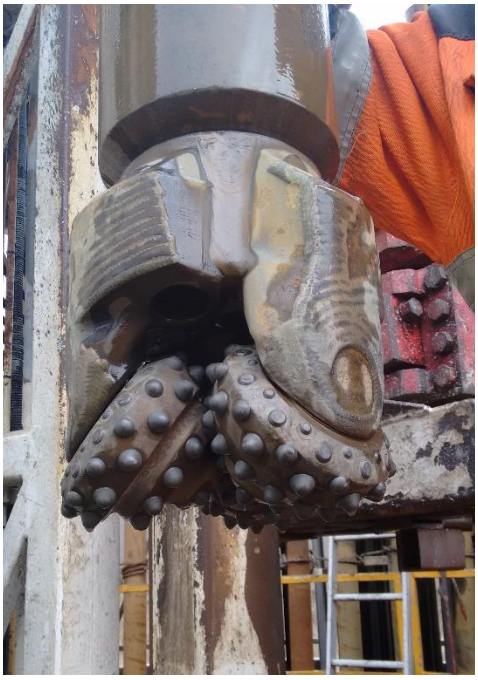

Figure 1. *Drill-bit back on the surface late yesterday afternoon. The bit looks pretty good with only modest signs of wear.*

Fixing the hydraulic system and cleaning up after the spill of hydraulic fluid was completed yesterday afternoon. Subsequently the crew continued POOH and the bit was back on surface around 18:00 (Fig. 1). After breaking out the last collars and centralizer the well was accessible for the logging engineers.

The logging engineer ran in with a combined P and T tool. The idea was to repeat the short step test performed after getting stuck at 1140 m depth about a week ago. Unfortunately, the profiles were affected by air pockets in the water column (Fig. 2). These were believed to be the result of air-injection while trying to get unstuck. However, thee logging established that the bottom fill in the well was approximately 6 m (Fig. 2).

Injection rate was increased to 30 L/s with the tool at 1000 m. However, the resulting pressure change due to increased injection made little sense so it was clear that the test would not give useful data.

The loggers ran the tool to bottom again before abandoning the test completely. The pressure profiles below 1140 m were apparently free of air pockets.

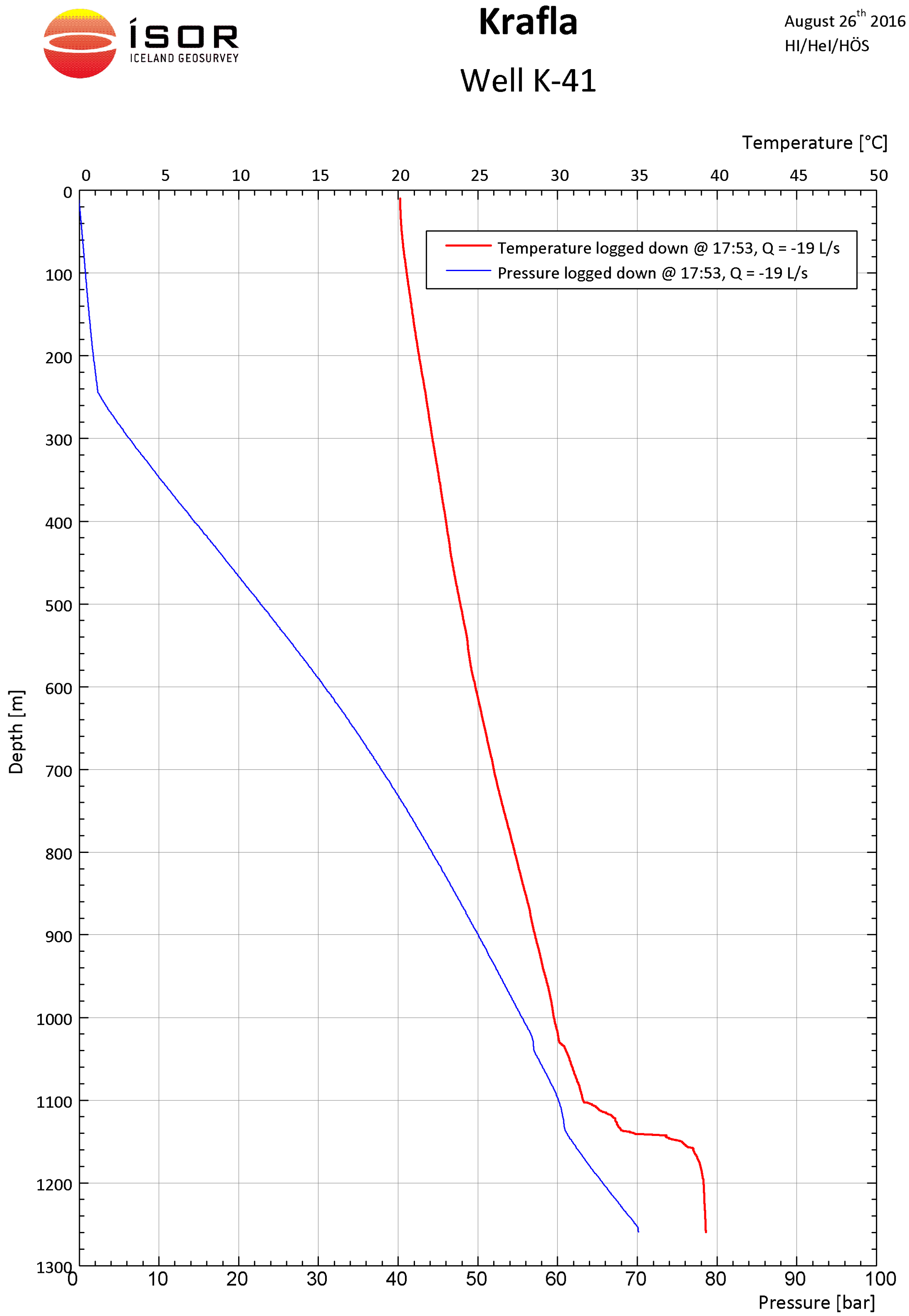

Figure 2. *Temperature and pressure profiles from yesterday's logging. Tools come to rest at 1253 m indicating a 6 m bottom fill. Note irregularities in the P profile indicating air-pockets in the water column.*

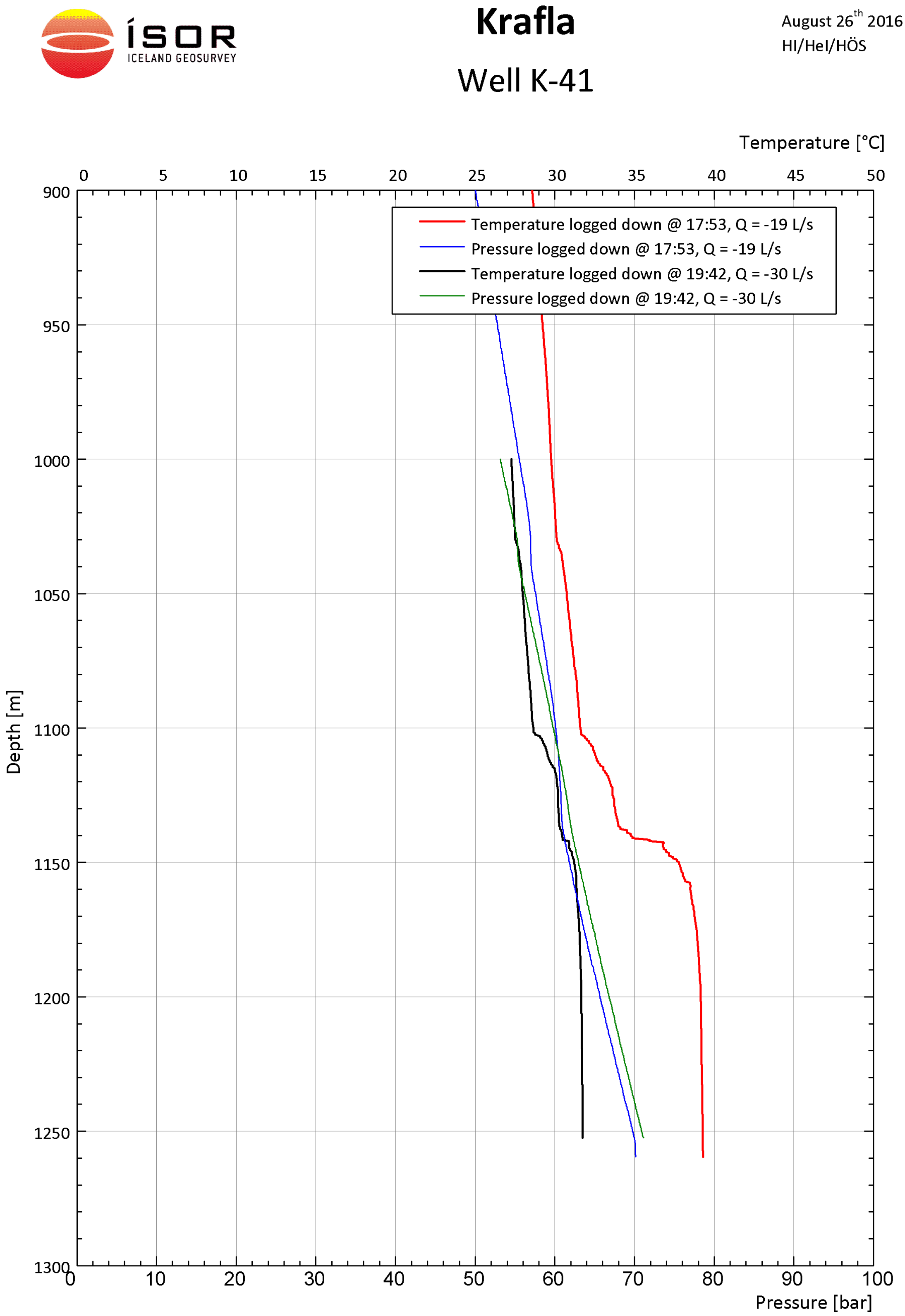

Figure 3. *The lowermost part of the T and P logs at both 19 and 30 L/s. A modest pressure change of < 2 bar for an increase in injection of 11 L/s suggests a reasonably high Injectivity Index of more than 5 L/s/bar.*

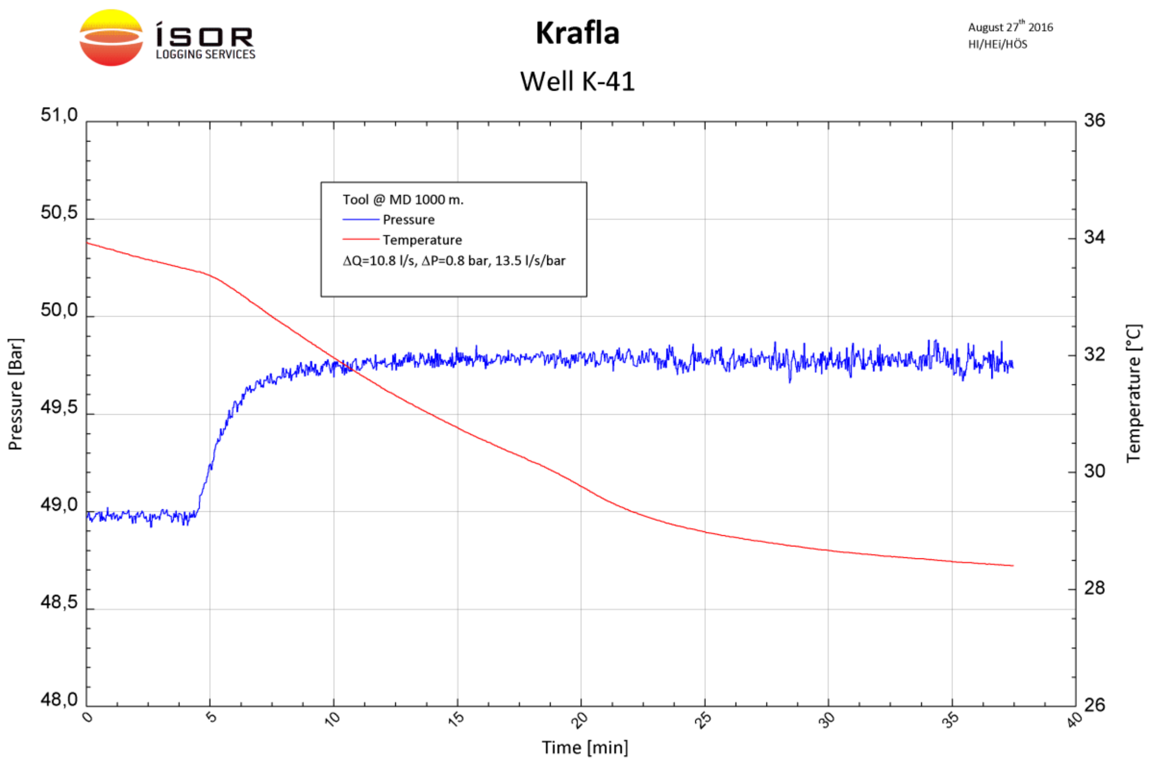

Figure 4. *The step test from Q = 19 L/s to Q = 30 L/s at 1000 m depth (MD) gives an injectivity index of 13,5 L/s/bar. The previous step (from 0 L/s/bar to 19 L/s/bar) suggested an injectivity index of 10,5 L/s/bar. This step is however affected by fairly rapid changes in temperature and is considered to be slightly poorer in quality than the step from Q = 19 to Q = 30 L/s.*

The difference between the profiles obtained with Q = 19 L/s and Q = 30 L/s injection were consistent throughout the depth interval from 1140 m to 1253 m at between 1 and 2 bars. The data suggests an Injectivity Index of approximately 5 to 10 L/s (Fig. 3).

To get a somewhat improved Injectivity Index and more comparable to the previous test, the following was done. Pumping into the well was stopped at around 20:10 and the kill line opened to let the air out of the well. At this point it became apparent that the kill-line valve had been open during the logging (BOP bellow closed) and that therefore the well had potentially received an additional injection of air during the initial logging. The well was left in this "degassing mode" for three hours. During that time, it burped significantly early on and the burp was then followed by a steady stream of air from the well.

After three hours, and prior to shutting the kill-line valve, the TP probe was lowered from 1000 m (MD) further into the well to examine the pressure profile. No signs of air pockets were observed. However, the probe came to rest at 1128 m depth.

After shutting the kill-line valve injection of Q = 19 L/s was initiated. After the tool had stabilized at that injection rate the rate was increased to Q = 30 L/s/bar. The result is shown in Fig. 4. An injectivity index of 13.5 L/s/bar is obtained. This value should be compared to 2.3 L/s/bar which was obtained after getting stuck at 1140 m. This is an enormous improvement.

Following these results, it was decided to RIH with a simple BHA and attempt to add some 50 m below the ~1259 m aquifer for "garbage collection."

Drilling is expected to commence around noon today.

For the readers benefit Table 1. from *The Geologists Daily Report #35* is included below. It compares the results of Injectivity tests from several wells in the Krafla area. The value for K-41 has been updated but is still presented with parentheses, because the quality of the test is not comparable to the other tests listed.

Table 1. *Injectivity index values for several wells at Krafla.*

Well	Well ID	Date	I-Index [*L/s/bar*]
K-13A	58113	26.09.1989	3,0
K-30	58030	26.07.1997	1,0
K-31	58031	07.10.1997	4,6
K-32	58032	14.09.1998	3,0
K-33	58033	08.08.1999	3,5
K-34	58034	09.09.1999	5,5
K-35	58035	05.07.2007	3,0
K-36	58036	18.11.2007	11
K-37	58037	18.01.2008	3,7
K-38	58038	20.07.2008	3,0
K-39	58039	31.10.2008	6,6
K-40	58040	28.08.2009	16
K-41	58041	26.08.2016	(~~2,3,~~ 13,5)

Borvakt

ÍSOR ICELAND GEOSURVEY	K-41	Sunday 28th of August 2016 Workday #40 of Sleipnir

Krafla	**Report for Workday #40** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	BG/HeI, HI, HÖS, HHT (E-mail: bg@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1299 m	Hole made last 24 hrs. :	49 m
Last casing depth:	1031 m	Depth at 8:00.	1313 m	Drilling time:	11,5 hrs.
Drilling fluid:	Water	Circulation losses at 8:00	> 40 L/s	Average ROP:	4,3 m/hr

Drilling operation

The crew RIH yesterday morning after the step test was completed (see yesterday's report). The crew found a 3 m bottom fill which was cleaned up prior to resuming drilling. Drilling then continued yesterday in total LOC with a ~6-7 ton WOB and ROP's < 10 m/hr and torque ~ 900 dNm. The pipe got stuck again at 1270 m for a short while. But after that the drilling was relatively problem free.

Drilling the production section was completed at 1313 m (MD) depth at 00:30 this morning. Each single has been reamed since getting stuck at 1259 m and the section above 1259 m got a "wiper" trip of sorts after the pipe got unstuck.

Figure 1. *The logging engineers arrived early this morning to carry out a gyro-log inside the drill-string in K-41.*

After pumping for ~2 hours at bottom injecting polymer pills the crew pulled the bit back to ~1100 m and then went back in to check for bottom fill at 7:00 this morning. Bottom fill turned out to be ~5 m. The well bottom was cleaned with pumping and polymer pills again and the bit was pulled back and the run in again to check for bottom fill at 8:00 this morning which turned out to be 3 m. This fill will be left in the well.

The logging engineers are now running in with the gyro-tool inside the drill-string (Fig. 1). This is in part because the engineers are servicing two rigs and the timing fits well with progress on ÞG-12 in Þeistareykir. It also means that the Sleipnir-crew will not have to RIH with a gyro-string later on in K-41.

Prior to running in with the gyro-tool temperature was logged inside the drill-string. The results are shown in Fig 1. The logging is done with the bit at 1302 m (MD), the temperature tool logged down to 1285 m. Pumping is currently Q = 19 L/s on kill line but no pumping is on string. Note the following cooling points in Fig. 1:

- i) at end of casing ~1030 m (MD) (may be related to well width i.e. change of well diameter at ~1040 m);
- ii) at ~1100 m (MD);
- iii) at ~1260 m (MD);
- iv) note also that the well is receiving water below ~1260 m (MD).

Furthermore, there is a subtle inflection point on the curve around 1140 m (MD).

The following steps are now planned:

1. Gyro inside drill-string (on-going) 5 hrs.
2. POOH 6-8 hrs.
3. Geophysical well logging including acoustic tele-viewer 15 hrs.
4. RIH with 7" liner 15 hrs.
5. Injection test with spinner 18 hrs.

Borvakt

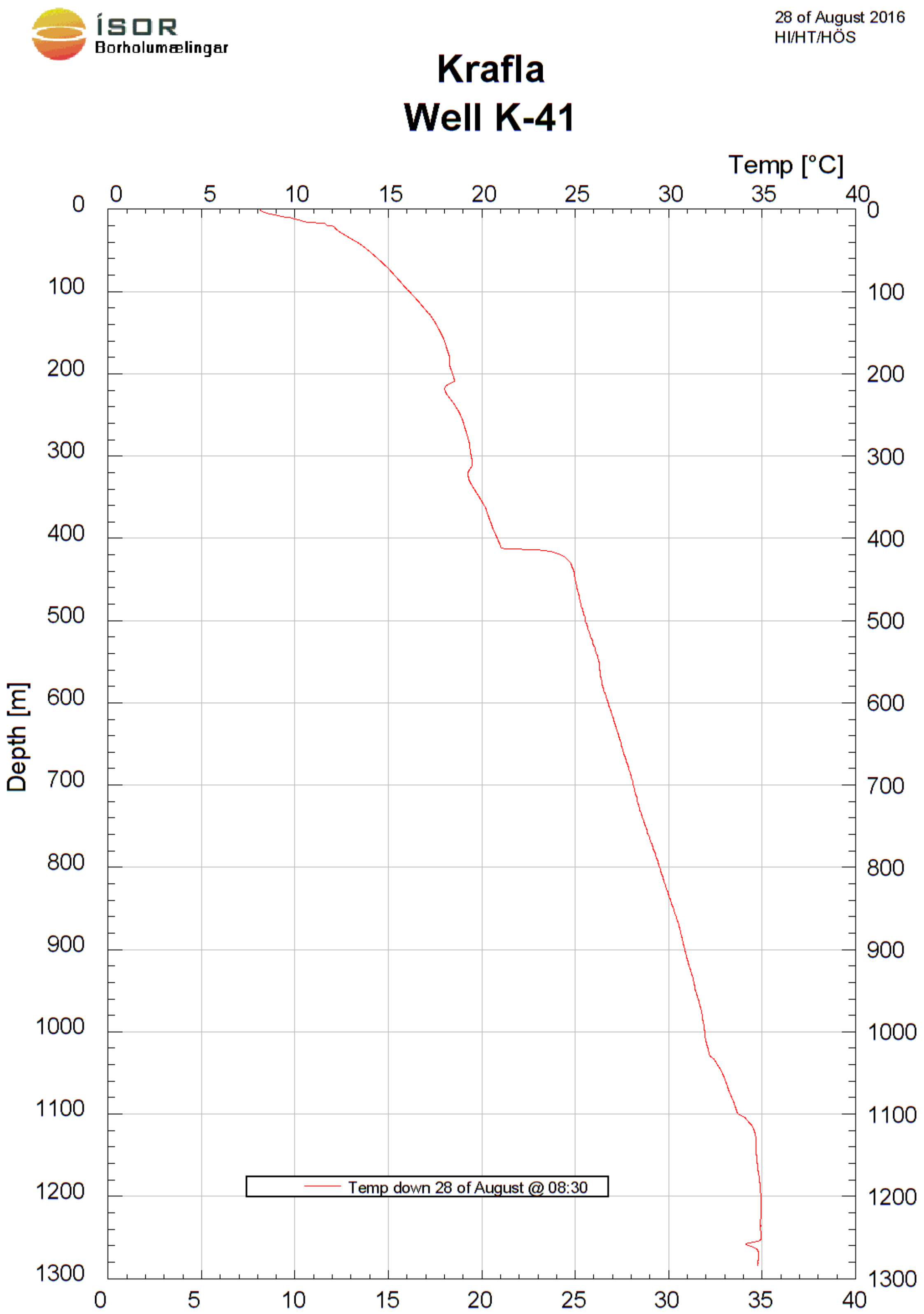

Figure 2. *Temperature log inside drill-string this morning carried out prior to running in with the gyro tool. The bit is at 1302 m (MD), the tool logged down to 1285 m. Q = 19 L/s on kill line no pumping on string. Note cooling points: i) at end of casing ~1030 m (change of well diameter at 1040 m); ii) at ~1100 m; and iii) at 1260 m. Note also that the well is receiving water below ~1260 m (MD).*

	K-41	Monday 29th of August 2016 Workday #41 of Sleipnir
Krafla	**Report for Workday #41** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	BP/HeI, HI, HÖS, HHT (E-mail: bastien.poux@isor.is)

Last casing size:	9 5/8" (prod. casing)	Depth at 24;00.	1310 m	Hole made last 24 hrs. :	3 m
Last casing depth:	1031 m	Depth at 8:00.	1313 m	Drilling time:	0.5 hrs.
Drilling fluid:	Water	Circulation losses at 8:00	> 40 L/s	Average ROP:	6.0 m/hr

Drilling operation

The logging engineers arrived at 8:20 am to run a gyro survey inside the drill-string, the measurement can be seen on table 1 and the final well trace of the well on Figure 1

Time	Depth	Inclination	Azimuth	Temperature
10:22:29	500,00	17,16	61,54	21,40
11:40:06	920,00	35,11	72,93	32,40
11:37:06	950,00	34,91	72,78	32,70
11:33:05	980,00	34,65	73,51	33,20
11:28:58	1010,00	34,15	73,85	33,90
11:25:22	1040,00	34,36	73,58	34,70
11:22:05	1070,00	33,98	71,00	35,30
11:18:52	1100,00	34,14	68,70	35,80
11:15:40	1130,00	34,59	67,58	35,90
11:12:27	1160,00	34,27	67,76	35,90
11:09:22	1190,00	33,76	67,85	35,80
11:06:09	1220,00	33,17	68,92	35,60
11:02:55	1250,00	32,46	68,31	35,30
10:57:24	1280,00	32,85	70,39	34,40

Table 1. *Results of the gyro survey run on August 28th at 12:00 pm*

Figure 3 shows the lithology and drilling parameters recorded at the rig from 1000 m to TD at 1313 m. Figure 4 shows the drilling progress curve for the well from surface to TD.

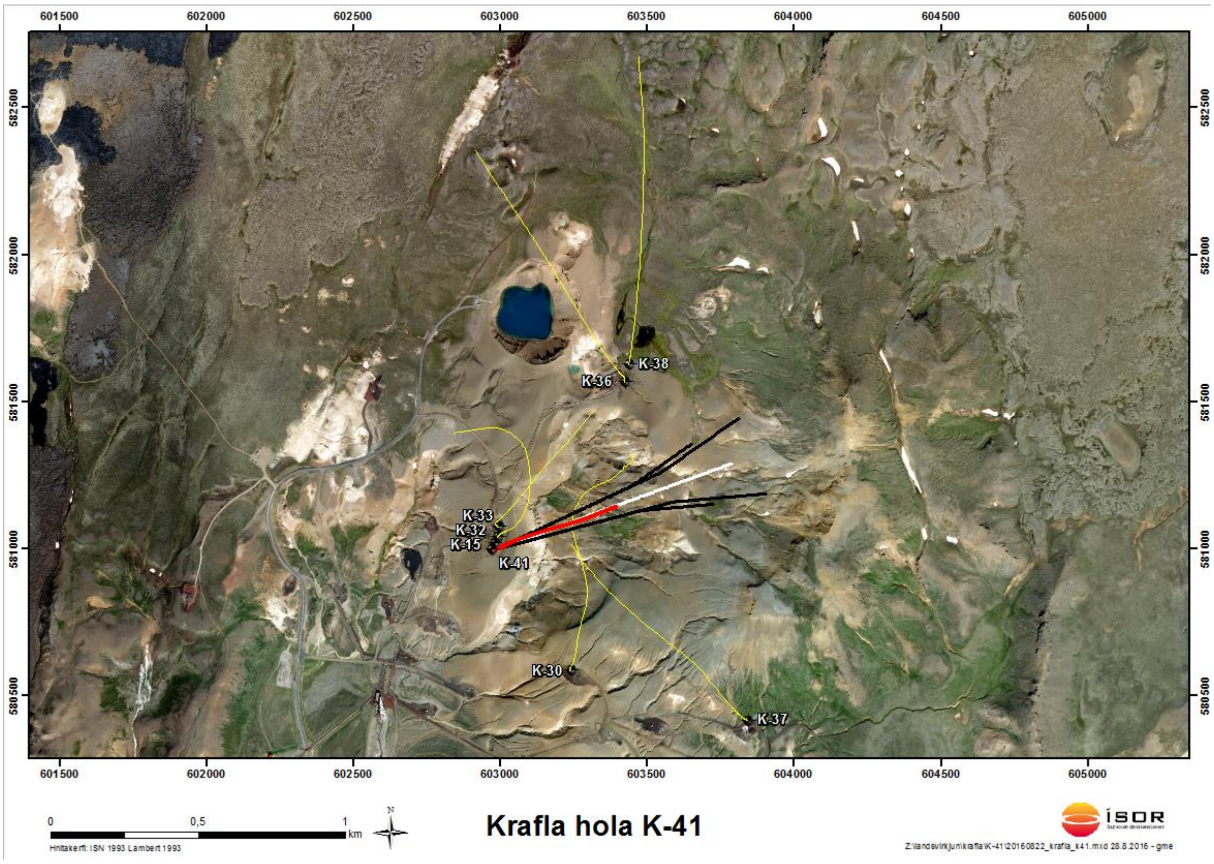

Figure 1. *Aerial picture showing the final trace of well K-41 (in red), superimposed to the planned well trace (in white), coupled with the traces of the nearby wells*

After some maintenance work the rig crew started POOH at 14:00 and the bit was out at 19:30. After some maintenance work and breaking out the BHA, Geophysical well logging started at 22.15.

Gamma, Neutron-Neutron, Resistivity and Caliper tools were run successively into the hole during the night. Results are shown on figures 5 and 6.

Like for the temperature survey run yesterday, several temperature change points can be seen on the temperature profile in Figure 5

v) at end of casing ~1030 m (MD), also seen in the previous survey showing a cooling point

vi) at ~1100 m (MD); with a sudden temperature increase

vii) at ~1120 and 1160 m (MD); two cooling points can be seen

viii) temperature stabilize below ~1200 m at ~41.5°C

At 8.20 this morning the Acoustic tele-viewer tool started being run down the hole. Logging up the bottom section started around 10 am and finished around noon.

The following steps are now planned:

6.	Gyro inside drill-string (COMPLETED)	4 hrs.
7.	POOH started at 14.00 (COMPLETED)	5 hrs 30 min.
8.	Geophysical well logging including acoustic tele-viewer (FINISHING)	14 hrs.
9.	RIH with 7" liner	15 hrs.
10.	Injection test with spinner	18 hrs.

Figure 2. *Picture of the ISOR logging engineers preparing the Acoustic Tele-viewer tool*

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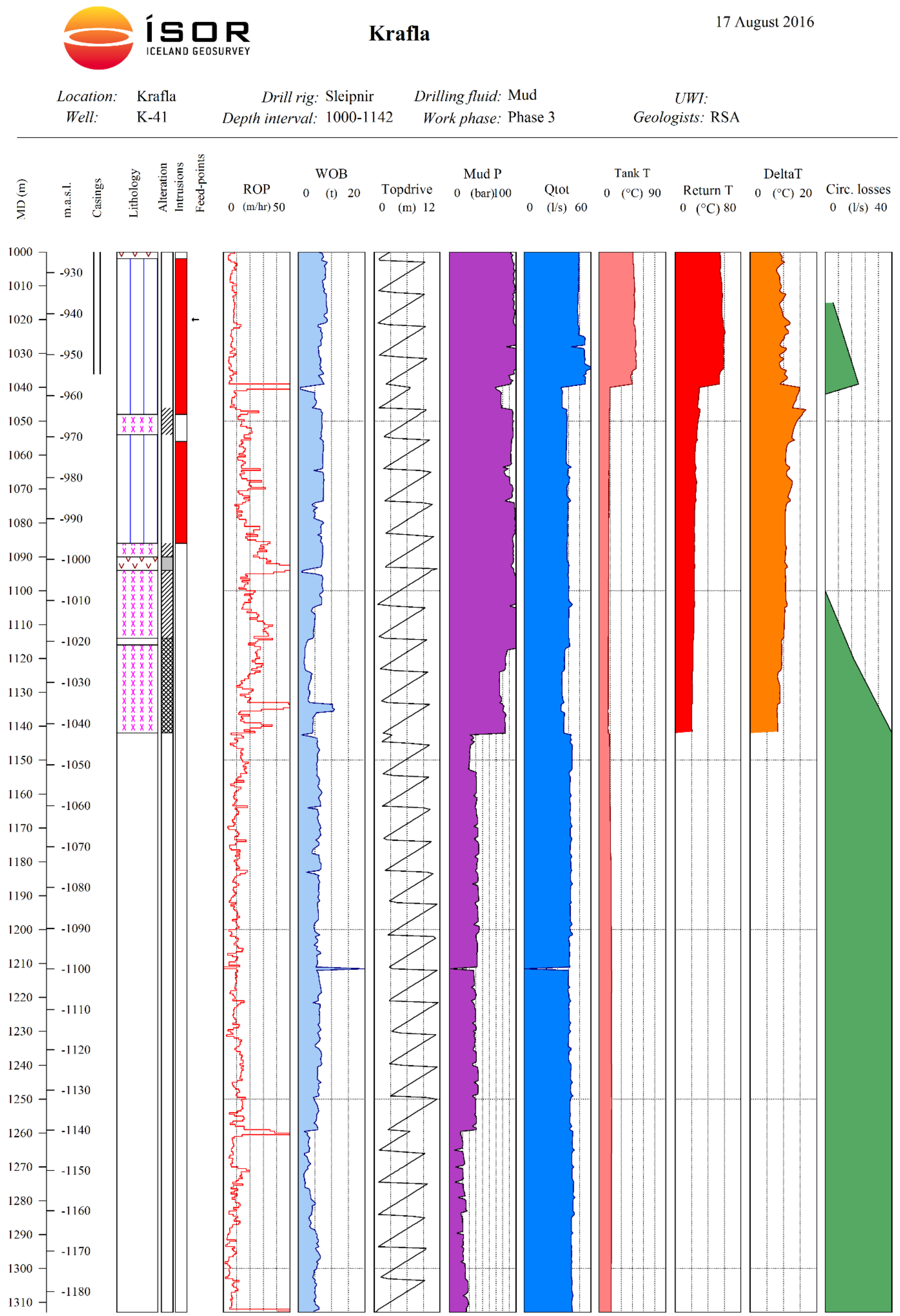

Figure 3. *Lithology and drilling data log from 1000 to 1313m*

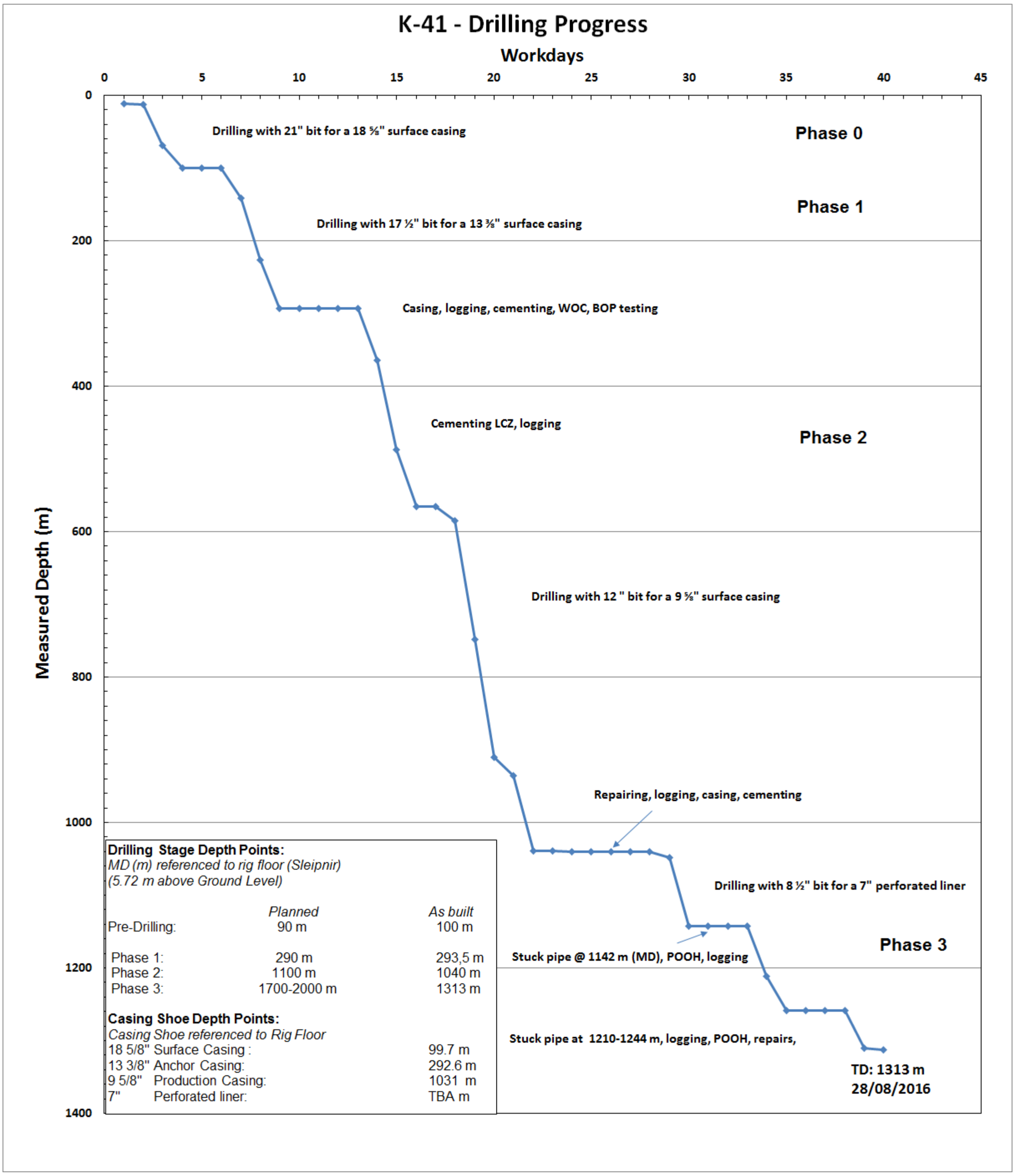

Figure 4. *K-41 drilling progress curve from spud date to Total depth at 1313m (day 1 to 40)*

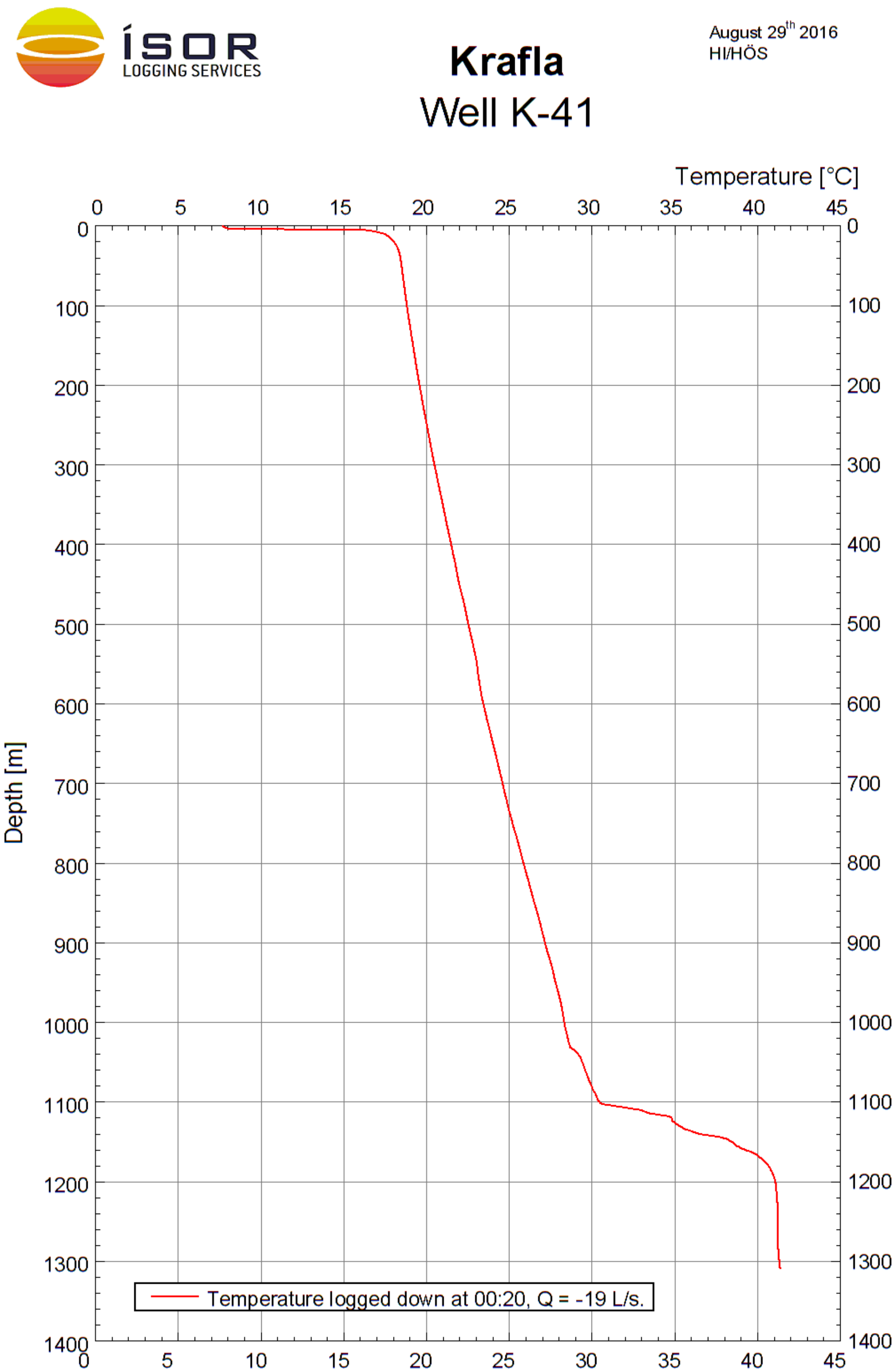

Figure 5. *Temperature profile from log run on August 29th to 1308.5 m*

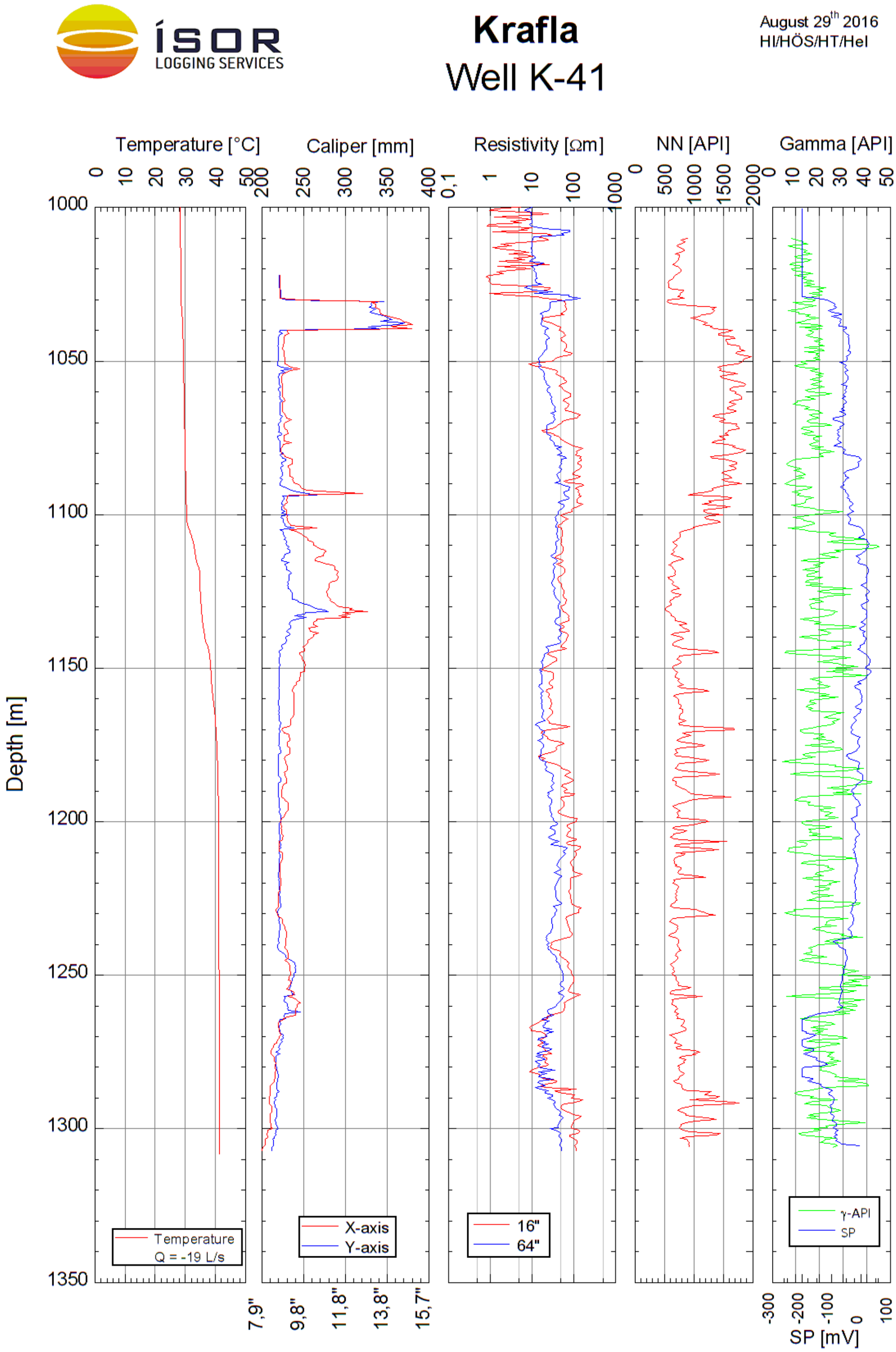

Figure 6. *Temperature, Caliper, Resistivity NN and Gamma profiles from logging surveys run on August 29th from 1000 to 1308.5 m*

	K-41	Tuesday 30th of August 2016 Workday #42 of Sleipnir

Krafla	**Report for Workday #42** Preliminary results	Phase 3 (7″ perforated liner)

Operator:	Landsvirkjun	*Drilling Company:*	Iceland Drilling Company
Well Name:	K-41	*Drill-Rig:*	Sleipnir
Well-Id:	58041	*Geologist/Geophysicist:*	BP/HeI, HI, HÖS, HHT (E-mail: bastien.poux@isor.is)

Last casing size:	7" (perf. liner)	Depth at 24;00.	1313 m	Hole made last 24 hrs. :	0 m
Last casing depth:	1309 m	Depth at 8:00.	1313 m	Drilling time:	0 hrs.
Drilling fluid:	Water	Circulation losses at 8:00	> 40 L/s	Average ROP:	0.0 m/hr

Drilling operation

The Acoustic tele-viewer log started at 8:20 and reached the open hole section at 1020 m around 9:25, it took about 25 minutes to log down to 1308 m, while recording in low resolution. The tool was then run upward at a slower pace for higher resolution from 1308 m to 1019 m before being brought back to the surface more rapidly in the cased section. ISOR logging engineers noted that a large part of the well was difficult to log due to washouts.

The rig crew started putting the 302 m of perforated liner in the hole at 13:00, followed by drilling rod to bring it to the bottom from 15:00 to 21:30. A 1,5-hour break was necessary at 18:00 to repair the hydraulic pump while the bottom of the liner was at 800 m.

The drill string was then POOH, which took about 4 hours. The casing report can be seen on Figure 1.

The 7″ liner is laying on the bottom of the well at 1309 m, the shoe is located at 1006,94 m.

The step test started at 3:00 this morning and is composed of 3 steps, between each of these steps, several spinner logs are run through the liner section. Pressure and Temperature measurements are made using ISOR logging tool at 1008 m, the preliminary results are shown on Figure 2 and 3

Details of the steps and results:

- Step 1: injection step from 19,2 l/s to 29,8 l/s, ΔP=0,8 bar, **13 l/s/bar**
- Step 2: injection step from 29.8 l/s to 40,4 l/s, ΔP=1,0 bar, **11 l/s/bar**
- Step 3: injection step from 40,2 l/s to 25,4 l/s, ΔP=1,2 bar, **12,5 l/s/bar**

Borvakt

ICELAND DRILLING	**Casing Information Report** **Rig: Sleipnir** Job No: 28178	**Iceland Drilling** **Rig No: 28000** Job Name: K 41

Casing Information

Run Date/Time:	29-ágú.-16 13:00		
		Leak Off Test (kg/cu m):	
Well Section:	PROD4	**String Type:**	LINER
String Top MD (m):	0,0	**String Top TVD (m):**	
Casing Shoe MD (m):	302,1	**Casing Shoe TVD (m):**	
String Nominal OD (cm):	17,78	**String Nominal ID (cm):**	15,94
Bit Diameter (cm):	21,59	**Avg. Open Hole Diam. (cm):**	21,59
Centralizers: No:		**Manufacturer/Type:**	
Depths:			
Hanger Type:		**Manufacturer:**	
Comments:	Transferred from Casing Tally Detail on 29-ágú.-16 01:10- 2 pakkar af límí notaðir á skó og hengistikki,,liner settist í 1009 m,top of liner 1006,94 m.		

String Component Details

Joints	Item	Length (m)	OD(cm)	ID (cm)	Weight (kg)	Grade	Connection	Torque
1	SHOE	0,280						
26	JOINT	301,510						
1	LHANG	0,270						
Totals: 28		302,060						

Figure 1. *Casing information report for 7″ perforated liner*

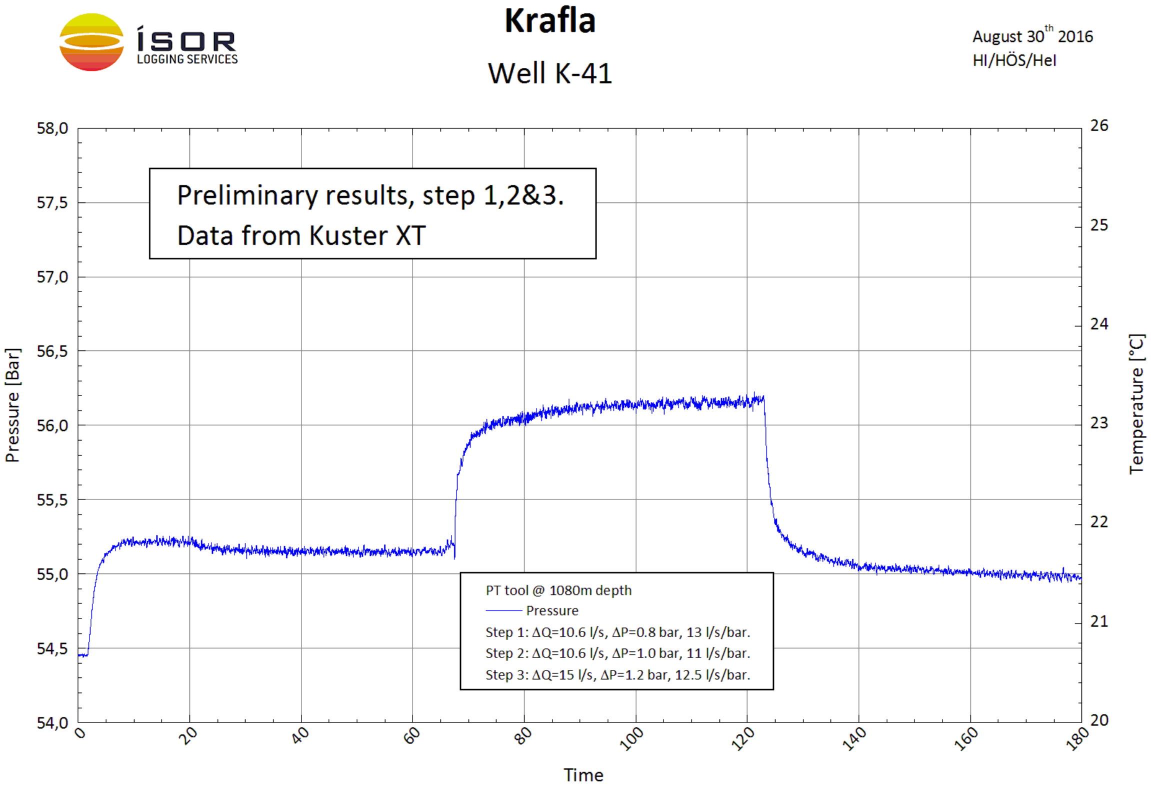

Figure 2. *Graphical representation of Pressure change during the step test*

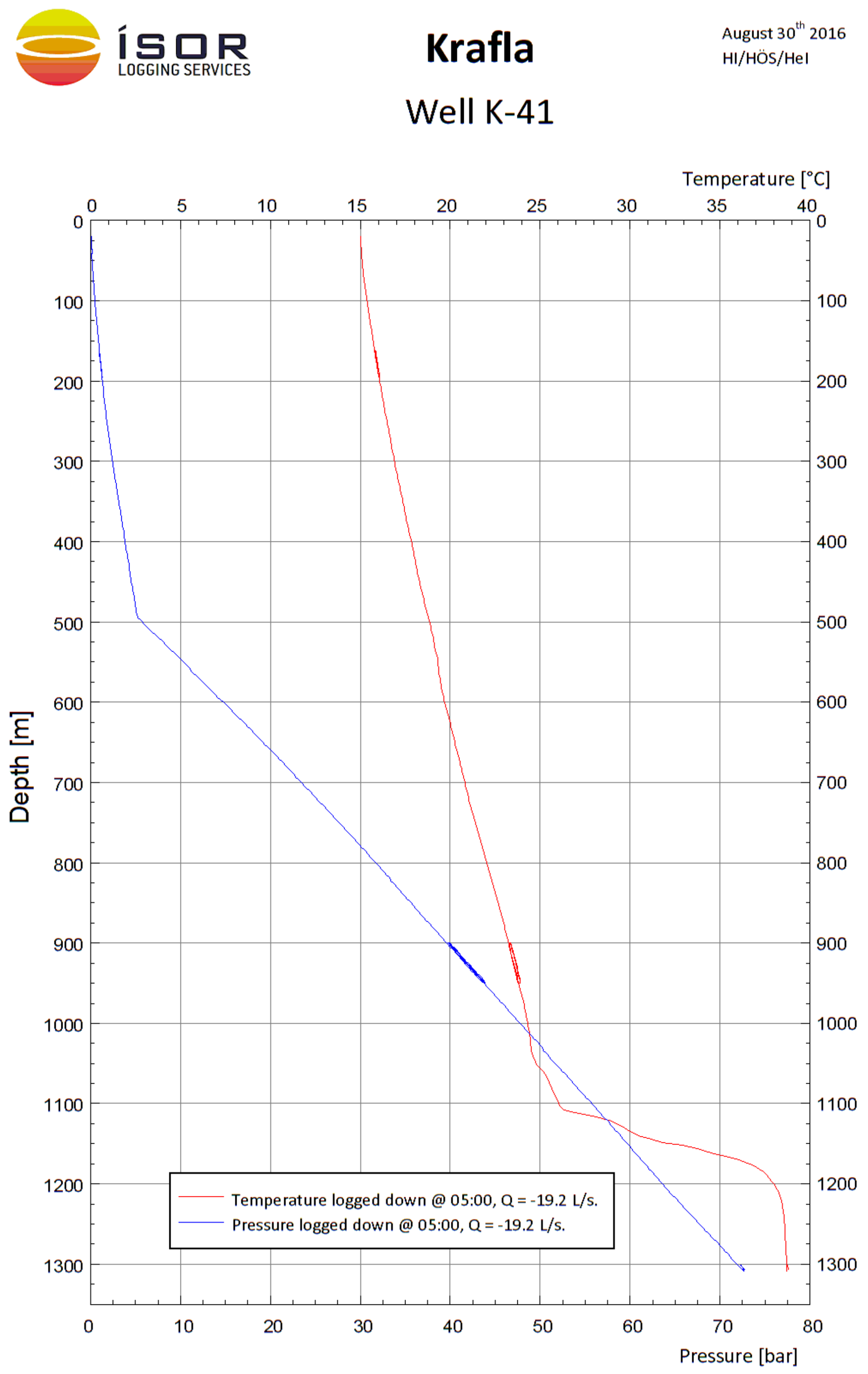

Figure 3. *Temperature and pressure logs completed before step test*

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