Optimization of Bit Selection and BHA Design for the Oberkling Gas Storage Drilling Campaign

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Affidavit

I declare in lieu of oath, that I wrote this thesis myself, using only literature cited in this volume.

Eidesstattliche Erklärung

Ich erkläre hiermit an Eides statt, dass ich die vorliegende Arbeit eigenhändig angefertigt habe, lediglich unter Verwendung der zitierten Literatur.

Date

Signature

Acknowledgement

First of all I want to sincerely thank **DI Heimo Heinzle** from RAG Rohöl-Aufsuchungs AG for offering me the chance to conduct this interesting thesis with direct involvement in real drilling projects. Further, I want to thank **DI Oliver Tausch** allowing me to participate in every possible way, and **DI Michael Brunneder**, **DI Karin Hofstätter** and **DI Georg Leipold** as well as all other engineers at RAG for providing incredible support.

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Last but not least, I want to thank my family for supporting me throughout my academic life and my friends, who were always there when needed.

Abstract (English)

During this thesis, two drilling projects of the Oberkling gas storage campaign were accompanied and have been investigated directly. A profound analysis of the used drilling bits and bottom hole assemblies (BHA) was performed in order to optimize performance. Results of the evaluation were directly implemented in the on-going planning.

The thesis covers an introduction into the challenging geological structure and gives a general overview of IADC's bit dull grading and bit wear. RAG's sensor system is introduced and presented as the foundation of further analysis with basic tools for a quick evaluation of the situation at hand. In addition, a detailed inspection of a roller cone bit used in the Oberkling well OKSP-001 documents its damage as investigated in Smith bits' reliability center. An analytical examination of each run was performed in order to detect shortcomings.

A final discussion includes the recommendation of a different BHA configuration along with the economic evaluation of such change.

Abstract (German)

Im Rahmen dieser Masterthesis wurden zwei Bohrungen des Gas Speicher Projekts Oberkling begleitet und umgehend untersucht. Es wurde eine gründliche Analyse der verwendeten Bohrmeißel sowie der Bohrgarnitur durchgeführt um die Leistung zu optimieren. Ergebnisse der Evaluierung flossen aus erster Hand in weitere Planungen mit ein.

In dieser Arbeit wird einleitend die anspruchsvolle geologische Struktur und ein Überblick über Meißelabnutzung und deren Graduierung nach IADC Standard diskutiert. Als Basis der weiteren Analyse mit Hilfsmitteln für eine rasche Evaluierung des Fortschritts wird das Messsystem der RAG erläutert. Zusätzlich wird ein Rollenmeißel, eingesetzt auf der OKSP-001, detailliert inspiziert und einer vollständigen Untersuchung in Smith bits Reliability Center unterzogen. Eine genaue Untersuchung jedes einzelnen Laufes wurde durchgeführt um etwaige Mängel festzustellen.

Eine Schlussdiskussion beinhaltet eine Empfehlung für eine Abänderung der Bohrgarnitur mit der damit verbundenen ökonomischen Evaluierung einer solchen Abänderung.

Contents

1. Introduction

RAG Austria has put focus on underground gas storage. For this reason, many wells have been drilled in the upper Austrian region and the Oberkling wells were planned for the same purpose. The drilling department of RAG plans to drill four wells at Oberkling

1.1. Problem statement

RAG enters new challenges in the Oberkling project with the given geological structures and lithologies, and therefore, a profound analysis of each bit's performance in combination with the bottom hole assembly (BHA) shall represent a proper foundation for onward decisions. This scope of the thesis covers the 12 ¼ inch and the 8 ½ inch sections.

Conglomerate layers and interbedded clay marl are expected to give challenges concerning bit selection. The strongly alternating layers of highly abrasive (conglomerate) and rather soft (clay marl) formations do not allow an "off-the-shelf" pick. Both, the bits' performance and wear resistance need to be combined even though being in stark contrast to each other. The impact of the bottom hole assembly (BHA) demands to be seriously considered as well.

1.2. Thesis objectives and scope of work

A detailed data analysis and investigation of the first two Oberkling wells should result in recommendations for the remaining 2 wells. This concept then could also be implemented for the next gas storage drilling campaign (Pfaffstätt) where similar Geology and technical challenges are expected. For this analysis the focus should lie on the following points:

- Compare the drilling performance between Oberkling-001 and Oberkling-002.
- If possible apply lessens learnt from Oberkling-001 on Oberkling-002.
- Based on real time data analyze bit and BHA performance and give recommendations for the remaining two wells.

- Discuss possible bit designs with various manufacturers.
- Liaise with the directional drilling service provider in optimizing BHA design and drilling parameters.

A literature research should give a general overview of bit selection and BHA design in conglomerates or similar geological environments to reduce vibrations and bit wear.

2. Geological background

2.1. Geology

Deepwater deposits (Oligocene – Miocene) of the Puchkirchen and basal Hall formations contain the main gas reservoirs of the Austrian Molasse Basin and yet they have been poorly documented. Only after implementing a new seismostratigraphic model, based on a regional 3D seismic dataset (Figure 2.1), the understanding of the depositional processes and reservoir distribution within classic deepwater foreland basin has changed.

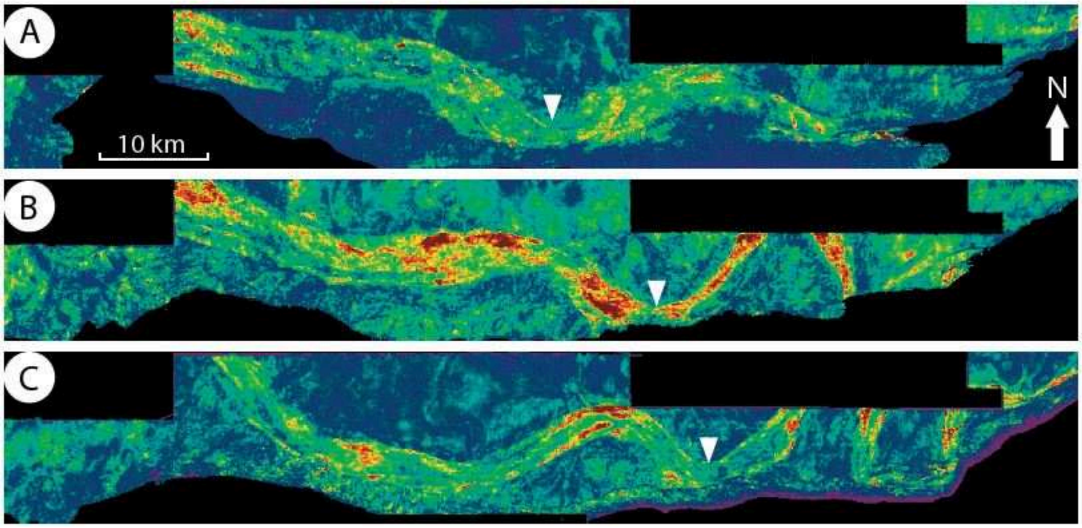


Figure 2.1 - Seismic channel map (younging from A to C) highlighting an individual changing channel morphology over time (white arrow)[4]

The regional 3D seismic mapping, which has been calibrated with attributes of nearly 350 wells, reveals that sedimentation took place in large meandering channel belts in the Molasse basin foredeep. These channels show low sinuosity. Turbiditic conglomerates and sandstones have filled the channels predominantly, as well as chaotic slump and debris flow deposits. On the other hand, chaotically fine-grained turbiditic sands and mudstone are the facies of the overbank areas. Further, the channels were backfilled by thin-bedded turbidites.

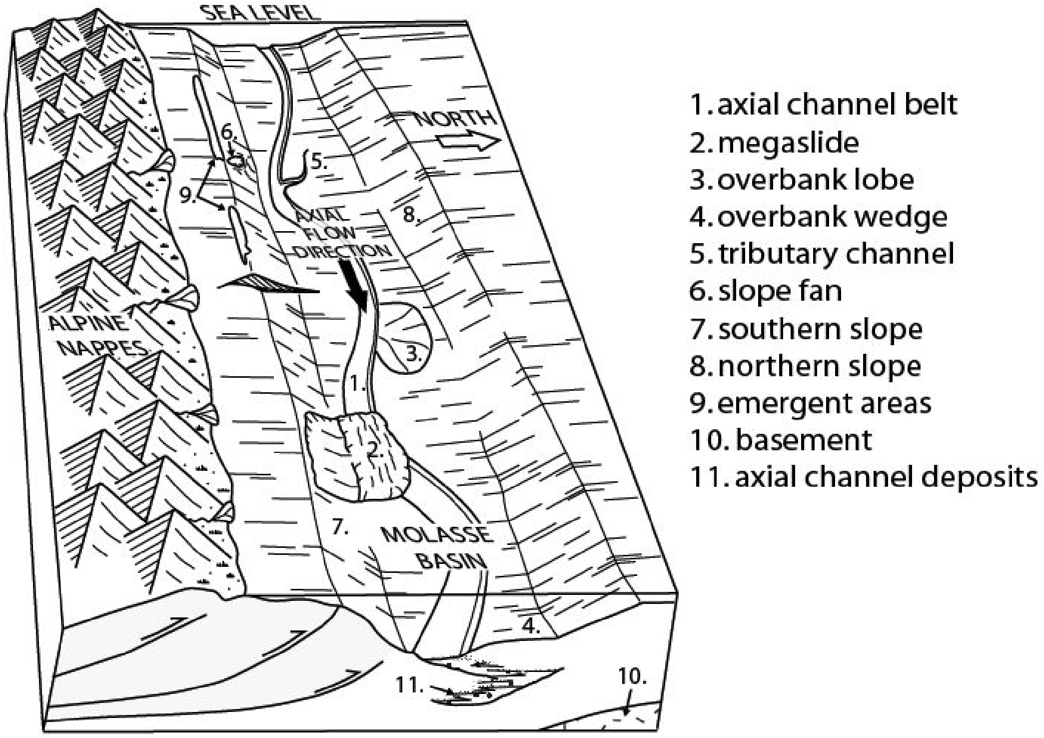


Figure 2.2 - Schematic paleographic reconstruction of the deposition in the Molasse basin with depositional elements defined by De Ruig and Hubbard (2006); 3 to 6 km wide.[4]

The overall 3 – 6 km wide channel belt thalweg consists of smaller sedimentation elements with 1 – 2 km in width (Figure 2.2). These smaller elements succeeded in upward fining and thinning gravity flow recording a waning of flows in the setting. The meandering flow pattern goes parallel to the Alp's crest from west to east.

Over Time, meandering patterns changed and different flow paths were created on top of each other. During the evolution of the so called Puchkirchen Formation, the channel belt with a lateral offset was stacked in sedimentary packages. This offset was formed mainly by composite erosion surfaces. The changing paleoflow pattern led to highly alternating lithologies. The comparable coarse grained conglomerate and/or sandstone layers are interbedded with mudstone, such as clay marl, from the overbank areas

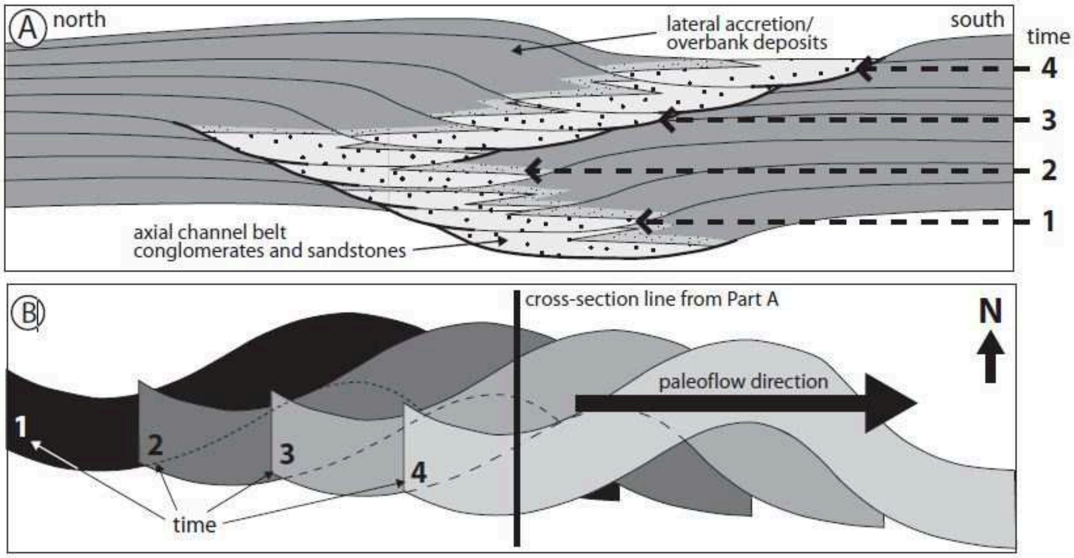


Figure 2.3 - Schematic evolutionary model for the Puchkirchen Formation in cross-section and map view[4]

2.2. Lithology

The overbank areas, as previously mentioned mainly mudstone, consist of clay marl. The dense clay marl shows good sealing properties. Whereas, the interbedded conglomerate and sandstone sedimentation is conceived to be more permeable, especially, the horizontal section in the reservoir layer.

These metamorphic clasts are mainly quarzites, but with some gneiss as well. The matrix consists of a calcite cementation. Quarzites are known as very hard and highly abrasive and in core samples of the offset well clasts with a diameter of 10 cm have been found.

3. Trajectory Design

The Oberkling Speicher wells #1 to #4 (OKSP–001 to OKSP–004) will be drilled as gas storage wells. Detailed information on the wells' coordinates will not be released and the following Chapter should only give insight on the wells' design and basic information for better understanding. The location of wells in Austria underlies two datum references.

3.1. Gauss-Krüger coordinate system

In Austria, a transverse Mercator system is in place for orientating. The projections are only 3° apart, as opposed to 6° in universal transverse Mercator (UTM) system, and there are two values describing a position

- Northing – distance from the equator,
- Easting – distance from the datum.

Datum Austria is the basis for the geographical location with Hermannskogel near Vienna as the datum reference.

3.2. "Normalnull" (NN) – Austrias height reference

Besides the geographical orientation, a height reference is inevitable. Austria's elevation reference system is the so-called "Normalnull" (NN) referring to meters above the Adriatic. This datum is the average water level of the Adriatic Sea in Triest (Italy).

3.3. Grid north – Azimuth reference

Since navigating needs a reference point as well, grid north is used for azimuth calculations using directions northwards along the grid lines of a map projection. For both, the OKSP–001 and the OKSP–002 an azimuth for the drilling operations was defined and all specifications for the vertical sections and the well plan refer to it.

OKSP-001	95.03°
OKSP–002	82.62°

3.4. Calculation Method - Minimum Curvature

For the Oberkling wells, Baker Hughes Inteq provides the directional drilling service. In their technical proposals all calculations have been performed on the basis of minimum curvature.

The minimum curvature model tries to minimize the total curvature within the physical constraints of the wellbore as an arc. The calculated well path shows a curvature defined by a ratio factor, the dogleg severity (DLS).

3.5. Trajectory of the 12 ¼ inch section of OKSP–001

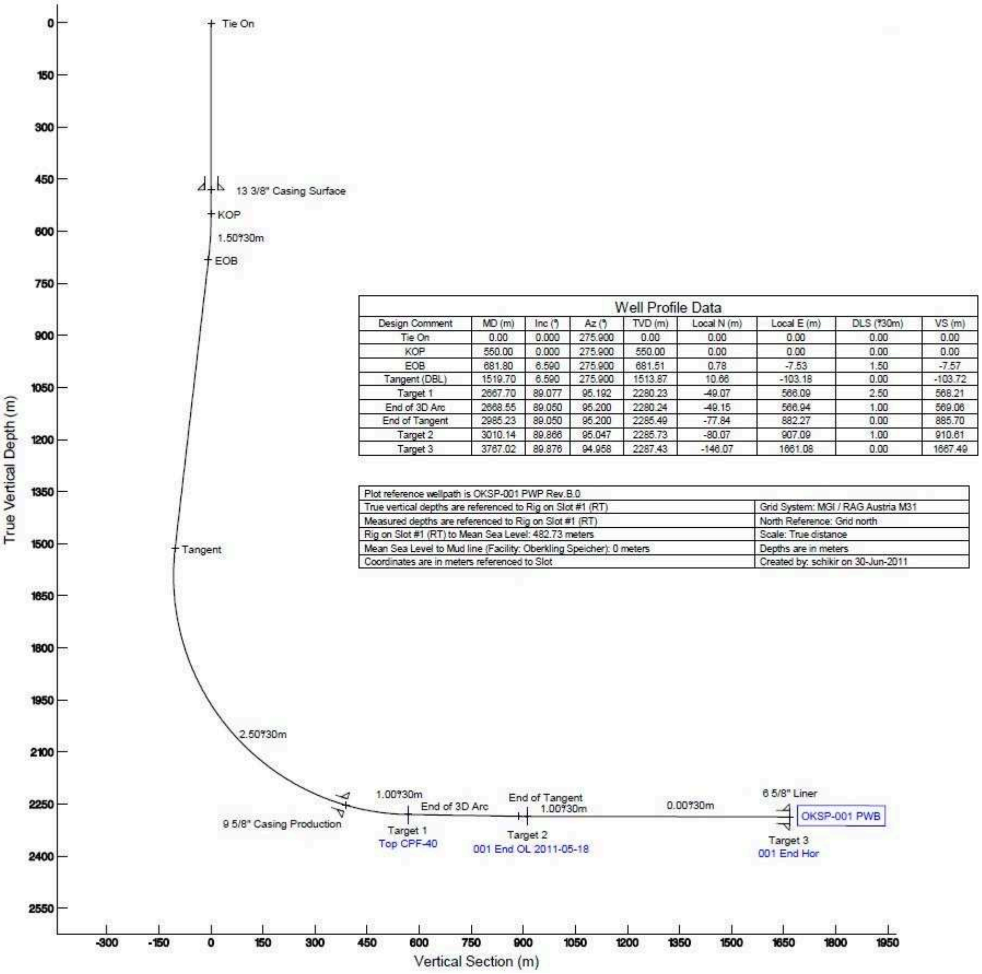
After the vertical 17 ½ inch top section, which will be drilled to the casing setting depth of 480 meters, the 12 ¼ inch part begins. Following a straight well path to 550 meters measure depth (MD), a kick-off to build up pointing towards 275.90° azimuth will be performed until 6.59° inclination is reached with a dogleg severity (DLS) of 1.50°/30 m. Thereafter, a tangential hold section is being drilled to the point where the trajectory drops again to straight vertical. The tangential part is planned to a depth of 1519.70 m MD.

Immediately after reaching vertical, the path is deviated towards 95.20° azimuth considering a dogleg severity of 2.50°/30 m. The constant build-up will be hold to the 9 5/8" casing setting depth at around 2485 m MD at an inclination of around 72.90°.

3.6. Trajectory of the 8 ½ inch section of OKSP–001

Consequently, the 8 ½ inch section will continue the build until reaching the first target (Top CPF-40) at 89.05°. The following horizontal section throughout the second target (001 End OL 2011-5-18) will hit the third target (001 End OL) and then finish at target depth – fourth target (001 End Hor). Planned target depth is at 3767 m MD.

The targets are defined as driller's targets as a sphere with a radius of 25 m without the consideration of ellipse of uncertainty.



Well Profile Data

Design Comment	MD (m)	Inc (°)	Az (°)	TVD (m)	Local N (m)	Local E (m)	DLS (?30m)	VS (m)
Tie On	0.00	0.000	275.900	0.00	0.00	0.00	0.00	0.00
KOP	550.00	0.000	275.900	550.00	0.00	0.00	0.00	0.00
EOB	681.80	6.590	275.900	681.51	0.78	-7.53	1.50	-7.57
Tangent (DBL)	1519.70	6.590	275.900	1513.87	10.66	-103.18	0.00	-103.72
Target 1	2667.70	89.077	95.192	2280.23	-49.07	566.09	2.50	568.21
End of 3D Arc	2668.55	89.050	95.200	2280.24	-49.15	566.94	1.00	569.06
End of Tangent	2985.23	89.050	95.200	2285.49	-77.84	882.27	0.00	885.70
Target 2	3010.14	89.866	95.047	2285.73	-80.07	907.09	1.00	910.61
Target 3	3767.02	89.876	94.958	2287.43	-146.07	1661.08	0.00	1667.49

Plot reference wellpath is OKSP-001 PWP Rev.B.0	
True vertical depths are referenced to Rig on Slot #1 (RT)	Grid System: MGI / RAG Austria M31
Measured depths are referenced to Rig on Slot #1 (RT)	North Reference: Grid north
Rig on Slot #1 (RT) to Mean Sea Level: 482.73 meters	Scale: True distance
Mean Sea Level to Mud line (Facility: Oberkling Speicher): 0 meters	Depths are in meters
Coordinates are in meters referenced to Slot	Created by: schikir on 30-Jun-2011

Figure 3.1 - Trajectory of OKSP-001

3.7. Trajectory of the 12 ¼ inch section of OKSP – 002

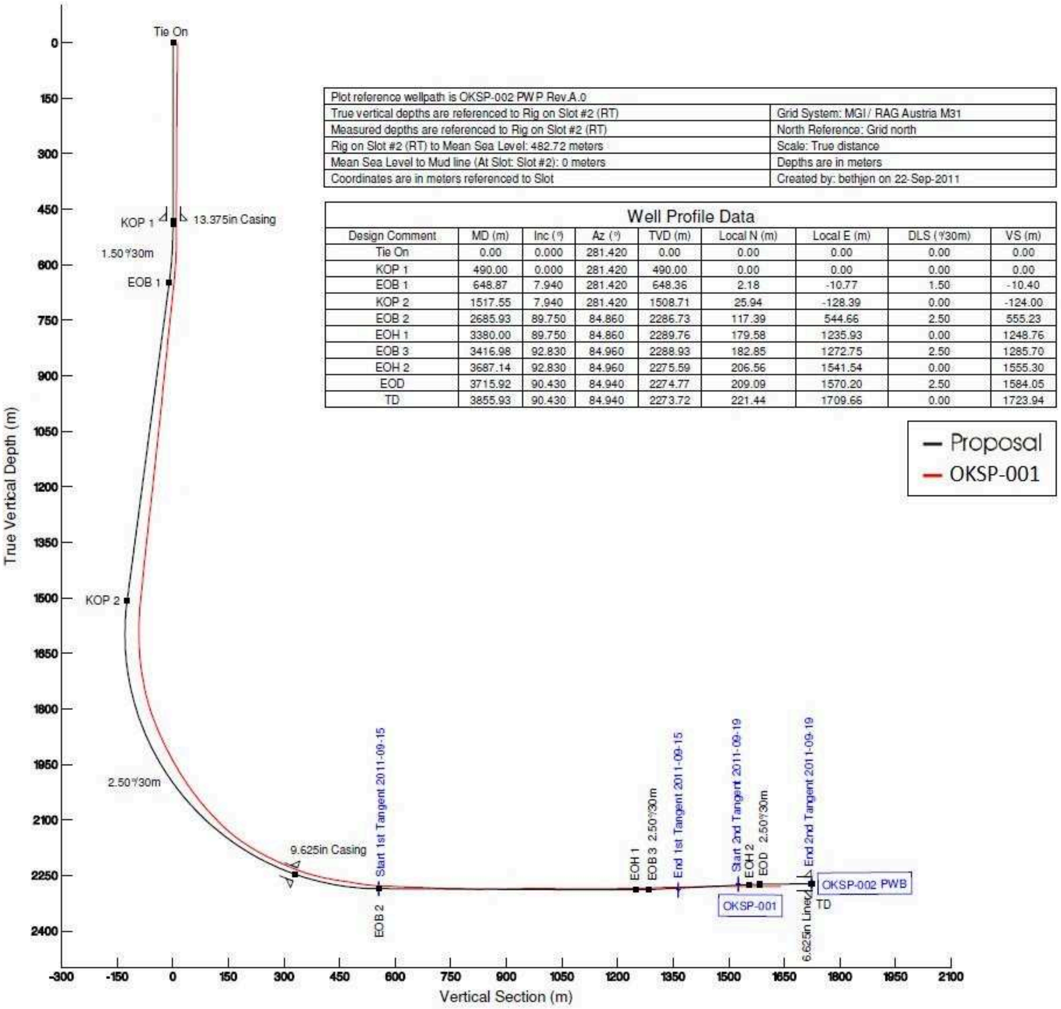
Similar to the OKSP–001, the top section in the OKSP-002 well is a 17 ½ inch straight vertical hole to a casing setting depth of 480 m. From there on, an only 10 m short vertical section will be drilled before kicking off towards 281.42° azimuth until an inclination of 7.94° is reached. This build-up is performed under the consideration of a DLS of 1.50°/30 m. Parallel to the Oberkling well #1 plan a tangential section is held to a depth of 1517.55 m MD, where a similar kick-off pattern is scheduled.

After dropping to vertical, an immediate build towards 84.86° azimuth is performed with a dogleg severity (DLS) of 2.50°/30 m until target depth is reached. Target depth is the casing setting depth at approximately 2456 m at an inclination of approximately 70°.

3.8. Trajectory of the 8 ½ inch section of OKSP – 002

As the trajectory is following a comparable plan, the first part in the 8 ½ inch section will be continued to be built to the first target (Start 1st Tangent 2011-09-15) with an inclination of 89.75° at the time when reached. The following tangential part will then turn into a trajectory with 92.83° inclination to reach target #2 (End 1st target 2011-09-15). Again, a tangential section will lead to the third target (Start 2nd Tangent 2011-09-15), where the inclination will be changed to 90.43° and held to get to the final target (End 2nd Tangent 2011-15-09) at target depth 3855.93 m MD.

For OKSP–002, the targets are defined as driller's targets as a sphere with a radius of 20 m without the consideration of an ellipse of uncertainty.



Plot reference wellpath is OKSP-002 PW P Rev.A.0	
True vertical depths are referenced to Rig on Slot #2 (RT)	Grid System: MGI / RAG Austria M31
Measured depths are referenced to Rig on Slot #2 (RT)	North Reference: Grid north
Rig on Slot #2 (RT) to Mean Sea Level: 482.72 meters	Scale: True distance
Mean Sea Level to Mud line (At Slot: Slot #2): 0 meters	Depths are in meters
Coordinates are in meters referenced to Slot	Created by: bethjen on 22-Sep-2011

Well Profile Data

Design Comment	MD (m)	Inc (°)	Az (°)	TVD (m)	Local N (m)	Local E (m)	DLS (°/30m)	VS (m)
Tie On	0.00	0.000	281.420	0.00	0.00	0.00	0.00	0.00
KOP 1	490.00	0.000	281.420	490.00	0.00	0.00	0.00	0.00
EOB 1	648.87	7.940	281.420	648.36	2.18	-10.77	1.50	-10.40
KOP 2	1517.55	7.940	281.420	1508.71	25.94	-128.39	0.00	-124.00
EOB 2	2685.93	89.750	84.860	2286.73	117.39	544.66	2.50	555.23
EOH 1	3380.00	89.750	84.860	2289.76	179.58	1235.93	0.00	1248.76
EOB 3	3416.98	92.830	84.960	2288.93	182.85	1272.75	2.50	1285.70
EOH 2	3687.14	92.830	84.960	2275.59	206.56	1541.54	0.00	1555.30
EOD	3715.92	90.430	84.940	2274.77	209.09	1570.20	2.50	1584.05
TD	3855.93	90.430	84.940	2273.72	221.44	1709.66	0.00	1723.94

Figure 3.2 – Trajectory of OKSP-002

4. Dull grading of bits

The following definitions and guidelines are taken from IADC Dull Grading System for both, roller bits and fixed cutter bits. The Smith Bits Dull Grading Manual also considers IADC structures. Still, the presented guidelines are taken from IADC standards offered by Hughes Christensen[1,2]. Smith bit rules have simply been added, because the majority of bits in use were held by Smith. The dull grading system is used to outline the bits' wear. Besides a general introduction into the grading schematic, typical signs of wear shown at the bits used at the Oberkling wells OKSP-001 and OKSP-002 have been focused on

The grading symbols can be used for all kind of bits:

- journal bearing bits, carbide and steel tooth,
- sealed ball and roller bits of both types,
- non-sealed bearing bits,
- natural diamond bits,
- polychrystalline diamond bits and
- thermally stable polychrystalline diamond bits[1].

4.1. System structure

As shown below (Figure 4.1), eight columns describe the extent of wear. First, four spaces refer to the cutting structure and the position of the cutter's wear, distinguished between the inner and the outer row, and special characteristics at a certain location. The fifth column indicates a bearing wear of roller cone bits. The sixth space provides information of the gauge measurement and the last 2 spaces are reserved for other dull characteristics and reasons pulled[3].

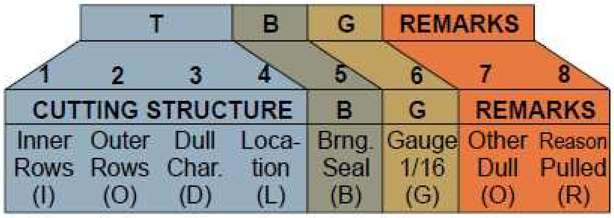


Figure 4.1 – Dull grading schematic structure[3]

4.2. Roller cone bits

Column 1 (I) describes the cutting elements not touching the wall and their wear. After IADC standardization this counts for the inner 2/3 of the bit. To report the wear of the cutters touching the wall (outer third of the bit), line 2 (O) is used, but a Smith guideline states clear not to include heel elements. So, both criteria are put into a linear scale from 0 to 8 measuring the structure reduction (Figure 4.2).

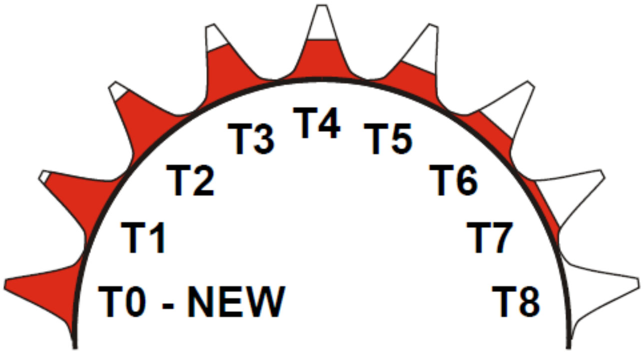


Figure 4.2 – Tooth height measurement[3]

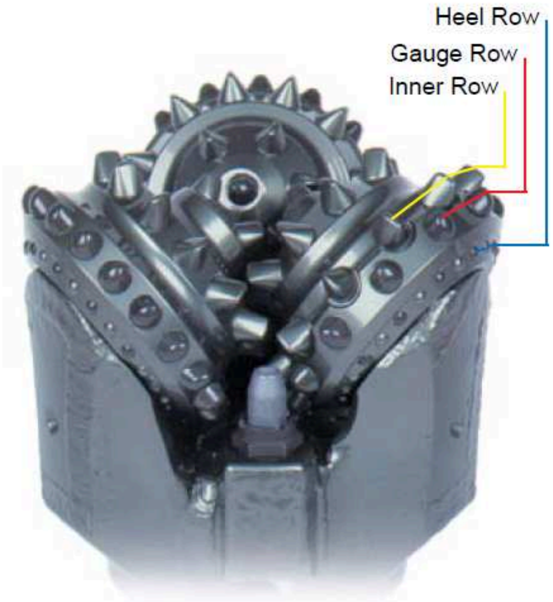


Figure 4.3 – Conventional cutting structure[3]

The Smith Bits Dull Grading Manual shows the clear distinction between the inner and the outer row (Figure 4.3). As already mentioned, the heel row is neglected in Smith's classification for the teeth/inserts height.

The third parameter described in the grading system is the characteristic of the dullness indicated in a two-letter code. Some of these characteristics need the additional information of the location of the failure represented in the column four. The number of the cone(s) needs to be added to precisely indicate the position, where the cutting structure dulling characteristic occurs:

- N – Nose row,
- M – Middle row,
- G – Gauge row and
- A – All rows.

Roller cone number 1 is identified as the cone with the centermost cutting element and 2 and 3 follow in clockwise orientation when looking down on the cutting structure sitting on the pin.

Table 4.1 lists the codes for the major dull characteristics from column 3 in the system structure. An additional Smith Bits definition states, that the observed cutting structure dull characteristic that most likely limits the further usage of the bit needs to be identified for this application.

Table 4.1 – Dull characteristics- codes[3]

BC*	Broken Cone	LN	Lost Nozzle
BF	Bond Failure	LT	Lost Teeth / Cutters
BT	Broken Teeth / Cutters	OC	OFF-Center Wear
BU	Balled Up Bit	PB	Pinched Bit
CC*	Cracked Cone	PN	Plugged Nozzle / Flow Passage
CD*	Cone Dragged	RG	Rounded Gauge
CI	Cone Interference	RO	Ring Out
CR	Cored	SD	Shirttail Damage
CT	Chipped Teeth / Cutters	SS	Self-Sharpening
ER	Erosion	TR	Tracking
FC	Flat Crested Wear	WO	Washed Out Bit
HC	Heat Checking	WT	Worn Teeth / Cutters
JD	Junk Damage	NO	No Dull Characteristics
LC*	Lost Cone		
* Show cone number(s) under column 4.			

When discussing roller cone bits, bearings are an important part. The fifth space allows a closer classification of the bearing's condition. Two types of bearings, sealed and non-sealed, are being analyzed individually.

The non-sealed type uses a linear scale from 0 to 8 to indicate the estimated bearing life used. On the other hand, sealed bearings are given a letter describing their condition – from “E” for an effective seal to “F” for a failed seal. If no grading is possible an “N” is put into the column.

Smith Bits gives an additional checklist to determine essential investigations in order to confirm a bearing’s condition (Table 4.2).

Table 4.2 – Items to check when determining seal / bearing effectiveness[3]

☐ Ability to rotate the cone
☐ Cone springback
☐ Seal squeak
☐ Internal sounds
☐ Weeping grease
☐ Shale burn
☐ Shale packing
☐ Gaps – backface or throat
☐ Bearing letdown – inner or outer

Further, the gauge of the bit can be classified within column 6. An “I” indicates no gauge reduction, but if an under-gauge condition can be detected, it will be recorded in 1/16th of an inch. A tolerance list after API specifications implies when a diameter reduction has occurred (Table 4.3).

IADC’s $^{2}/_{3}$rd rule[4] that is used for tri-cone bits works as following:

A gauge ring needs to be pulled so that the surrounding ring touches two cones. Afterwards, the distance between the outermost point and the gauge ring at the gap needs to be multiplied by $^{2}/_{3}$ and rounded to the nearest $^{1}/_{16}$th of an inch to estimate the reduction of the diameter.

Table 4.3 – API tolerance for new bits[3]

Bit Size	API Tolerance
$5\ {}^{5}/_{8} – 13\ {}^{3}/_{4}$	$+\ {}^{1}/_{32} : -\ 0$
$14 – 17\ {}^{1}/_{2}$	$+\ {}^{1}/_{16} : -\ 0$
$17\ {}^{5}/_{8}$ & larger	$+\ {}^{3}/_{32} : -\ 0$

The last section of the system structure – two columns under remark – describes first an additional cutter dull characteristic to the first one listed under column three. The final space left is used to report a reason for terminating a bit run and pulling out of hole[1]. Therefore, two- to three-letter codes are used (Table 4.4).

Table 4.4 – Reason pulled or run terminated[3]

BHA	Change Bottom Hole Assembly
CM	Condition Mud
CP	Core Point
DMF	Downhole Motor Failure
DP	Drill Plug
DSF	Drill String Failure
DST	Drill Stem Test
DTF	Downhole Tool Failure
FM	Formation Change
HP	Hole Problems
HR	Hours On Bit
LIH	Left In Hole

LOG	Run Logs
PP	Pump Pressure
PR	Penetration Rate
RIG	Rig Repair
TD	Total Depth / Casing Depth
TQ	Torque
TW	Twist Off
WC	Weather Conditions

The dulling characteristics which are seen to be those most likely being encountered at roller cone bits in the abrasive conglomerate and sandstone layers of the Oberkling gas wells, are discussed in more detail in Appendix .

4.2.1 BT – Broken teeth

Tooth breakage is considered an indicator for wrong bit selection or other improper bit applications and can be described as missing tungsten carbide inserts (TCI) or chipped out TCI's of a roller cone bit. Not necessarily is this considered as an abnormal wear characteristic, only when the formation's compressive strength exceeds the inserts' and significantly short performances are observed.

Consequently, if a cone shows steady-going broken teeth in the gauge row, excessive revolutions per minute (RPM) might be the cause due to the relatively high velocities and the generated impact force. On the other hand, broken teeth in the middle rows indicate an immoderate weight on bit (WOB).

If tooth breakage is apparent without a specific pattern, the problem might be as mentioned an excessive compressive strength. But also clasts, as seen in conglomerates, bear higher wear on the inserts.

To improve performance and reduce dulling patterns on behalf of formation influence as described, changing the strength of the bit is the first step. IADC codes allow simple comparisons between roller cone bits.

4.2.2 FC – Flat crested wear

Cutting elements with an even reduction in height are a characteristic called flat crested wear. Due to worn surfaces the cutters can be considered “flat” - to have lost their aggressiveness.

A reason for this dulling can be a lack of weight on bit and high rpm.

4.2.3 WT – Worn Teeth

This is a normal and expected wear mode and describes the reduction of height of inserts. Usually, this dulling characteristic is noted as flat crested wear (FC).

4.2.4 CI – Cone Interference

Unlike other dulling characteristics, cone interference does not imply improper bit selection and is often mistaken for formation damage. But this condition is caused when the cutting structure of one cone has impacted upon at least one of the adjacent cones.

A bearing or seal failure is in many cases the cause allowing one cone to contact another one. An exceeded bearing wear may be a potential indicator of problems in bit selection or operating practices, especially when performance falls significantly short of expectations. In many cases, bits for a capacity for a greater number of total revolutions need to be selected.

4.3. Fixed Cutter Bits

As already mentioned, a similar dull grading characteristic system is applied, when discussing wear of fixed cutter bits.

The distinction between inner (I) and outer row (O) follows the 2/3 rule of IADC, leaving the first column for the inner 2/3 radius. The second space then is intended for the outer 1/3 of cutters (Figure 4.4).

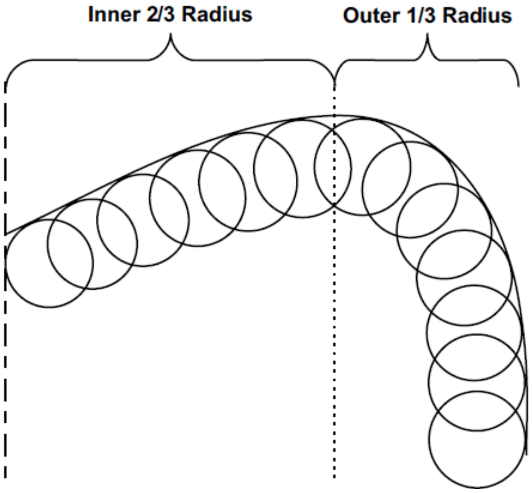


Figure 4.4 – Inner / outer body designation of fixed cutter bits[3]

Parallel to the roller cone criteria, a linear scale from 0 to 8 (Figure 4.5) is used to describe the wear of cutters. To get a value representative for the inner or outer section, the arithmetic average of the degree of wear for each area is utilized.

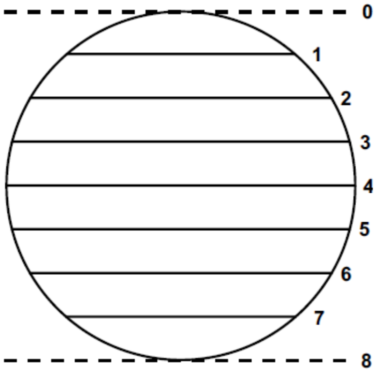


Figure 4.5 – Degrees of cutter wear[3]

When discussing dull characteristics in more detail, a close look into the location designation is inevitable. Again, a letter coding specifies the occurrence of specific dulling characteristics:

- C- Cone,
- N – Nose,

- T – Taper,
- S- Shoulder,
- G – Gauge and
- A – All areas.

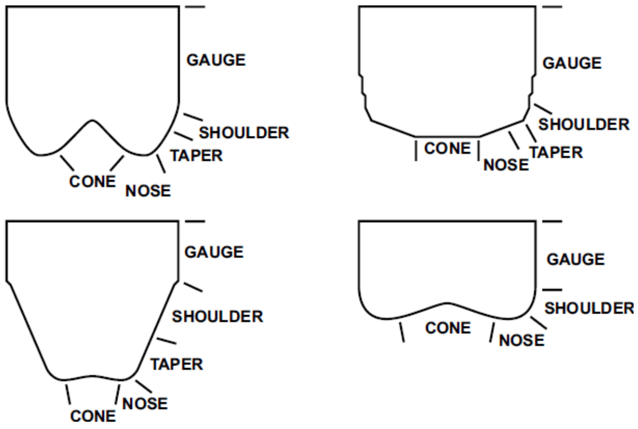


Figure 4.6 – Location designation of fixed cutter bits[3]

Fixed cutter bits show a varying range of design, but the designation of the location has been standardized (Figure 4.6).

To describe the dull characteristic Figure 4.1 is used. But, since fixed cutter bits don’t have any bearings, the column for the bearing’s condition needs to be marked with an “X” to cope for the lack of bearing wear. The following columns, from 6 to 8 are interpreted as previously discussed.

Dulling characteristics encountered at the PDC bits in use at the Oberkling wells, have been narrowed down to two main noticeable problems.

4.3.1 RO – Ring Out

If a bit shows a pattern, where a circular band of cutting elements are worn, broken or lost, it is considered to have a ring out. Usually, abrasiveness of the formation or bit bouncing cause a single cutter to fail and hence, distributing the load onto the other elements. Increased impact causes the “following” bits to bear more loading, which might lead to failure especially in the typical circular shape due to the rotation.

A less aggressive bit design can overcome this issue a priory. If still apparent, drilling parameters need to be adjusted, especially to minimize axial vibration or excessive weight on bit.

4.3.2 WT – Worn Cutter

The simple condition, where the cutters' height has been reduced is described by the linear scale of worn cutters. This normal situation usually appears, when drilling highly abrasive formations or if the design of the bit has been performed for a rock with less compressive strength.

5. Bit disassembly

In combination with the investigation of bit failure, Smith Bits offered a visit at their reliability center in Saline di Volterra. A detailed inspection of the roller cone bits used at Oberkling should give a clearer indication of the wear and the failure the bit faced under the premises that improvement can only happen if one fully understands what went wrong.

3 roller cone bits of OKSP-001 were sent to Saline di Volterra. The offer was to accompany the procedures performed on a bit from start to finish. The GFi 12 BVECPS TCI (Serial Number: PR 7554) of run #2 was chosen since it showed the most damage. A loose cone was clear indication of a seal failure and broken cutters allowed assuming that wear was quite advanced (Chapter 8.1.2).

10 steps were followed to investigate possible reasons for failure:

5.1. Arc welding

After the first visual inspection, where signs of wear were documented as apparent, the bit was brought to a laboratory in which the bit was deconstructed into its original 3 parts. This was accomplished by arc welding, where the old weld seam was melted away by a very high voltage.

After breaking all old weld seams, the original parts were able to be investigated one by one.

Figure 5.1 – Disassembled leg after arc welding

5.2. Disassembly – bearing section

The 12 ¼ inch Gemini bit is built with a friction-ball-friction (F-B-F) bearing. This bearing is sealed and filled with special grease as a lubricant.

A pin (Figure 5.2 – green arrow) holding the balls in the bearing in place and a reservoir (Figure 5.2 – circled red) for the lubricant need special treatment to be dismantled. Both sections have been installed to withstand high forces and consequently the dismounting asks for welding and hammering the locked parts free.

Without removing the pin, the cone cannot be dismounted and a detailed analysis would not be possible.

Figure 5.2 – Dismantled pin (green) and reservoir section (red)

5.3. Disassembly – cone

Via a magnet, the balls are removed from their position. Only after removing every ball of the 13 in the bearing, the cone can be removed from the leg (Figure 5.3). All parts can be dismounted and are being investigated visually.

Figure 5.3 – Dismounted cone – bearing and leg with remaining lubricant

In the beginning, it is checked whether there are all parts and in what condition they are found. The parts of the bearing in each cone are:

- 13 balls,
- 2 rubber seals,
- thrust washer,
- rubber boot (grease reservoir),
- bearing sleeve.

The disassembly is important to be able to perform the grease – water analysis.

5.4. Analysis - Grease – water

The first visual inspection of the bearing's lubricant defines if or if not a grease water analysis is necessary. If so, grease samples are being collected from

- seal gap,
- bearing and
- boot

giving information about the water percentage in each part of the bearing. Evidently, the water cut combined with the position can give an insight on the point of intrusion.

If the reservoir shows a higher water contamination than the bearing, a failure of the boot seal is more likely. Analogical, an increased water percentage in the bearing, combined with a lower water cut in the reservoir, it is very likely that a bearing seal is broken.

Figure 5.4 – Collected grease samples, ready for grease – water analysis

In a discussion with the reliability center's lab technologist it was mentioned, that the bearing's lubricant has water concentration of less than 0.1%, when leaving the factory. Also, that if the water cut of 2% is being exceeded; the seal is considered "failed". In tests a water percentage of 4% showed a total loss of carrying capacity meaning that no loads can be carried by the fluid.

When analyzing the samples from each position, the water percentage is being measured by a chromatograph. First, small samples are put on an aluminum foil and the exact weight is being detected. Then, the sample is being heated and all the water evaporates. The steam particles are then carried by a nitrogen stream to a chromatograph and the percentage is measured immediately.

5.5. Analysis – bearing components

During the grease - water analysis, all components of the bearing are being washed and the grease is removed. Then, the components as mentioned in Chapter 5.2 are being investigated and damage can be observed since all dirt and grease is gone.

Figure 5.5 – Internal bearing components (#3 components show strong mud intrusion)

5.6. Analysis – legs and cones

The disassembled cones are being cleaned together with their legs. Physical damage is documented if observed.

5.7. Dimension measurement

The carefully cleaned cones and legs' dimensions are also measured. 0.02 mm deviation from factory specification is within range of acceptance. With this measurement, failure in manufacturing is crossed out.

5.8. Analysis – cutting structure

The cutting elements of each cone are investigated in order to find irregularities of signs of wear. Broken cutters indicate excessive loads or wrong API grading. Also, gauge rounding can indicate a use that is not optimum.

5.9. Analysis – seals

The main feature of the Gemini bits is the 2 rubber seal system. The primary bullet-shaped seal protects the bearing with a dynamic face elastomer. As a secondary seal to protect the primary seal from abrasive particles, an elastomer seal resists wear with a proprietary thermoplastic fabric at the seal's dynamic face.

Both seals are analyzed visually and measured to observe the maintaining squeeze. To get a clearer view, little pieces are cut out and investigated with a microscope (Figure 5.6 and Figure 5.7). Unusual wear will be reported such as the extreme wear highlighted on the primary seal in Figure 5.6.

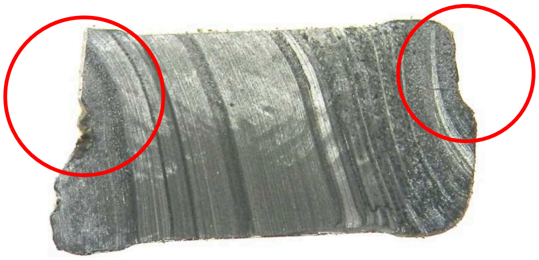


Figure 5.6 – Primary seal under microscope

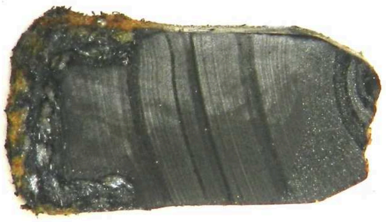


Figure 5.7 – Secondary seal under microscope

5.10. Reporting

During each step of the reliability analysis, right documentation leads to a fine report that summarizes the wear and failure in detail (Appendix A). The report including a conclusion and a recommendation is sent to the reliability center in Houston for double-check before it is sent out to the costumer.

5.11. Report - PR 7554 - GFi 12 BVECPS

The PR 7554 was considered a tight hole run, meaning that some data was missing. The bit was pulled due to hours. When retrieving the bit, bearings from cone #1 and #2 were still effective but when rotated no springback was observed. It can be concluded that they were in process of failure. Cone #3 had failed.

#1 and #2 primary seals suffered severe wear on the inner diameter side with a wear mostly located towards seal gap side. Seal #1 also shows moderate wear on the outer diameter. #3 primary seal was not found in the cones and most likely destroyed after mud intrusion and cone misalignment. All 3 secondary seals were found failed, because there was no mud in the seal gap. Anyhow, #1 and #2 secondary seals still maintained filtering qualities taking out cuttings from contact with the primary seals. #3 secondary seal was not found either due to destruction after mud intrusion and cone misalignment.

#1 and #2 legs were found in good condition and suffered no wear – all dimensions within the required specification. #3 leg suffered severe wear on the loading side because of cone misalignment after a seal/bearing failure. #1 and #2 legs suffered moderate wear on the secondary seal hub caused by a sliding action of the seals fabric embedded with cutting particles. #1 and #2 cones suffered no wear and were found within all specifications. #3 cone showed minor wear due to cone misalignment and mud intrusion.

#1 and #2 internal components were found without signs of wear, but #3 bearing sleeve was not found in the bearing because it was destroyed after the seal failure. #3 internal parts were strongly contaminated with mud.

The grease – water analysis of the #1 lubricant indicated a seal failure. When there was no grease in the seal gap, there was also a high water cut of 14% in the bearing. A 0.7% water percentage in the #1 boot was close to residual oil quality. The analysis of the #2 grease gave similar results, where no grease was found in the seal gap area and the bearing water percentage was at 20% whereas the #2 boot water cut was at 5%.

The #1 boot was found in a semi-extended position with a reservoir almost empty. The partial depletion was caused by the primary seal leaking the systems pressure compensation, derived from the grease – water analysis. The #2 boot was in a relaxed position and nearly empty as well. A similar reason was found for the depletion of the #2 reservoir. The #3 boot was found in a relaxed condition but contaminated with mud. No damage was observed on neither of them and all three boots passed the nitrogen test within Smith specification.

Gauge rounding was seen at all three cones suggesting excessive wear. The severe gauge rounding provokes in-thrust loading that is very detrimental for the seal bearing life. Also, severe breakage of the cutting structure was observed and most likely caused by vibration and bouncing due to drilling in a conglomerate formation.

Based on the results of the 1.5 day investigation and on past experience, one can conclude the #3 assembly failure was caused by primary seal wear. The #3 seal bearing failure was accelerated by gauge rounding, inner cutting structure breakage and low hydraulic horse power per square inch (HSI). An HSI of less than 2 does not provide sufficient cutting-removal and thus, allows re-grinding the cuttings, making them smaller and easier to enter the seal/bearing.

6. Sensor system and real time data

As part of every project, monitoring plays a big part and has a major impact on success. When talking about a complex project, such as a drilling project, monitoring starts with an appropriate sensor system gathering necessary data from all aspects of a rig. The optimum outcome of the sensors from all different parts of a modern rig is real time data.

6.1. Sensors

Before data can be saved and interpreted, right measurement is inevitable. For this reason, sensors are installed at all crucial elements of the rig. The main sensors and their channels, which record all main operations on the rig E 202 of RAG, are listed below (explosion proof is self-evident):

6.1.1 Rotary pulse generator

This type of sensor is an incremental encoding device that converts shaft rotations into two electrical output signals that are in a relationship to one another. The signals' frequencies depend on the counts per run and are either 120 kHz (for higher counts per run) or 250 kHz (for lower counts per run). On the one hand, the direction of the movement is being detected needed to determine positioning and, on the other hand, bi-directional counting allows computing speed. The sensor's shaft is usually mounted to a rotating component of the rig, such as the top drive or the draw works.

If the rotary pulse generator is mounted on the draw works, information about the block position and the block speed is gathered. In this particular case, two redundant rotary pulse generators mounted on the shaft. Further, bit position and measure depth can be computed by the data provided from this sensor as well as the penetration rate (ROP). The ROP is computed instantly by RAG's PVSS.

The same measurement principle underlies the measurement of the top drive's revolutions per minute (RPM) as well as the rotary table's rotations. But, in case of the top drive, the rotary pulse generator is an integral part of the whole top drive.

6.1.2 Electronic frequency converter

Torque measurements are performed with an electronic frequency converter calculating the actual value over the current power consumption. Using the example of the top drive, the electronic frequency converter is an integral part, similar to the rotary pulse generator.

6.1.3 Pressure sensor

The pressure measuring device, mounted on the standpipe, is an electronic pulser that converts a detected pressure into an electronic signal. The pressure sensor installed at the standpipe sends a signal between 4 and 20 mA, and this range can be pre-programmed.

Another pressure sensor being installed at the dead line anchor measures the pressure induced by the weight between 0 and 100 bar, where 100 bar equals 618 tons. With the weight at the dead line the hook load can be computed to an accuracy of +/- 2 tons. This measurement is the hook load.

Another drilling parameter, derived under assistance of this sensor, is weight on bit (WOB). Yet, the WOB also has a human component. When the driller is near bottom with the bit, he resets the “drill-o-meter”. At the same time the weight on bit channel needs to be set to 0 as well. The difficulty concerning the WOB will be discussed later.

6.1.4 Flowmeter – micro motion Coriolis

Pump rates on the E 202 are computed in two ways, because unfortunately one of the micro motion Coriolis flowmeter does not work properly. This measurement device is a flowmeter being installed right before the pump. This is a multi-variable measurement device providing precision measurement of:

- mass flow rate,
- volumetric flow rate,
- density and
- temperature.

The underlying principle of this gauge combines two vibrating curved tubes, where both coils move through uniform magnetic field and hence create a sine wave voltage. The oscillating flow tubes, when fluid is pumped through, create Coriolis forces at both the inlet and outlet and combined with the vibration, it is possible to measure the previously mentioned parameters.

On the one hand, since one of the two micro motion Coriolis devices does not work, there is the straight-forward calculation performed by RAG's own real time data system as a back up. The pumps parameter's such as volume per stroke are known, and as a consequence, the pumped volume can be computed via the pump speed without any problems. In this case, only the pump's liner size needs to be entered. The outcome of either measurement is the pump rate.

6.1.5 Ultrasonic distance sensor

The final sensor is the ultrasonic distance sensor measuring the fluid level in the tanks. With the knowledge of the tank's geometry the volume can be calculated fairly easily. Nevertheless, this sensor plays only a minor role in the context of this thesis.

6.2. Real time data

All of the data gathered around a drilling rig needs proper processing. Data is not only needed on-site, but also in the office to monitor and even control operations immediately. A bus system delivers data to the process server from all sensors, where data is saved and prepared for displaying (Figure 6.1). Displaying is important, especially in the driller's cabin, where monitoring of the drilling parameters is crucial. Additional firewalls protect the systems to make them visual in offices allowing project-related engineers to check on the on-goings on the rig site as well.

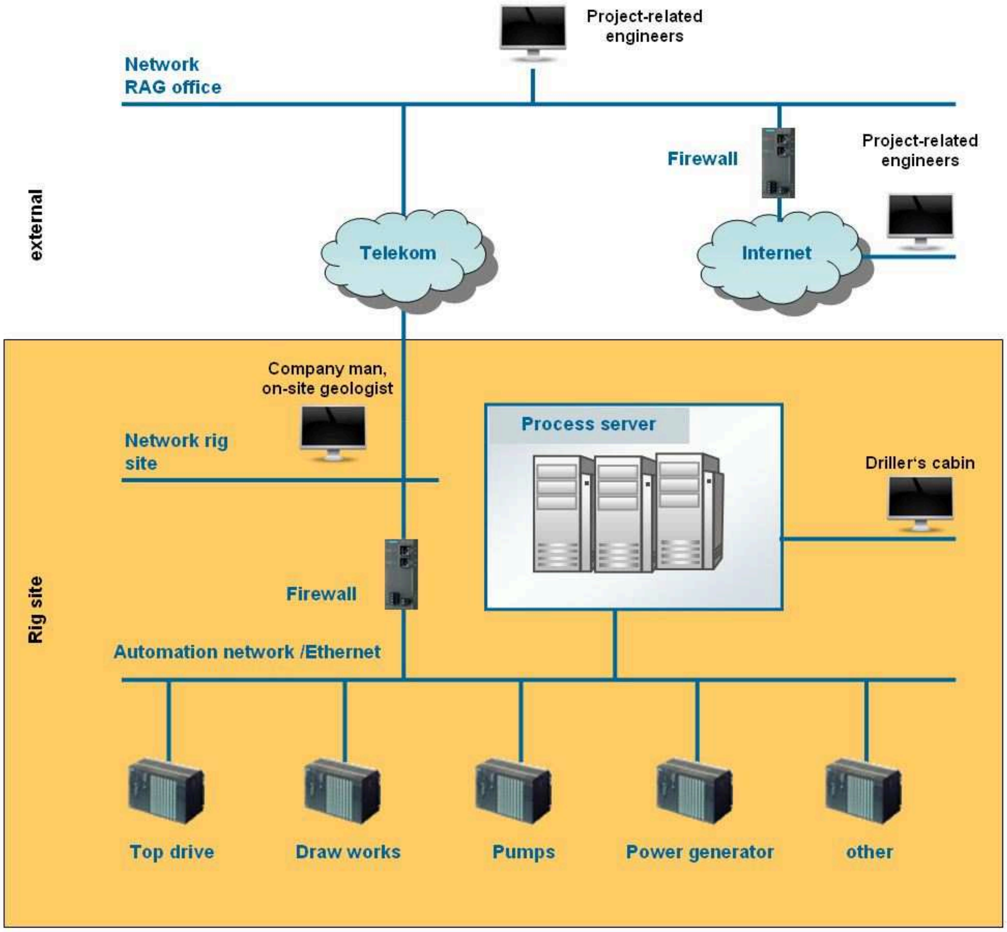


Figure 6.1 – Sensor system / network

6.2.1 Storage

Sensors on the rig site measure performance related data in real time and send them to the process server at a frequency of 2 Hz; the server receives every 0.5 seconds. This data density leads to 172,800 data points per day for each measured parameter. Due to a limited storage capacity, RAG has introduced criteria to decide when to store data from the sensors. Data is sent to the process server continuously and displayed for monitoring on the previously mentioned screens, but programmed limits determine whether data is stored for interpretation.

The process server compares for each incoming real time channel the current value with the previous one and decides, if the value has changed enough to be stored. These limits that need to be overcome are mostly 0.1% of the maximum input value, but in some cases absolute values define the limiting criteria. So, if the threshold is not overcome, no new value will be stored. A new value will only be saved after a sufficient change in value.

6.2.2 Thresholds

The channels measure depth (MD) and bit depth are both measured at the draw works by the rotary pulse generator and set to be saved with a timestamp, when the change in value exceeds 0.02 m. Another value derived from this sensor device is the rate of penetration (ROP), which is computed in min/m. The threshold to overcome is a change of 0.1 min/m – the following conversion to m/h is simply performed by the process server. As for torque, an increase or a decrease of 1000 Nm needs to happen to save a new value.

The consideration of the percentile change (0.1%) is used regarding weight on bit (WOB), standpipe pressure and the pump's flow rate. The maximum WOB determined to enter the measurement is 25 tons. Respectively, the standpipe pressure is calibrated up to 400 bars. Further, the pumped volume is set to reach 6000 l/min at most.

6.2.3 Storage-related problems

Since every channel only saves data points with an according timestamp after a sufficient change in value, no channel is equidistant, making it very difficult to monitor. Accurate correlations between the various channels are nearly impossible with the current standard provided by RAG. Up-scaling and generating the missing data was considered, but the time-based quality was achieved as discussed in the following chapter.

Yet to be noted, during the scope of this thesis the shortcomings of data storage have not been overcome leaving room for improvement in data engineering, where automated progresses could support the engineers.

6.3. Data acquisition

Without an influence of the storage-related drawback, it was possible to get processable data. The electrical engineering department for RAG's drilling rigs provided Excel data after implementing a new script to convert the previous comma-separated values (*.csv) with required channels as equidistant with reference to depth. Now, it was possible to use Microsoft Excel for the depth-based data, since spreadsheets were generated per each run.

A total continuous data set throughout the entire drilling operation was on the one hand not compatible with Excel's limit of 65,536 rows, on the other hand irrelevant for the comparison of different runs; ergo drill bits and BHA configurations. Hence, run-related separation of data allowed a detailed analysis of the tools' performance exclusively. And, depth-based data dispenses with the problem of measurements during not hole-generating operations like circulating, connections, or reaming, as well as repairing.

6.4. Vibration data provided by Baker Hughes Inteq

In addition to RAG's own surface sensor system, Baker Hughes Inteq (BHI) provided downhole information with measurement while drilling (MWD) tools such as AziTrak and OnTrak. Besides resistivity, gamma ray or even directional measurements, the tools also featured vibration information[5]:

- Lateral vibration,
- Axial vibration and
- Stick-slip vibration.

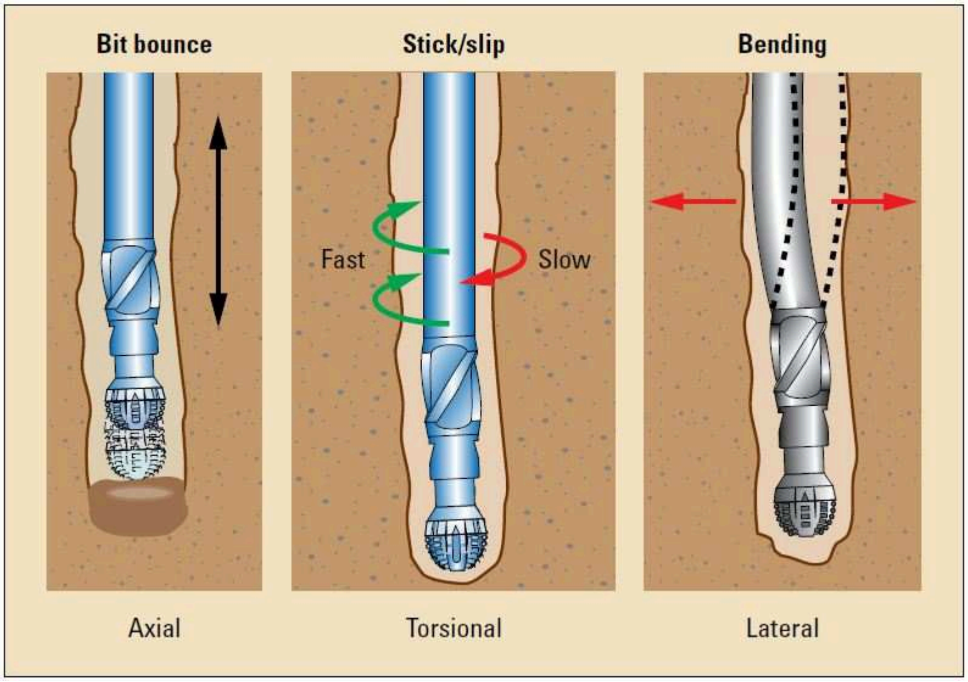


Figure 6.2 – Vibration in the drill string[5]

Lateral vibrations cause large shocks on the BHA, when the drill string is bent and hits against the borehole wall. As a consequence, these shocks bear high risk of breakage of various bottom hole assembly's parts. Measurement while drilling devices are sensible to lateral shocks.

Axial vibration can simply be described as bit bouncing, where the bit "jumps" and hits the bottom severely. The non-constant contact with the formation causes exceptional loads on both, the bit's bearings and cutting elements.

Stick-slip vibration is the result of irregular down hole rotation. The torsional oscillation comes from the drill string being stuck and a spontaneous release. Another side effect of this "twisting" can be an axial shortening of the drill string causing additional axial vibration at the release.

6.4.1 Accelerometer

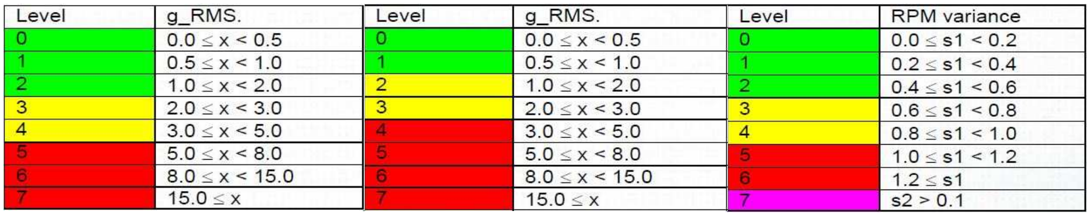
To measure lateral vibration the downhole sensor consists of two accelerometers (in x and y direction), and for axial vibration analysis, the BHI tool uses one accelerometer (in z direction). BHI's accelerometer is a device measuring proper acceleration from 0 to 15 g (gravitational force) at a frequency between 0 and 82 Hz. The underlying physical principle is inertia of mass and when accelerated, the displacement is measured and converted.

6.4.2 Magnetometer

Unlike the lateral and axial vibration, stick-slip movement of the BHA uses a two axis magnetometer, where the rotation of two coils is compared. As a consequence, the variance of revolutions per minute (RPM) can be seen as stick-slip torsional anomaly (s1 and s2).

6.4.3 Severity level reference

A BHI internal severity level reference assigns a level to the magnitude of the measured vibration. In all three divisions, a scale from 0 to 7 (unit-less) describes the vibrations' severity. A color scheme facilitates a rapid identification of the vibration status during drilling operations. The severity of every vibration movement can be easily detected on the screen, where directional control is being monitored as well.



Level	g_RMS.	Level	g_RMS.	Level	RPM variance
0	$0.0 \leq x < 0.5$	0	$0.0 \leq x < 0.5$	0	$0.0 \leq s1 < 0.2$
1	$0.5 \leq x < 1.0$	1	$0.5 \leq x < 1.0$	1	$0.2 \leq s1 < 0.4$
2	$1.0 \leq x < 2.0$	2	$1.0 \leq x < 2.0$	2	$0.4 \leq s1 < 0.6$
3	$2.0 \leq x < 3.0$	3	$2.0 \leq x < 3.0$	3	$0.6 \leq s1 < 0.8$
4	$3.0 \leq x < 5.0$	4	$3.0 \leq x < 5.0$	4	$0.8 \leq s1 < 1.0$
5	$5.0 \leq x < 8.0$	5	$5.0 \leq x < 8.0$	5	$1.0 \leq s1 < 1.2$
6	$8.0 \leq x < 15.0$	6	$8.0 \leq x < 15.0$	6	$1.2 \leq s1$
7	$15.0 \leq x$	7	$15.0 \leq x$	7	$s2 > 0.1$

Figure 6.3 – BHI's vibration severity levels for axial, lateral and stick-slip vibration

6.4.4 Vibration data quality

BHI's service measured vibration data downhole, where the signal was pulsed alongside all other information to the surface. Baker Hughes Inteq provides depth- and time-related data. Basically, the depth-related data is the time-related data arranged in order of the depth measurements. With a low penetration rate, data becomes more concentrated, whereas with a high ROP, the data points become more spread along the depth scale.

Another restriction of the data quality provided was that vibration was not measured during sliding sections. Only during rotary drilling, lateral, axial and Stick-Slip vibration was measured and stored. BHI's explanation is that Stick-Slip vibration will not be encountered during sliding mode. Furthermore, lateral and axial vibration is less on behalf of the non-rotating string. Also, orientation data like tool face and running surveys are considered more important during directional mode.

As part of a data bundle, the data of every channel was recorded all 20 seconds (f = 0.05 Hz). Physical limitations when pulsing information through the mud were the reason for the data tightness. But, also memory gauge information did not provide a higher data quality. The required tool for high-frequency measurements of downhole vibration (BHI CoPilot) was by no means affordable for an onshore drilling operation.

7. Tools used for analysis

With the direct involvement in the Oberkling gas storage project, fast tools for on-site and post-job interpretation of performance were needed. Directional drillers, company men and engineers in the office asked for tools, which were easy to implement and suitable for daily business.

To fit the demands of an on-site tool to allow the correlation of lithology, drilling-relevant parameters and vibration data, a log has been designed to fit the given requirements. Normal logs were already in use, but all of them were provided by the geological department and thus, changes were needed and new channels needed to be implemented.

To build a basis for decision criteria, an analysis of the gathered data from the rig was important. Comparing different runs to show influences of BHA or bit changes was done statistically.

7.1. Log as a firsthand foundation for decisions

The firsthand integration in the drilling operation asked for an easy and quick tool to detect trouble-bearing layers and visualize performance during each run. A fast way to allow on-site personnel to see the correlation between specific layers and drilling issues is the widely approved log. Yet, for the particular case of the Oberkling wells, new channels needed to be implemented. The depth correlation of drilling parameters was considered very important on behalf of the occurring problems with several layers. The distinction between clay marl and conglomerate was a major criterion for each drilling parameter, because most of the problems were caused by lithological changes.

All work for the log has been done with GEOLogger, which is a program designed to visualize measured data in various formats (.txt, .las, .xls…). As a basis, the well site geologist’s log was used to get the first and most important channel: lithology (Figure 7.1 – point 6). This channel was generated on behalf of the samples taken during the drilling process and then corrected with gamma ray readings from the MWD/LWD measurements. Since other geophysical data was seen negligible, no further channels were taken from the original log, besides the depth scale (Figure 7.1 – point 1) and the formation description (Figure 7.1 – point 2).

Now, Baker Hughes Inteq's vibration data, in .las files, was introduced and plotted regarding depth as BHI provides both, depth-based and time-based VSS data (Chapter 6.4). Data quality, a problem throughout the whole project, lead to a special display of the vibration data (Figure 7.1 – point 3, 4 and 5). The missing amount of available vibration data inhibited a line plot. Consequently, a bar plot was used to overcome the limitations with missing data during sliding drilling. The scale was introduced from 0 to 7.

Another channel relevant to analyze performance and to pin down troublesome areas is the inclination (Figure 7.1 – point 6). With the given signs of wear during OKSP-001 and massive abrasion of stabilizers, the inclination was identified to bear additional impact on vibration and performance as well as wear. Dog leg severity (DLS) was kept low on behalf of the sensitivity of BHI's tools and therefore considered minor important. The project leader and directional drillers were keen to have this additional data represented in the log. Data for the inclination channel was available in Halliburton's Landmark. Its survey program Compass allows analyzing the data from trajectory design and as well the input from MWD/LWD measurements. For the channel, the measured MWD/LWD data was saved as a .txt file for importing into the GEOLogger.

Drilling performance parameters, which were considered relevant by the engineers in charge, were given three channels (Figure 7.1 – point 10, 11 and 12). A main indicator for performance, the rate of penetration (ROP), was given an exclusive channel. RAG's internal PVSS data (.csv) was loaded into GEOLogger without problems, since data is saved depth based. Boundaries of 0 to 20 were used to show better focus on the troublesome regions, where performance dropped drastically. The second drilling parameter channel contained torque and weight on bit (WOB) values. Similar to values for the ROP, data was imported in a .csv file. Torque boundaries were set from 0 to 38.000 Nm and WOB was between 0 and 30 tons. The third channel for drilling parameters was filled with data concerning pump pressure, top drive revolutions and downhole revolutions. The pressure measured in the pump was displayed with boundaries between 0 and 260 bar. RPM's were visualized with limits from 0 to 240. This channel was introduced to detect pressure peaks, which can be used to identify an increased torque generated by the increased flow resistance in the PDM.

RPM of the top drive was used for generating an auxiliary channel describing the drilling mode. Black bars were integrated into a minor channel, where top drive revolutions were 0 (Figure 7.1 – point 9). This had to be done manually, since no automated program was at hand. The last channel included a bit and BHA description (Figure 7.1 – point 8).

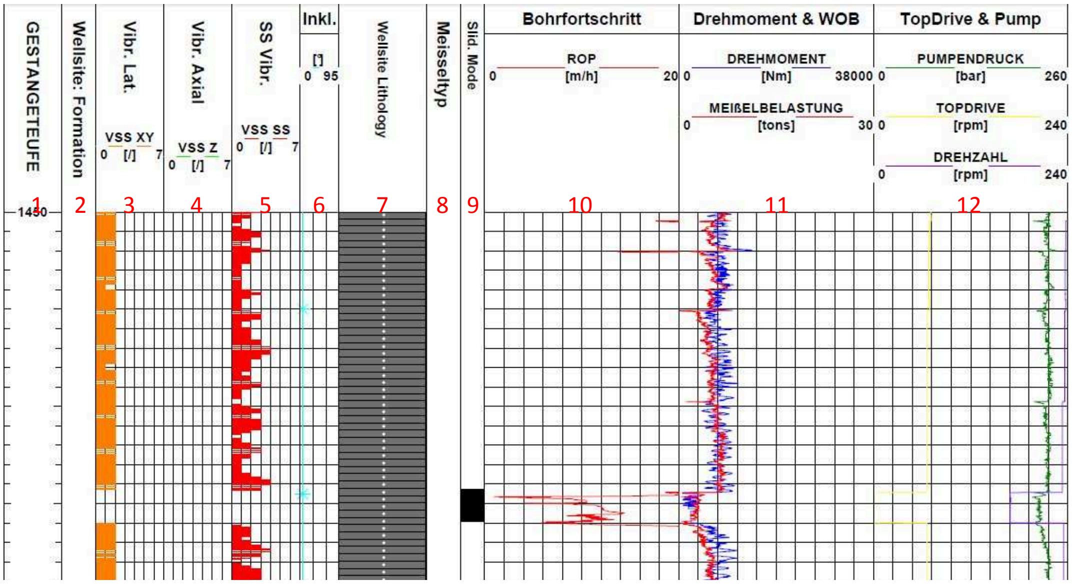
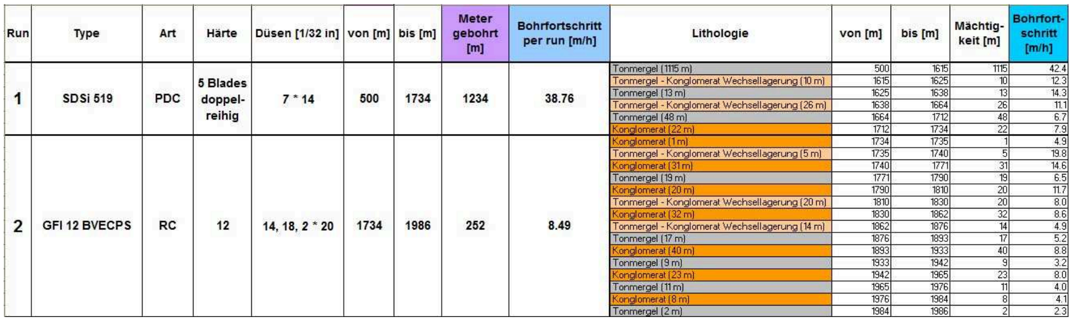


Figure 7.1 – Log with combined channels for first interpretation

7.2. Statistical analysis of Prozess Visualisierungs System Software (PVSS) data

To analyze each bit separately, all gathered data needs to be categorized prepared accurately and then visualized to easily interpret the results. For this reason, Microsoft Excel was used. With data sets of less than 65,536 rows per run, Excel's capacities were sufficient to process the quantities provided by PVSS. Hence, each run was processed separately and then combined in one main Excel sheet.

At first, each run was categorized and major properties were summed up. Overall meterage, depth and penetration rate were added to general information of the bit, such as nozzles or type. Yet, first the challenge faced was to compute the accurate ROP. PVSS computes its own penetration rate automatically, but after comparing values from the bit report with the PVSS data, it was assumed, that the bit report stated the gross ROP, which was not favorable for the analysis. The mean value of each run was easy to compute and showed a higher penetration rate at every run than originally calculated.



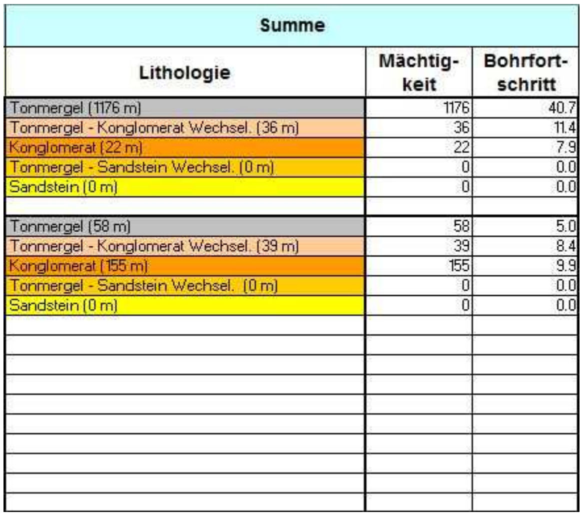
Run	Type	Art	Härte	Düsen [1/32 in]	von [m]	bis [m]	Meter gebohrt [m]	Bohrfortschritt per run [m/h]	Lithologie	von [m]	bis [m]	Mächtig-keit [m]	Bohrfort-schritt [m/h]
1	SDSi 519	PDC	5 Blades doppel-reihig	7 * 14	500	1734	1234	38.76	Tonmergel (1115 m)	500	1615	1115	42.4
									Tonmergel - Konglomerat Wechsellagerung (10 m)	1615	1625	10	12.3
									Tonmergel (13 m)	1625	1638	13	14.3
									Tonmergel - Konglomerat Wechsellagerung (26 m)	1638	1664	26	11.1
									Tonmergel (48 m)	1664	1712	48	6.7
									Konglomerat (22 m)	1712	1734	22	7.9
2	GFI 12 BVECPS	RC	12	14, 18, 2 * 20	1734	1986	252	8.49	Konglomerat (1 m)	1734	1735	1	4.9
									Tonmergel - Konglomerat Wechsellagerung (5 m)	1735	1740	5	19.8
									Konglomerat (31 m)	1740	1771	31	14.6
									Tonmergel (19 m)	1771	1790	19	6.5
									Konglomerat (20 m)	1790	1810	20	11.7
									Tonmergel - Konglomerat Wechsellagerung (20 m)	1810	1830	20	8.0
									Konglomerat (32 m)	1830	1862	32	8.6
									Tonmergel - Konglomerat Wechsellagerung (14 m)	1862	1876	14	4.9
									Tonmergel (17 m)	1876	1893	17	5.2
									Konglomerat (40 m)	1893	1933	40	8.8
									Tonmergel (9 m)	1933	1942	9	3.2
									Konglomerat (23 m)	1942	1965	23	8.0
									Tonmergel (11 m)	1965	1976	11	4.0
									Konglomerat (8 m)	1976	1984	8	4.1
									Tonmergel (2 m)	1984	1986	2	2.3

Figure 7.2 – General properties of each run with lithological correlation

Now, the main concern was the correlation of performance and lithological properties. The strong variation of clay marl and conglomerate asked for a differential analysis of each layer as documented by the geologist. Depth based performance parameters were then interpreted with each layer correlating. The thickness of each layer has been reported as well to indicate the impact of the discussed formation. In the next step, every defined lithological layer was assigned its computed average ROP. The average rate of penetration was used to overcome inaccuracies of the defined layers. Since data was depth based, the distinction between layers was easily performed and all performance related data filtered out to represent the range required. The computed mean value was referred to each lithology. In order to allow a fast distinction between layers in every chart and diagram, a color coding has been introduced:

- Grey – clay marl,
- light orange – clay marl – conglomerate interbedding,
- orange – conglomerate,
- dark yellow – clay marl – sandstone interbedding and

- yellow – sandstone.



Summe		
Lithologie	Mächtig-keit	Bohrfort-schritt
Tonmergel (1176 m)	1176	40.7
Tonmergel - Konglomerat Wechsel. (36 m)	36	11.4
Konglomerat (22 m)	22	7.9
Tonmergel - Sandstein Wechsel. (0 m)	0	0.0
Sandstein (0 m)	0	0.0
Tonmergel (58 m)	58	5.0
Tonmergel - Konglomerat Wechsel. (39 m)	39	8.4
Konglomerat (155 m)	155	9.9
Tonmergel - Sandstein Wechsel. (0 m)	0	0.0
Sandstein (0 m)	0	0.0

Figure 7.3 – Color coding of lithologies and corresponding ROP

To summarize each bit and its performance in conglomerate, clay marl or interbeddings, the various layers encountered during one run have been added giving an overview of the bits general performance. Here, the weighted average was applied to account for the different thicknesses of the lithologies.

$$x_{mean} = \frac{\sum_{i=1}^{n} w_i \times x_i}{\sum_{i=1}^{n} w_i}$$

Equation 7.1 – Weighted average

Another important factor of each run is the percentage of drilling performed in sliding mode. For this reason, the acquired data also contained the top drive's revolutions. With RPM below 10, it was assumed that sliding drilling was applied. Orienting the tool face was not considered drilling rotary. With Excel's filter and count function, the fraction of sliding was computed. To assure easy handling of the computed results, a summarizing sheet of all runs per section has been generated. All data gathered and interpreted so far, is put together and plotted in a bar chart, combining ROP's per lithology and on average, percentage of sliding drilling, meterage and thickness of lithologies encountered (Figure 7.4).

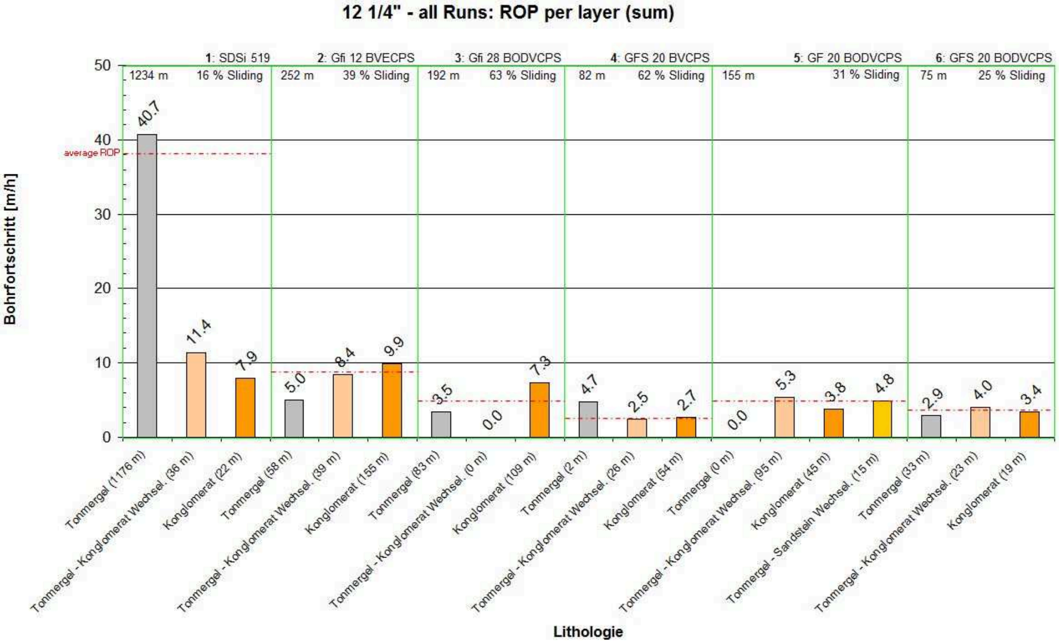


Figure 7.4 – Summary sheet for the 12 ¼ inch section of OKSP-001

The discussion of each run in detail was performed similarly. A comprehendible graphic output was required for a quick review of the performance, and therefore, the sliding percentage and the penetration rate in sliding and rotary mode were to be displayed in a bar diagram. For means of visualization, the average ROP of each layer has been multiplied with its sliding percentage and then put on top of the layer's bar showing no quantitative value but the fraction of sliding and rotary within each layer.

In Figure 7.5 three bars are shown for each lithology encountered during run #1 – from left to right with increasing depth. Green bars represent the average penetration rate during rotary drilling, whereas, blue bars show the performance in sliding mode. Every left bar (average ROP in distinct layers), a blue fraction indicates the percentage of sliding drilling in each lithological layer. A red dotted line gives an insight on the average ROP during the whole run giving a reference level for the performance in each single layer.

The overall sliding percentage every run has been computed on a time basis. All values were put in order of depth, but with a consistent change based on time (Chapter 6.3).

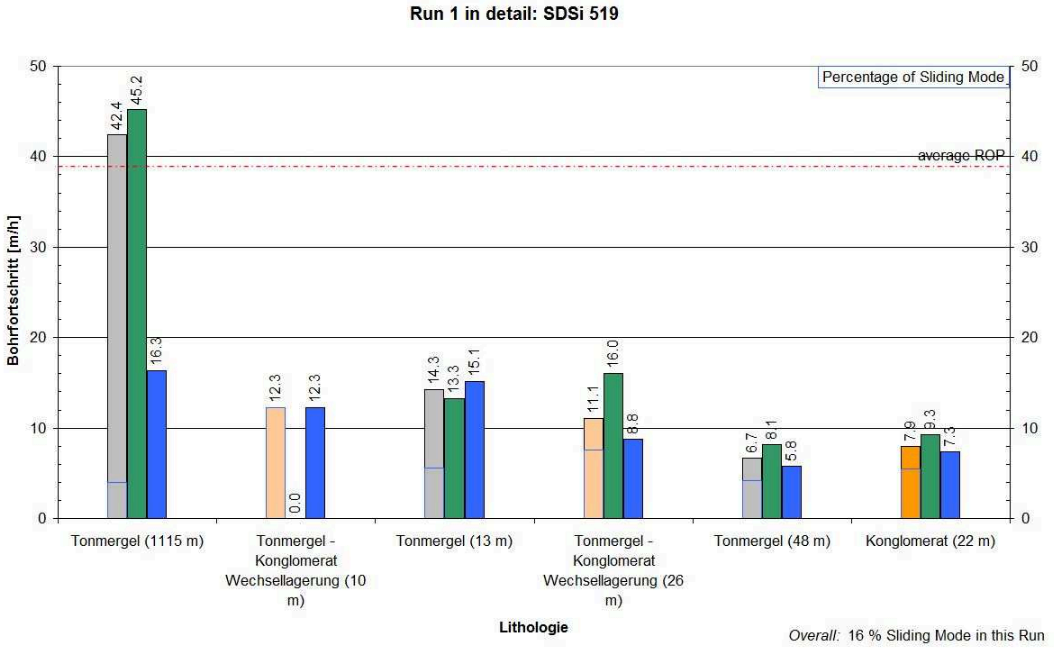


Figure 7.5 – Detailed sheet for run #1 of OKSP-001

To compute the penetration rate of each, sliding and rotary drilling, data needed to be filtered and interpreted. First, Excel's filter function was used to acquire just data of one layer. Secondly, ordering the data package by the top drive RPM's allowed to investigate values of each mode separately. The average penetration rates of both, sliding and rotary, have then been computed and displayed next to the average ROP of each layer as explained in the previous passage.

For runs, where no conventional directional BHA was used, the computation of sliding and rotary ROP's was obsolete.

8. Oberkling gas storage well OKSP - 001

The Oberkling gas storage wells are being drilled in a complex area as mentioned in Chapter 2. But, data from a vertical offset well (Oberkling 1) cannot entirely cope with the demands for the exploration of new frontiers.

As drilling mud, RAG's standard drilling fluid program recommends a potassium carbonate fluid with citric acid for pH value control. Since the clay marl and conglomerate layers of the Puchkirchen series, as well as target layer, are expected to be hydrostatic, the mud program is set to be at 1.20 to 1.22 SG in the 12 ¼ " and 1.10 to 1.12 SG (specific gravity) in the 8 ½ " section.

The trajectory design's targets, as discussed in Chapter 3.6, have been provided by geologist Ruzbeh Aliabadi from RAG's department for subsurface engineering for gas storage. In collaboration with Baker Hughes Inteq (BHI), the drilling engineer in command realized the well path. For the purpose of a gas storage facility, a 6 $^{5}/_{8}$ inch pre-drilled liner needed to be run. As a consequence, a 9 $^{5}/_{8}$ inch casing was installed first.

This casing design leads to two hole sections:

- 12 ¼ inch
- 8 ½ inch

8.1. 12 ¼ inch section

After drilling out the cement shoe of the 13 $^{3}/_{8}$ inch casing, the first bit run was performed. To facilitate, the OKSP-001's first two bit runs are neglected (the 17 ½ inch top hole section and the 12 ¼ inch milled tooth bit used to drill out the cement shoe). So, bit run #3 is considered to be the first run (run #1), since the outline of the thesis considers the consecutive bit runs as the important ones. This reconfiguration needs to be kept in mind. Since a bit's performance is directly connected to the bottom hole assembly (BHA), its composition is investigated along with every bit run.

8.1.1 Run 1 – SDSi 519

A large clay marl layer in the Puchkirchen series arises to be drilled ideally with a polycrystalline diamond compact (PDC) bit. For the upcoming conglomerate interbedding, wear resistance was a decision criterion, alongside with performance in the soft clay marl. Smith bits suggested the SDSi 519. The SDSi 519, from the Smith High Abrasion Resistance Configuration (SHARC) series, claims to fulfill both with a second row of cutters, optimized hydraulics and exclusive cutter material. Despite the promising features, the five-bladed PDC with 19 cutting elements (519) could only keep the performance high in the top clay marl layer.

8.1.1.1 Operational parameters

A conventional positive displacement motor (PDM) with a bent of 1.2° degrees was used together with the measurement while drilling (MWD) NaviGamma (SIEHE ANHANG) and two under-gauge stabilizers. Baker Hughes Inteq designs a traditional BHA with a PDM and a bent housing always with under-gauge stabilizers to assure the geometry needed to build up successfully. Furthermore, a near-bit stabilizer (TurboBack) was run to guarantee a smooth wellbore.

A feature, not to be neglected, of every PDM is the lobe ratio being the basis for the revolutions per liter pumped. The Mach-1 8“ Ultra XL with a lobe ratio of $^{5}/_{6}$ powers the bit with 0.06 rev’s per liter pumped. At an average pump rate of 2656 l/m the down hole motor provided the bit with additional ~160 rpm. During rotary operations the top drive added around 60 revolutions per minute. In both cases, sliding and rotary drilling, approximately 5 tons weight on bit (WOB) was applied.

WOB was defined a priori by the directional driller (BHI) considering the sensibility of the down hole tools (MWD). A performance optimization, like the drill-off test (DOT) or an optimum HSI (hydraulic horsepower per square inch), has not been implemented. A low HSI of 1.45 was achieved, but operational limitations are responsible for neglecting further improvement.

Increasing the hydraulic horsepower at the bit was restricted by two main reasons. First and main problem is the pumps’ capacity. With 6 ½ inch liners, the flow rate and the pump pressure were limited. In addition, the temperature of the mud did not allow further increase through friction. An upper limit of 72° C was targeted to make operating on and around the mud treatment facilities bearable.

8.1.1.2 Performance and performance-related problems

The Smith SDSi 519, as already said, did perform well in the upper clay marl layer where the more than 40 m/h were achieved. With top values up to 50 m/h, the PDC allowed an outstanding 42.4 m/h average ROP. This performance was hold from 500 m measure depth (MD) to 1615 m MD.

After encountering the first conglomerate layer, the bit immediately fell back to about 12 m/h. The highly abrasive layer of coarse sandstone / conglomerate assumably broke the cutting structure at the edge. Poorly cemented clasts applied high shock-like wear onto the bit. The sudden loss of cutting capacity can be noticed in Figure 8.1. Here, it needs to be stated, that lithological properties (red square) are measured on the rig site and visually, the time lag of the cuttings (required time for a cutting to reach surface) is estimated. Hence, the depth correlation done by the rig site geologist might show inaccuracies.

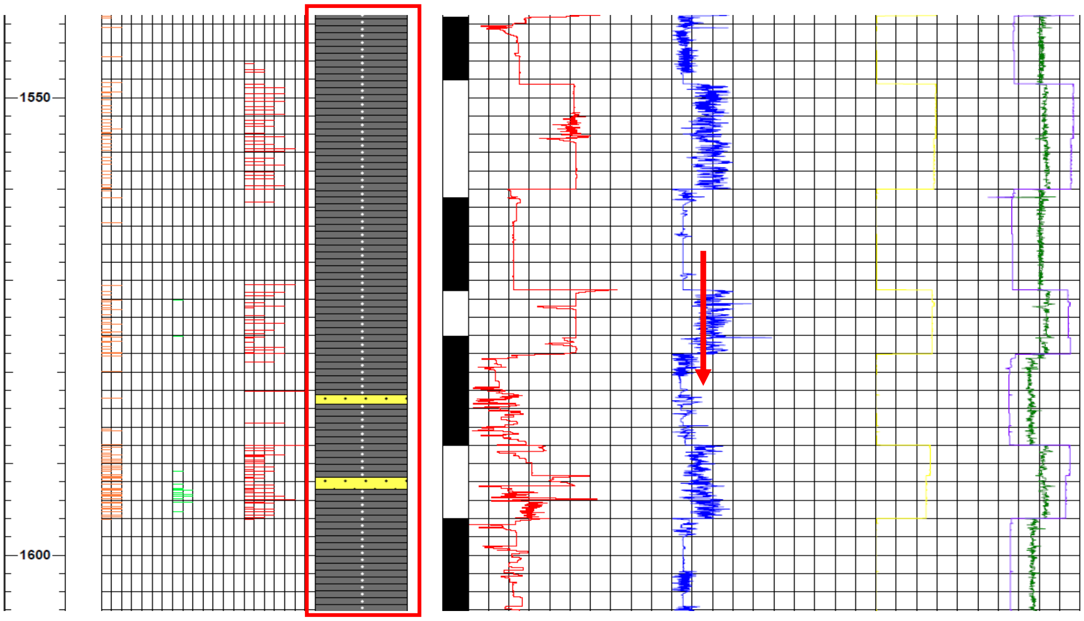


Figure 8.1 – Log of OKSP-001 showing the increased torque fluctuation and first lithological changes

Nevertheless, around 1580 m MD, a change in lithologies can be observed, on behalf of the rate of penetration and the top drive torque. Both show a change from a higher fluctuation than before. A high fluctuation of torque values during sliding operations suggests that the bit gets caught frequently and the mud motor's torque is exceeded regularly, implying a change from clay marl to conglomerate or coarse sandstone (Figure 8.1– red arrow).

In addition to the obvious changing in ROP and torque, the directional driller observed an increased difficulty with the tool face. After reaching the interbedded layers, he described problems when setting the tool face and holding it as well. Presumably, when the bit gets caught and the torque exceeds the motor's capacity, the BHA tends to abruptly break free and slip through. As a consequence, additional re-adjusting the orientation of the BHA is inevitable. The presence of this phenomenon additionally slows down the rig's performance.

As previously brought up, the PDC showed a significant drop of ROP, allowing the assumption that cutting elements have been destroyed after encountering the first conglomerate layer. This can be observed, because the penetration rate did not increase in the following clay marls again (Figure 8.2). A reduced penetration depth of the cutters and a chamfered structure ruined the PDC's capability to drill.

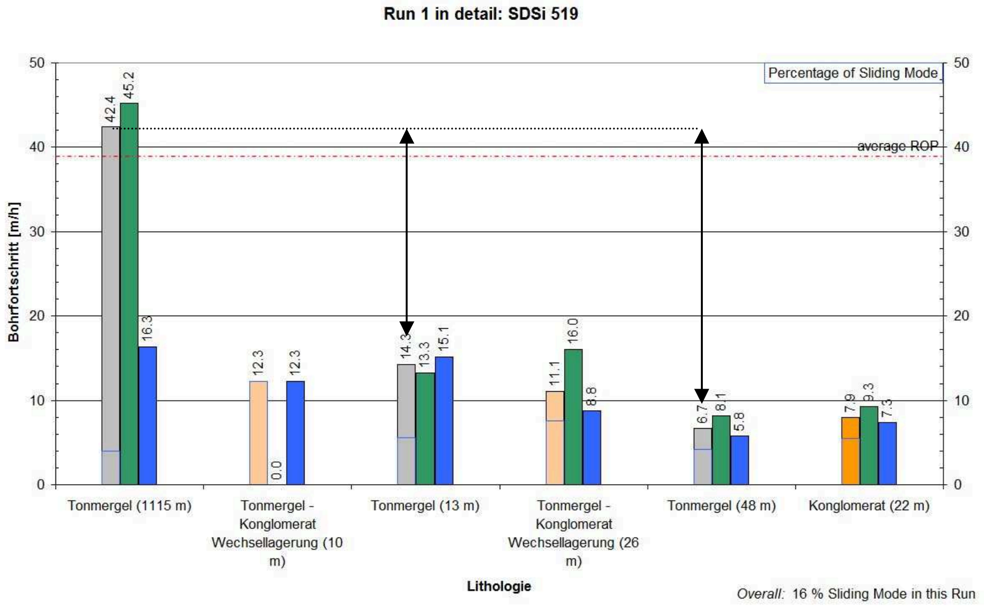


Figure 8.2 – OKSP-001 run #1: loss of cutting capacity after encountering conglomerate layers

Vibration data, provided by BHI, additionally strengthened the hypothesis of cutter-breakage. The real-time data for lateral, axial and stick-slip vibration showed increased values implying that the bit faces unusual shocks. The high impact forces allow the assumption of crushed cutters as well. Axial and stick-slip vibration measured with altered values do have a destructive effect on cutting elements, especially when the individual clasts with a high compressive strength are hit and the supposedly soft matrix has already been removed.

8.1.1.3 Summary

The SDSi 519 made 1234 m (from 500 m MD to 1734 m MD) with an average ROP of about 38 m/h. Due to the early stage of the well with a long tangential section, only 16% of the drilled distance was done in sliding mode. Further, since most of the clay marl was drilled in rotary mode, high a high rate of penetration of more than 40 m/h document the above-average performance. However, as soon as conglomerate layers were encountered the bit's performance dropped significantly by three fourths, not only because of the breakage of the cutting structure, but also because of the increased build-up rate demanding for more sliding time.

8.1.1.4 IADC dull grading

3 3 WT A X 1 RO PR

The dull grading is performed by the company man on-site based the visual perception and his experience.

In a conglomerate layer at 1234 m MD and with a rate of penetration below 3 m/h the PDC was pulled and on surface, it showed the already assumed forms of dullness. Worn teeth at all areas and a ring out (see Chapter 4.3) could be observed leaving a clear damage pattern and the reason for the significant performance drop.

Figure 8.3 – OKSP-001 run #1: PDC with a ring out and worn teeth

8.1.2 Run 2 – GFi 12 BVECPS

With given issues, such as the lithological condition and the derived challenges with vibration and shocks or holding the tool face, a tungsten carbide insert (TCI) roller cone bit was chosen to overcome those problems. The GFi 12 BVECPS with an IADC grading of 437X was chosen. The TCI of Smith bits is from the Gemini series, equipped with a Dynamic Twin Seal to seal the bearing's lubricant and the components of the friction-ball-friction (F-B-F).

Due to the high quota of moving parts, a roller cone turns out having an end of its lifetime depending on the total revolutions performed. Smith bits grants 700,000 revolutions in abrasive formations such as conglomerate (1 million for regular operations). If the number of revolutions is not satisfying, the bits will be investigated in Smith bits' reliability center to conclude the exact wear and breakage (Chapter 5).

8.1.2.1 Operational parameters

The BHA was configured similarly, but with one minor change. An installed bypass valve reduced the flow through the PDM by about 600 liters at given surface pump rates. Thus, the down hole rpm of the Mach-1 8“ Ultra XL were reduced by approximately 36 revolutions per minute, leaving about 160 rpm for rotary (130 rpm in sliding mode). The reason for this bypass valve is not only that roller cone bits are supposed to be rotated slower than PDCs for the different cutting technique, but even more that the lifetime of a roller cone bit is directly connected to the number of total revolutions. A PDC generates the hole by shearing, whereas a roller cone crushes the formation to break out chips. The difference in cutting action also effects the applied weight on bit (WOB), allowing to increase the WOB to 15 tons. Again, BHI’s “best practice” determines the WOB.

With similar limitations concerning the pump’s flow rate and pressure capabilities, the HSI was 0.84. A slightly higher flow rate was achieved after the bit change on behalf of different nozzles and the increased total flow area (TFA) as a consequence, but the bypass valve reducing the flow rate of about 600 liters did not enable an improvement of the hydraulic horsepower per square inch.

8.1.2.2 Performance and performance-related problems

When being run at 1234 m MD in alternating conglomerate - clay marl layers, the roller cone bit showed a significant reduction in stick-slip vibration and also, orienting the tool face and holding it was eased. But, on behalf of its crushing rock cutting nature, axial vibrations showed an increase – yet, still acceptable. In conglomerate formations, the TCI proved its potential with an average ROP between 10 and 15 m/h. Still, throughout the whole bit run, significant drops in clay marl-dominated beddings were obvious. While 8 meters per hour, even later in this run, were still possible in conglomerate layers, the bit was unable to perform similarly in clay marls (less than 5 m/h) although being an aggressive TCI (Figure 8.4 – green line).

As to be found out later, the increased axial impacts wore off the TCI cutters, explaining the ongoing decrease of ROP (Figure 8.4 – red arrow).

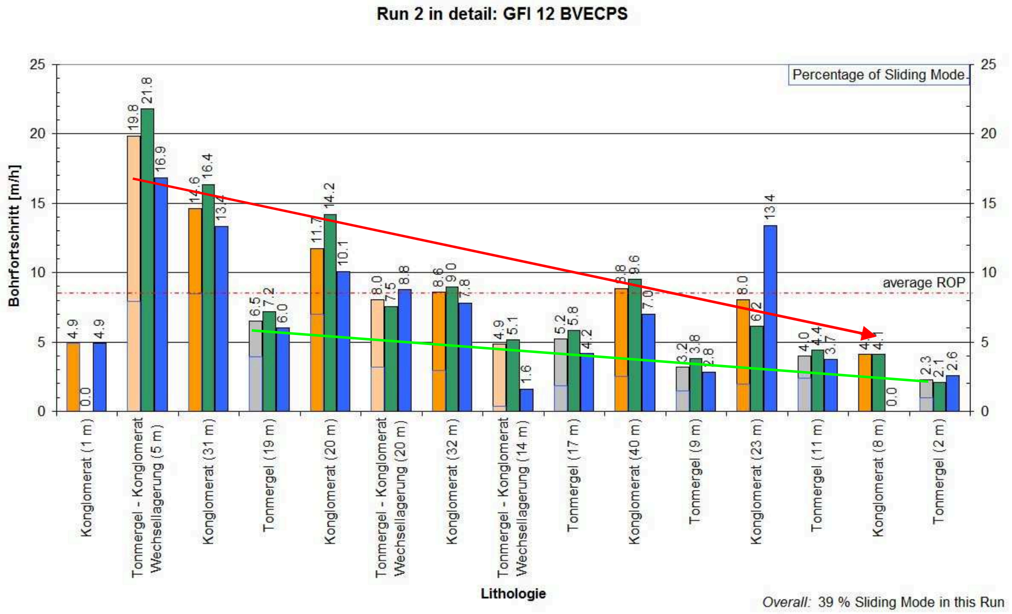


Figure 8.4 – OKSP-001 run #2: constant decrease of ROP indicating bit dulling

8.1.2.3 Summary

Smith bits' GFi 12 BVECPS drilled 252 m (from 1734 m MD to 1986 m MD), of which 61% were done rotary with remarkable 8.5 m/h in average. The reason for pulling out of hole was due to hours (55 hours on bottom) and the linked total revolutions of 550,000, due to a low ROP in the end of less than 3 m/h and on behalf of pulsing issues of the BHA (weak pulsing). Summing up, the bit performed as expected in conglomerate layers, but showed shortcomings when being in clay marl environment. The unsatisfying number of total revolutions needed further investigations as well, since the factory-statement of 700,000 revolutions was missed and the high chance to lose a cone down hole was present.

8.1.2.4 IADC dull grading

3 8 BT M F 4 FC BHA/HR

With broken teeth and flat crested wear, the bit was not able to keep an efficient ROP in the clay marl layer at 1986 m MD. On surface, the problem was revealed showing insufficient cutting potential. Additionally, a loose cone suggested that pulling was right on time and consequently defined an upper limit for future TCI runs. With the highest wear, this bit was chosen to be investigated at Smith bits' reliability center in Saline di Volterra (Chapter 5) for a detailed analysis of separate components and to specify the induced wear. On top of the bit disassembly and the report, one other factor has been put into consideration: in combination with the trajectory and the developed lateral loads on the bit, the BHA, especially the bent housing, forms additional side forces on each cone lifting them off their leg.

8.1.3 Run 3 – GFi 28 BODVCPS

Directional advantages to a PDC and the above-average performance of the previous TCI, another roller cone bit was picked. Due to the previous bit's dullness, a harder, or less aggressive, bit was run – the GFi 28 BODVCPS. The hardness is described by the "28", whereas the following letters of the Gemini series ("GFi") describe the bit's additional features (gauge protection, diamond enhanced heel inserts,…). This is shown with the IADC grading of 527X.

8.1.3.1 Operational Parameters

For run #3, a new tool was picked up and implemented in the BHA configuration. The NaviGamma tool was replaced by BHI's OnTrak, which adds resistivity to MWD measurements. Furthermore, an additional third under-gauge stabilizer was implemented in the BHA. Reducing the TFA at the bit by 0.012 in² increased the HSI slightly to 0.86, yet being beyond the efficient window of 2 to 5.

As for the previous run, the bypassed volume reduces the down hole revolutions leaving similar parameters. Again, the WOB is not derived by finding the most efficient one via a DOT, but predetermined by the directional driller.

8.1.3.2 Performance and performance-related problems

The GFi 28 BODVCPS was run at 1986 m MD, where the well was already inclined to 30°. Being less aggressive, the bit was able to perform at 8 m/h in conglomerate layers. Also, the different design of its cutting structure and the additional stabilizer showed a significant impact on axial vibrations as highlighted red in Figure 8.5. Lateral vibration was reduced as well, most likely by the additional stabilizer. But, parallel to run #2, stick-slip vibration appeared and with the given inclination the assumption that not only the bit, but also stabilizers induce stick-slip vibration, arose. Again, orienting the tool face and drilling in sliding mode was easy, but when rotating the whole string high variations in torque with the described vibrations were caused. (Figure 8.5 – red arrow).

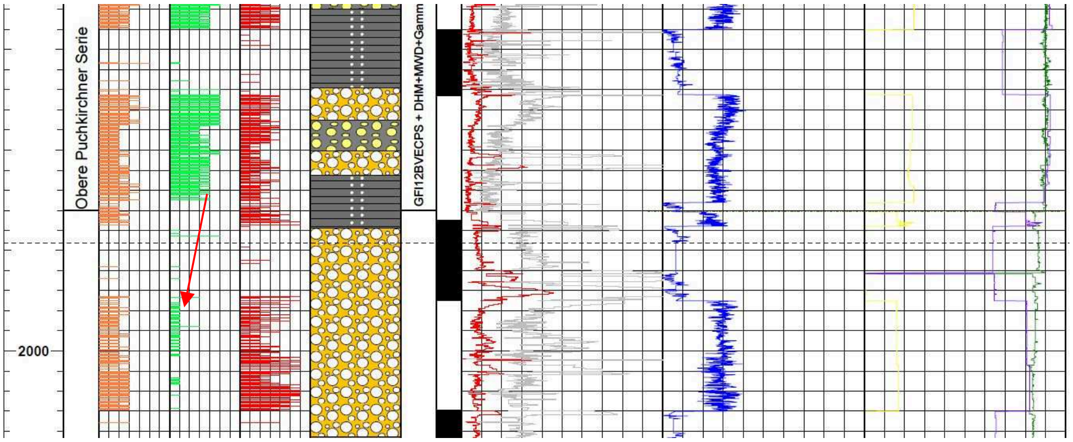


Figure 8.5 – Log from OKSP-001: changes observed from run #2 to run #3

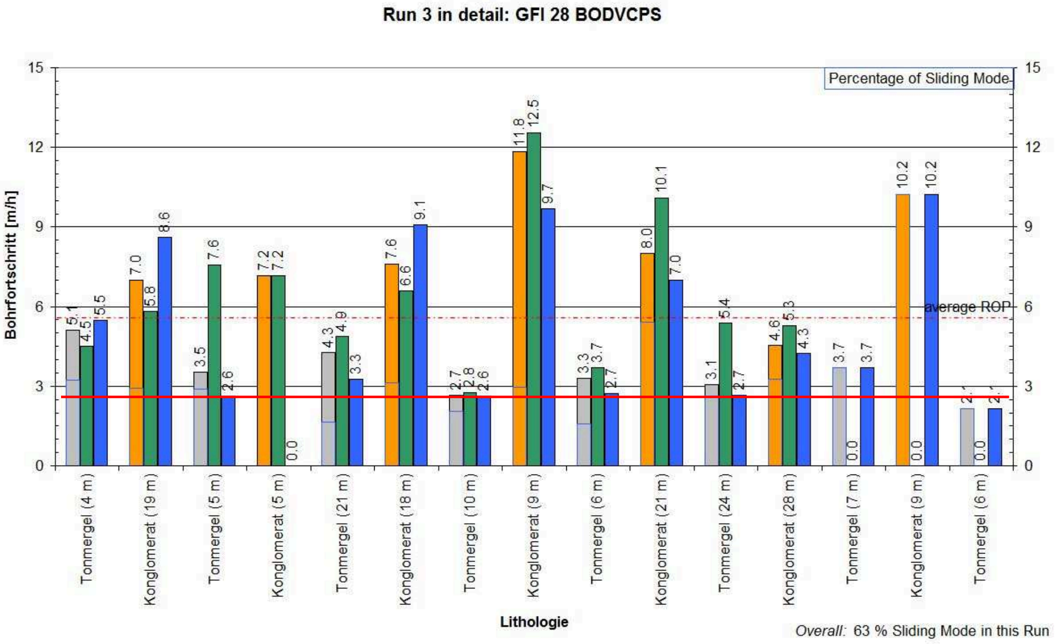


Figure 8.6 – OKSP-001 run #3: increasing sliding time and constant low ROP in clay marl

The low depth of entry of the tungsten carbide inserts was not able to achieve a high ROP in the soft clay marl formations (Figure 8.6 – red line). With advancing duration, a new problem occurred. The ROP decreased, but not because of the bit, but the drilled well path dropped under the designated curve and consequently, sliding needed to be increased. The 50-50 distribution between rotary and sliding mode drilling from the first 100 m were turned into nearly 80% sliding resulting in a 63% average sliding time across run #3 (Figure 8.6 – blue rectangles indicate sliding percentage per layer). With the high cut of sliding, the rate of penetration evidently decreased.

The effort put in to stay on the well plan soon became the reason to pull out of hole. A measured 4 meter drop would soon turn out to create later on a dogleg severity (DLS) to reach the target which would not allow the casing to be run. When retrieving the BHA, the problem could be detected soon. The stabilizers showed sever damage due to the abrasiveness of the conglomerate. Also, the TurboBack (near-bit stabilizer) showed that from 30° to the 45° inclination (when POOH) the BHA, lying on the low side, bears strong wear on the used tools. Yet, the most significant effects of the formation were shown on the bearing sub, where the bent can be found. The low side of the stabilizer which experienced the highest exposure to the formation on behalf of the given geometry was by far the most damaged one. The point, where the momentum to the bit is transferred, is consequentially the one with the most contact to the formation causing the biggest damage (Figure 8.7).

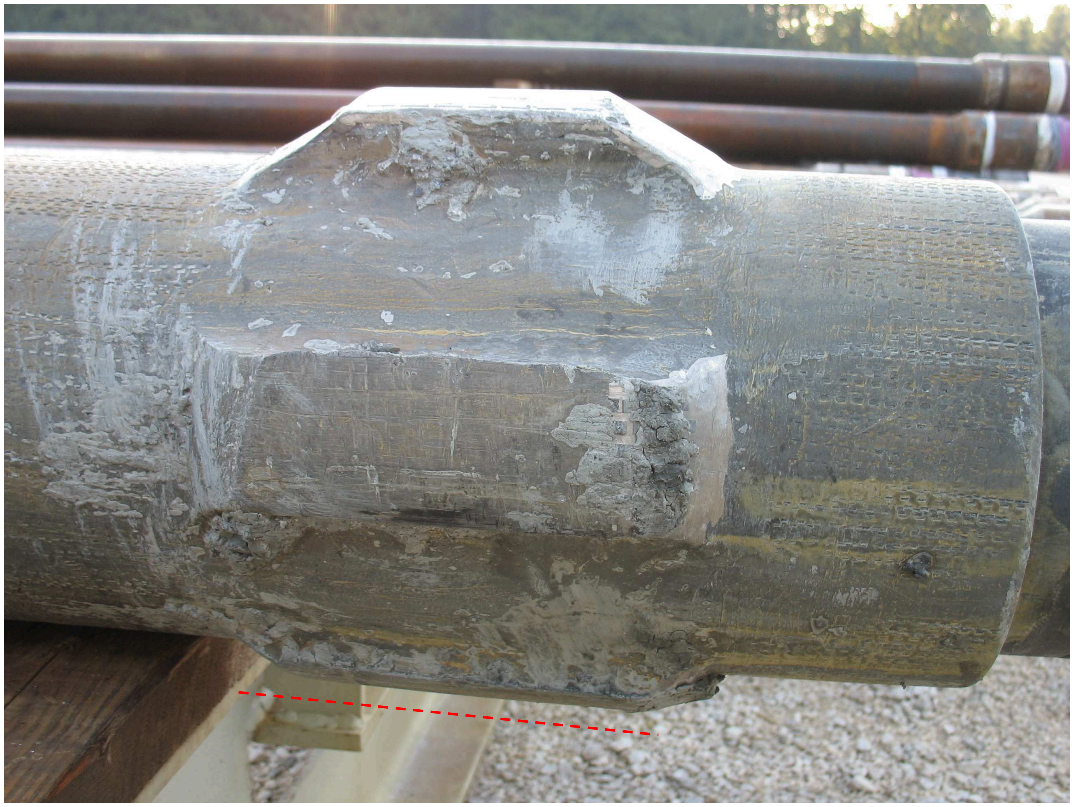


Figure 8.7 – OKSP-001 run #3: bearing sub with extensive wear on low side

8.1.3.3 Summary

With a total performance of 192 meters from (1986 m MD to 2178 m MD), the GFi 28 BODVCPS did well and was pulled because of a BHA failure. The inability to build up was the reason for POOH, and with the increased sliding times in the end of the run, the rate of penetration was not at the bit's possibilities. Even though, weight on bit is applied, during sliding drilling, the missing rotation strongly increased friction along the drill string and the BHA, thus, leaving less WOB actually at the bit to generate the hole. The issue with WOB measurements, where an exact downhole measurement is impossible, also applies in this case, when the drill-o-meter is set to zero while the string is rotated neglecting additional friction when drilling sliding. Still, the average ROP of 8.5 m/h of this run can be considered satisfying.

8.1.3.4 IADC dull grading

2 8 BT M E 1 NO BHA

The high IADC grading of the bit allowed coming out of the well without severe damage. Therefore, the company man's visual inspection and dull grading of 8 for the outer rows (Chapter 4.2) do not apply. As shown in Figure 8.8, the outer rows show regular signs of wear, most likely gauge-rounding, but no broken teeth as reported, allowing the assumption, that a more aggressive bit might have improved ROP.

Figure 8.8 – OKSP-001 run #3: roller cone bit with minor signs of wear

8.1.4 Run 4 – GFS 20 BVCPS

In regard of the previous bit's dull grading, a more aggressive bit was chosen for run #4. Smith bits' GFS 20 BVCPS with an IADC grading of 517X was picked to increase the rate of penetration in clay marl layers and keep a comparable performance in the coarse conglomerate.

8.1.4.1 Operational parameters

With problems faced during the end of run #3 and breakage of various stabilizers, new tools were configured into the BHA. A new PDM and two new stabilizers were installed, whereas the near-bit stabilizer was left away. Hole clearance has not been a problem so far, and thus the TurboBack was not needed. Besides, without the near-bit stabilization, the BHA was less tight and building up was easier. Other parameters have not been changed.

8.1.4.2 Performance and performance-related problems

With measurements showing that the well path dropped about 4 meters under plan, more sliding in run #4 was necessary to get back on track. In combination with nearly just conglomerate in this section, a low rate of penetration was the consequence. Furthermore, a high dogleg severity (larger than 4°/30 m) started to cause unwanted stick-slip vibration.

8.1.4.3 Summary

With 82 meters drilled (from 2178 m MD to 2260 m MD), the GFS 20 BVCPS showed the lowest output. But, with nearly two thirds (62%) drilling time in sliding mode, a low rate of penetration was inevitable. But, it has to be said that in this run, the shortcomings of run #3 needed to be taken care of and thus the weak performance of only 2.7 m/h is a consequence. This becomes obvious when comparing the inclination of the well at the beginning with the inclination of the well when the bit is pulled. 45° in the beginning compared to 56° after 82 m drilled visualize the struggle to get back on plan.

8.1.4.4 IADC dull grading

3 4 FC A 4 1 FC PR

With broken teeth in the outer rows and flat crested cutters at all rows, the GFS 20 showed the expected wear. One thing, which does not appear in the company man's dull grading, is the loss of lubrication at two cones. Mud intrusion (Figure 8.9) already happened and the cones were easy to rotate without any springback on their legs.

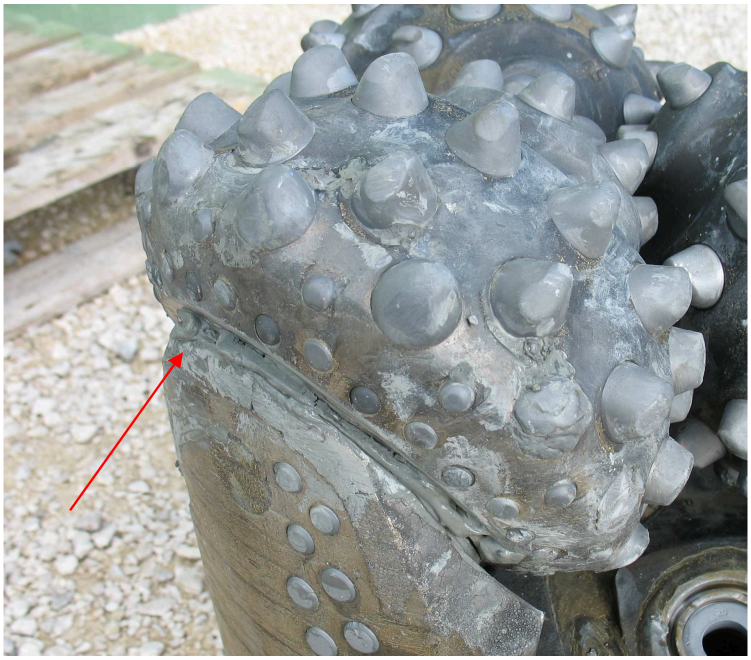


Figure 8.9 – OKSP-001 run #4: roller cone bit with seal breakage and mud intrusion

8.1.5 Run 5 – GF 20 BODVCPS

With the experience of run #4, where the bit's dullness was within an acceptable range, a bit with a similar IADC grading was picked. The large variation of layers was still the major concern, cancelling out a PDC solution. Tool face orientation and steerability restricted the bit selection, and as a consequence, accuracy and "smoothness" of the well path were considered more important than simple drilling speed.

8.1.5.1 Operational parameters

There were no further changes, neither in the BHA configuration, nor in drilling parameters.

8.1.5.2 Performance and performance-related problems

With given parameters, the bit performed as expected. Directional orientation and ROP were within the expected range and problems did not appear. Lithological challenges did not influence performance as in the previous runs and a learning curve could be observed. Still, a DOT was not considered.

Throughout run #5, stick-slip vibrations stayed in an altered level and lateral vibrations began to increase. With the increased friction along the string at 60° inclination, axial vibrations dropped to an insignificant level.

8.1.5.3 Summary

With an average of 5 m/h, the GF 20 BODVCPS drilled 155 m (from 2260 m MD to 2415 m MD) without any problems. But, it has to be stated as well, that with only 31% sliding time, the bit was able to benefit from long rotary sections.

8.1.5.4 IADC dull grading

2 5 BT H 7 1 NO TQ

With a large rotary percentage, the wear at the heel row was anticipated and no surprise. Same counts for the high side forces acting on the cones themselves, inducing a seal failure and mud intrusion as seen in the previous run.

8.1.6 Run 6 – GF 20 BVCPS

With satisfying performances in previous runs and the expectation of more clay marl near the casing setting depth, another GF 20 BVCPS was used for the final run.

8.1.6.1 Operational parameters

After long conglomerate sections in the last two runs, a beginning wear, similar to the one in run #3, was observed on surface. To not face identical problems in building up, it was decided to change the motor. Risking too much of wear on the old bearing sub stabilizer was out of discussion, considering run #6 the final run, with the goal to reach target casing setting depth. Hence, a new PDM was put into the BHA with a bent of 1.3°, since it was the only motor on site.

8.1.6.2 Performance and performance-related problems

The final section to casing setting depth at 2490 m MD was dominated by sealing clay marl layers. Besides, the new PDM with 1.3° bent housing allowed shorter sliding times due to a smaller radius. Consequently, sliding times were shorter and the rotary drilling dominant.

8.1.6.3 Summary

The final 75 meters to the target depth of 2490 m MD (casing setting depth) were drilled with 3.7 m/h average ROP. Long periods in clay marl formations slowed the progress down. Nevertheless, a rational rate of penetration was demanded by the subsurface engineer to make sure that the casing is set at the right point. The mentioned bigger bent in the PDM allowed reducing the sliding time to 25% with the same DLS along the section as in run #5.

8.1.6.4 IADC dull grading

2 2 NO A F 1 NO TD

The small distance drilled resulted in little wear. Reaching target depth was the reason for pulling.

8.2. 8 ½ inch section

The horizontal section was, as already mentioned in Chapter 8, planned an 8 ½ inch. The reservoir formation was assumed to be coarse sandstone or conglomerate. Again Smith bits provided most of the bits with only one exception – run #8. Parallel to the 12 ¼ inch runs, the first run in the 8 ½ inch section to drill out the cement shoe with a milled tooth bit was not considered in the numeration. The original run #10 was cancelled out due to insignificance, as done before.

8.2.1 Run 7 – FH 35 ODV

After a formation integrity test (FIT), the first bit chosen was a Smith bits' TCI with an IADC grading of 547X. The FH 35 ODV was equipped with one dual component bullet seal in the bearing to remain lubrication. The mid-hardness of the bit was picked on behalf of soft clay marl layers and the chance to face the abrasive conglomerate.

8.2.1.1 Operational parameters

Unlike the 12 ¼ inch section, a rotary steerable system (RSS) was used for the horizontal section of OKSP-001. Baker Hughes Inteq's RSS uses a push-the-bit principle. Along with the steering section of the BHA, a modular motor (PDM with a 5/6 lobe-ratio) was installed adding 0.05 revolutions per liter pumped to the top drive rpm. For reservoir navigation, the MWD device AziTrak was installed and hence, communicating from the surface to the bottom hole assembly was granted.

With additional 115 rpm provided by the PDM, the bit's revolutions were continuously at around 150 per minute. The smaller diameter of the bit and its compact construction technique reduced the maximum allowable revolutions to 400,000. Concerning the WOB, BHI determined 10 tons.

After installing smaller liners (5 ½ inch), the pumps were able to withstand higher surface pressures and the pressure drop at the bit could be increased resulting in 3.4 HSI and thus, more effective hole cleaning.

8.2.1.2 Performance and performance-related problems

Implementing the RSS showed immediate benefits on behalf of its advantages. The continuously rotating string reduced torque and drag and so, WOB was transferred constantly.

8.2.1.3 Summary

With an average of 5 m/h, the FH 35 ODV drilled 181 m. Even though drilling through clay marl, conglomerate and interbedded layers, ROP stayed constant. No performance was lost during the bit's life.

8.2.1.4 IADC dull grading

3 4 NO A 7 1 NO HR

This dull grading reveals that the bit was used efficiently and performance consistency fortified the bit's selection.

8.2.2 Run 8 – MSF 616 M-A2B

Expecting a thick clay marl layer, a PDC bit was run. But with the experience of the 12 ¼ inch PDC run and the bit's wear (SIEHE RUN 1), a less aggressive bit with additional impact protection was needed. Reed's MSF 616 M has dome-topped inserts on critical areas, such as the inner area, where a ring out is most likely. The torque control components (TCC) by Reed should, along with an additional blade (6 blades), withstand possible abrasive encounters during the run.

8.2.2.1 Operational parameters

Without further changes, the BHA was assembled. Only the nozzles of the bit are different with an HSI of 3.2 and more rpm act on the bit (170 to 210 rpm).

8.2.2.2 Performance and performance-related problems

Initially, the choice looked promising with a high rate of penetration, despite the fact that the expected clay marl turned out to be another conglomerate – clay marl interbedded formation. Yet, at 2714 m MD the pipe got stuck and after the maneuver to get free, the ROP dropped significantly.

8.2.2.3 Summary

With only 57 meters performed, the PDC was by far the one with the lowest meterage. With over 12 m/h from the beginning of the run, the performance dropped under 3 meters per hour, leaving no other choice than to pull out of hole (POOH). The average ROP was 8.5 m/h.

8.2.2.4 IADC dull grading

7 3 WT C X 1 NO PR

After retrieving the MSF 616 M-A2B, observations of the dome-topped inserts showed the protection against a ring out. High wear on inner-row cutters were a sign of the high percentage of clasts in the layers. Nevertheless, the dome-topped inserts protected the bit’s center cutters (Figure 8.10 – circled red). Still, the relatively high wear on the bit with little meters drilled was alarming (Figure 8.10 – highlighted green).

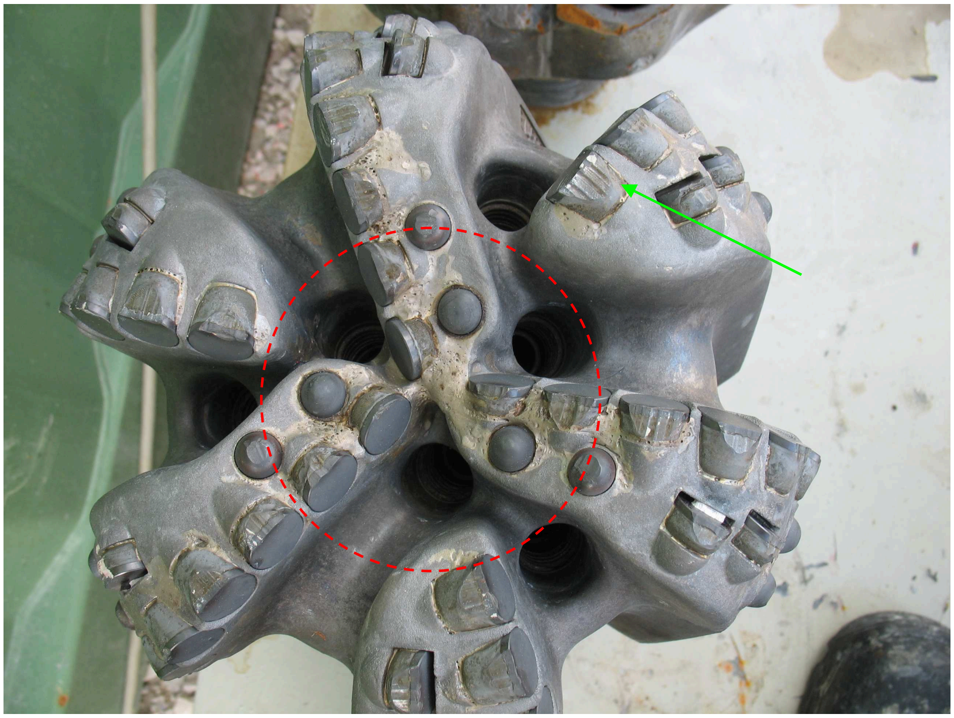


Figure 8.10 – OKSP-001 run #8: PDC with dome-topped inserts preventing a ring out, high wear though at outer cutters

8.2.3 Run 9 – FH 35 ODV

With coarse layers of conglomerate ahead and the visual effects on a PDC in the previous run, a TCI was picked. Satisfying results in run #7 strengthened the use of another FH 35 ODV.

8.2.3.1 Operational parameters

Drilling parameters were set back to run 7's. Especially, the revolutions on the bit were reduced to extend its life. With an HSI of 4.1, bit hydraulics were optimized. Time was lost though, when a function test of the MWD showed no communication. When retrieving, it was found that a cover plate was missing supposedly lost down hole. The cover broke off probably during the maneuver to get the pipe free after being stuck.

8.2.3.2 Performance and performance-related problems

Similar to run #7, the bit's performance was better than expected, especially because of the large conglomerate sections. Another positive side effect was a significant torque reduction. Also, less vibration was detected describing the difference between the two cutting means. While lateral vibration was reduced by one level, stick-slip vibration was reduced by about two levels.

8.2.3.3 Summary

With 260 meters (from 2730 m MD to 2990 m MD) in total and 6.6 m/h on average, this run was the best in the 8 ½ inch section. Not only, that in clay marl layers, an ROP of about 5 m/h was held, also, coarse sandstone/conglomerate layers were drilled with remarkable 7.5 m/h. 46.5 hours on bottom were the top value as well.

8.2.3.4 IADC dull grading

5 5 CI A 8 1 NO HR

Being the bit with the most hours on bottom, bit wear was severe. Parallel to previous runs, the roller cone's TCIs were normally worn and the factor limiting the TCI's lifetime is detected as the bit's bearing. In a highly altered position (Figure 8.11), beginning cone interference was at hand. This being observed, drilling hours of the next 8 ½ inch TCIs were kept at 40.

Figure 8.11 – OKSP-001 run #9: loose cone at TCI after 46.5 hours

8.2.4 Run 10 – FH 35 ODV

On behalf of run #9, this run was similarly designed.

8.2.4.1 Operational parameters

The success of run #9 did not imply any changes. Still, 225 bars surface pump pressure were kept, as well as 2100 liters per minute. WOB was set by the directional driller at 12 tons.

8.2.4.2 Performance and performance-related problems

Without changes, there were hardly effects in drilling performance, yet one could observe a general drop in the penetration rate. Also, clear distinctions between clay marl and the coarse sandstone became more obvious (Figure 8.12).

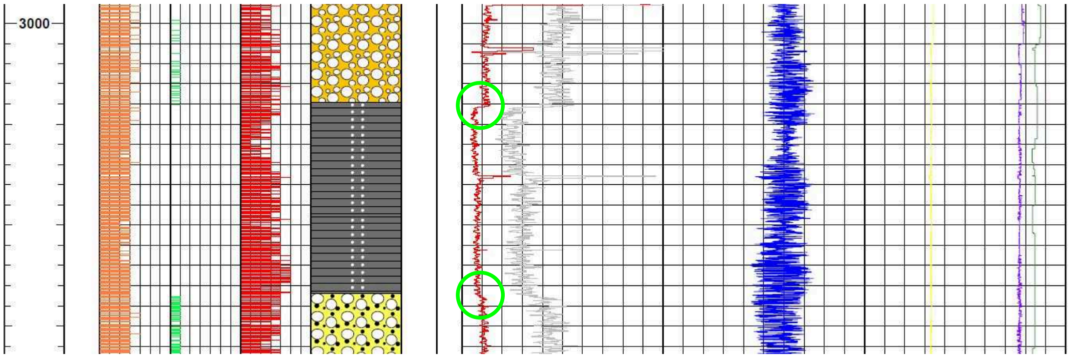


Figure 8.12 – Log of OKSP-001: ROP change from conglomerate to clay marl

8.2.4.3 Summary

Hard formations, such as conglomerate and sandstone layers, obliged the FH 35 ODV and consequently, a ROP of about 6 m/h was possible. On the contrary, Soft clay marls drove performance down below 4 m/h. Yet, 170 meters MD was achieved with an average of 5.3 m/h.

8.2.4.4 IADC dull grading

3 4 NO A E 1 NO HR

Without exaggerating the TCI's running limit, all seals were considered effective and no risk of losing a cone was taken. Signs of wear were as expected.

8.2.5 Run 11 – FH 35 VPS

The FH 35 VPS simply differs with slightly different features from the ODV, but has the same IADC grading of 547X. Without taking a risk, the same bit was picked.

8.2.5.1 Operational parameters

Again, no changes were made during the change of runs.

8.2.5.2 Performance and performance-related problems

The rate of penetration proceeded as expected and with long sections in conglomerate-dominated formations, the TCI proved its potential. But, during the run, the roller cone lost cutting efficiency due to wear and parallel, stick-slip vibrations increased substantially. This might be an effect of an inclination of 91°.

8.2.5.3 Summary

In run #11, 193 m were drilled. From 3160 m MD to 3353 m MD, average 6 m/h were achieved. It was observed, that the bit became duller during its use, dropping from 7.5 m/h in the beginning to 3.5 m/h.

8.2.5.4 IADC dull grading

4 4 BT H E 1 NO HR

The FH 35 VPS was pulled after 40 hours on bottom and so, all bearings were effective. Despite normal wear, some heel row inserts were broken, but negligible.

8.2.6 Run 12 – MDSi 816 LUBPX

Knowing that with the given well path (inclination above 90°) a clay marl package was about to be encountered again and the reservoir section would be sandstone, using a PDC was worth testing. Smith bits' PDC had 8 blades and thus, the fixed cutter bit was considered unaggressive.

8.2.6.1 Operational parameters

In order to reduce vibrations (lateral, axial and stick-slip), a roller reamer was implemented into the BHA. Considering the dulling of the previous bits, vibrations seem to have influence on cutters breakage. Shock-like impacts destroyed the cutting elements throughout all runs with noticeable vibrations. Consequently, in order to overcome the breaking of the cutting edge, a roller reamer was installed allowing smoother revolutions. An HSI of 3.1 was accomplishable at the given depth.

8.2.6.2 Performance and performance-related problems

Optimizing the BHA by installing the pivot-mounted bearing leaded to an additional benefit: a significant torque reduction of 4,000 Nm. Despite the change from roller cone to PDC which would actually increase torque from the bit, the installation of the roller reamer had a torque reduction as a consequence. In addition, improvement in lateral and stick-slip vibrations was observed as well. Axial vibration was not encountered during run #12.

In the predicted clay marl section, the PDC was able to deliver, yet the reservoir sandstone of the upper layer seemed to be very coarse showed a drop of ROP as one would have expected in a conglomerate. At 3511 m MD, the pipe got stuck and only after pulling with an over pull of 35 tons, it got free again.

8.2.6.3 Summary

The biggest improvement was the torque-reduction, especially since the top drive was about to meet its limits. Nevertheless, the MDSi 816 LUBPX was able to drill at 11 m/h average throughout the clay marl layer. But, as soon as clasts were present, either in coarse sandstone or in conglomerate, the performance dropped drastically. In interbedded sections, more than 7.5 m/h were still possible, whereas, when the bit got into the reservoir layer, 3.5 m/h were the penetration rate. Hence, the 234 meters were drilled with an average of 6.2 m/h, from 3353 m to 3587 m MD.

8.2.6.4 IADC dull grading

7 2 WT T X 1 RO MF(DTF)

The highly abrasive reservoir section, destroyed the PDC’s cutters and a ring out was observed as well (SIEHE BILD RING OUT). With 8 blades and 18 cutters the PDC should have provided more wear resistance, but where the second row of cutters ended a ring out could happen – right where the MSF 616 M-A2B had the dome-topped feature. Nevertheless, the bit was pulled because of MWD failure (MF). MF is the RAG internal description for downhole tool failure (DTF) after IADC. Similarly to the ending of run #8, the MWD's cover plate was missing, supposedly downhole. Lack of the ability to communicate down hole, was reason for an early POOH. Yet, the bit was damaged beyond repair (DBR).

8.2.7 Run 13 – FH 40 ODV

The last bit used was a TCI roller cone again, since they showed to work best in the abrasive reservoir formation. And, torque limitations by the top drive would not allow the increased counter-torque of a PDC either. During run #12, sporadic torque peaks of about 38,000 Nm were already exceeding the top drive's limitations.

8.2.7.1 Operational parameters

The BHA configuration was kept the same, similar to the previous run, including RedBack's roller reamer. Also, the HSI was kept at 3.1.

8.2.7.2 Performance and performance-related problems

The reservoir section in the abrasive conglomerate/sandstone was drilled with a remarkable penetration rate. But again, supposed wellbore stability issues caused a stuck pipe at 3589 m. Nevertheless, total depth (TD) was reached without any decrease in ROP.

8.2.7.3 Summary

The FH 40 ODV drilled the last 183 meters to TD at 3770 m MD with constant 5 m/h and without further incidents due to wellbore stability.

8.2.7.4 IADC dull grading

3 2 BT M 8 1 NO TD

The high IADC grading of 617X mislead the company man to grading 3 and 2. The small tungsten carbide inserts showed minor signs of wear and a long time on bottom did not affect the bearings. With so little signs of breakage, a more aggressive bit might have increased the performance.

8.3. Lessons learned from OKSP-001

On behalf of the performance in combination with the interpretation of the given data, an analysis has been performed. Shortcomings have been discussed and improvements for Oberkling well #2 (OKSP-002) have been made.

Summing up, there were six considerable runs in the 12 ¼ inch section and seven in the 8 ½ inch section. The milled tooth bit runs before the FIT were ignored.

8.3.1 Summary of the 12 ¼ inch section

During five of the six runs, TCI bits were in use, whereas, during the first run, a PDC was used to drill the hole. In every run, a positive displacement motor (PDM) was installed and the BHA only changed slightly regarding the MWD/LWD tools.

With a more than satisfying performance during the first run, the PDC was the right choice. Only, with the presence of conglomerates, ROP and steerability dropped (Chapter 8.1.1). From then on, roller cones were used, being limited by the number of total revolutions; ergo drilling time on bottom. During every run, vibration, rotation and stick-slip data (VSS) was collected as well in addition to RAG’s real time data. BHI’s VSS detected measurements with a low frequency (every 20 seconds) due to the restrictions of pulsing (Chapter 6.4.4).

When discussing the lifetime of the bits, it became clear that the PDC was unable to drill conglomerates, not only because of high wear at the cutters, but also because of the inability to orientate the tool face. For the second kind of bits in use, the challenge was to improve the lifetime. The unsatisfying number of total revolutions needed to be improved.

In discussions with the main provider of the bits, Smith bits, one main reason has been identified. Axial vibration, in the form of shock-like impacts, causes early breakage of both, the cutters and the cones’ bearings. Lateral vibration has less influence on the bit. Yet, the axial vibration is not only caused by the bit’s running on coarse clasts, but can also be an effect of stick-slip vibration.

Now, stick-slip vibration is primarily generated by the string, considering that the change from PDC to roller cone did not significantly influence the vibration pattern. The stick-slip movement along the string generates a torque and considering the length of the drill string, a winding up of it is inevitable. This means that the across the length of the string, axial reduction and elongation is happening alongside highly frequent WOB variations.

8.3.2 Summary of the 8 ½ inch section

During the second part of the OKSP-001, two PDC runs stood against five with roller cones. The horizontal section, entirely drilled with a RSS, had one change in the BHA during run #12 with the installation of the roller reamer.

With a constantly rotating string and the ease to steer with the RSS, the 8 ½ inch sections was planned to stay horizontally in the reservoir. Reservoir navigation, provided by BHI, changed the trajectory of the well on site. Gamma ray and azimuthal resistivity data from MWD/LWD was used to stay in the promising layer. Yet, after comparing to offset wells, it was decided that the upper minor reservoir was to be entered again until reaching total depth (TD).

With the concern of high costs during tripping, two PDC bits were in use to increase the bit’s lifetime and hence, to prolong runs. Similar wear patterns to the 12 ¼ inch section’s PDC were observed at both, Reed’s MSF 616 M-A2B and Smith bit’s MDSi 816 LUBPX. As mentioned, the MSF 616 M-A2B’s impact-resistant dome-topped inserts, retarded a beginning ring out (Figure 8.10). Performance was unsatisfying though.

The sandstone package drilled by the 8-bladed MDSi 816 LUBPX was coarse and conglomerate-like causing a ring out. So, after a remarkable beginning, conglomerates wore the cutters off drastically.

The dominating bit was Smith bit’s FH 35 ODV, with an average ROP of over 5 m/h in every run.

8.3.3 Recommendations for OKSP-002

Results found during Oberkling Speicher 001 were directly implemented in the planning and execution of OKSP-002. Wear and performance were correlated to the lithological structure. Further, vibration analysis was combined with the data to figure out problems.

But first, one of the biggest problems faced during OKSP-001, besides drilling-related ones, was a significant overdrawing of the budget. With more troubles than anticipated caused by the conglomerate – clay marl interchanging layers, the tight plan took its toll. Decreasing costs was set to be the primary goal. Day rates for the rig and service rates were considered to be the main cost drivers. Expensive solutions were crossed out in the beginning.

The First section was planned with a PDC again, but due to the wear patterns of OKSP-001's PDC bits, a bit with dome-topped inserts was chosen to begin with. Reed's MSF 616 M was less aggressive and with additional impact and wear resistance, especially against ring outs, one hoped to get through the first layers of conglomerate. Baker Hughes Christensen has not been considered, because of the extensive costs of their PDC bits.

The interchanging layers, drilled with a TCI, were planned again with roller cone bits. But, for the OKSP-002 a hierarchy of their grading has been set. Unlike the more or less random arrangement of the TCI's was replaced with an increase of grading: the arrangement "12-28-20-20-20" (Smith bit's serial grading) was given a clear structure of "15-20-20-23-23" in the planning.

A problem identified during OKSP-001 was vibration. Confirmed during the bit disassembly (Chapter 5.11), bearing failure is accelerated by vibration and thus, increasing the lifetime leads over the reduction of vibration. With the experience of a smooth running string in the 8 ½ inch section after installing a roller reamer in run #12 and the torque and vibration reduction, a similar solution was planned for the 12 ¼ inch section of OKSP-002. This approach was fortified by the wear observed at the stabilizers. Under-gauge stabilizers, which were retrieved plane after drilling conglomerates, could not be neglected and indicated accountability for vibrations.

In order to reduce costs, the BHA was also planned differently, considering the lack of need for azimuthal resistivity in the top sections. Directional control and gamma ray MWD were provided by the NaviGamma tool, but the change to OnTrak will be performed during a later run to cut costs as well.

9. Oberkling gas storage well OKSP-002

The Oberkling gas storage well #2, OKSP-002, had similar design parameters, concerning the trajectory, mud program (Chapter 8) and casing design. The horizontal section and the round-bodied build are identical to OKSP-001. With only 10 meters clearance between the spuds, lithological analogies are expected. Also the azimuthal direction is comparable.

One adaption necessary for OKSP-002 was the demand for a controlled sound level. To cope with neighbor-parties' complaints about the noise level, the source was quickly identified being the top drive. With noise control walls, most of the sound was contained, like the pumps or the generators, but with the exposure of the top drive, the noise level was at critical 42 dB. As a solution for the problem, the stands being drilled were reduced from doubles to singles.

9.1. 12 ¼ inch section

Parallel to OKSP-001, after drilling out the cement shoe of the 13 $^{3}/_{8}$ inch casing, the first bit run was performed. Again, the OKSP-002's first two bit runs are neglected (the 17 ½ inch top hole section and the 12 ¼ inch milled tooth bit used to drill out the cement shoe). So, bit run #3 is considered to be the first run (run #1), since the outline of the thesis considers the consecutive bit runs as the important ones. This reconfiguration needs to be kept in mind. The BHA composition is investigated along with every bit run.

9.1.1 Run 1 – MSF 616 M

Due to OKSP-001's findings, Reed's PDC was chosen to be able to do both, perform and keep an impact resistance. The experience gained from the well #1 showed chances for a ring out as soon as conglomerate is encountered. Dome-topped inserts and an additional blade (six blades) were found to be less aggressive, so that conglomerate beddings can be dealt with. Yet, the massive clay marl layer in the Puchkirchen series was drilled appealing, but the promising impact domes could not keep up to the expactations.

9.1.1.1 Operational parameters

The BHA was not changed; similar components were configured and assembled. Again for this section, a near-bit stabilization was implemented in combination with the Mach-1 8” Ultra XL PDM. A detailed description of the PDC BHA can be found under Chapter 8. The only adaption made alongside the bit change was a lower HSI (HSI = 1.1) due to different nozzles. Again, the WOB was kept at 5 tons.

9.1.1.2 Performance and performance-related problems

Reed’s MSF 616 M, was able to drill the upper section, where clay marl is dominating, with average 37.4 m/h net ROP being slightly under Smith bit’s five-bladed competitive product. The loss of approximately 5 m/h ROP due to a less aggressive design was expected. Parallel to OKSP-001, at 1620 m MD first conglomerate layers were encountered and the clasts applied strong shocks onto the bit/cutters.

A strong fall-back to 10 m/h was the consequence and the decrease was ongoing and soon to be found at 5 m/h ROP, even in clay marl dominated beddings. The anticipated shock-resistance of the featured dome-topped inserts was lacking. A reduction of the measured vibration was not achieved.

9.1.1.3 Summary

The MSF 616 M drilled 1266 m (from 480 m to 1746 m MD) with an average ROP of 34 m/h. This high value was mainly achieved by the long tangential section with few sliding stages, alike the OKSP-001 run #1. Still, the dulling after the encounter of conglomerates was obvious. Besides, the inserts did not have the effect of improvement with conglomerates-layers. Yet, the performance in the upper section was worse than Smith’s SDSi 519.

9.1.1.4 IADC dull grading

8 6 WT A X 1 RO PR

When being pulled because of a ROP under 3 m/h, the PDC showed severe wear on the cutters at all areas. Additionally, a ring out happened at similarly to OKSP-001 and no conservation of cutting strength due to the dome-topped inserts was observable.

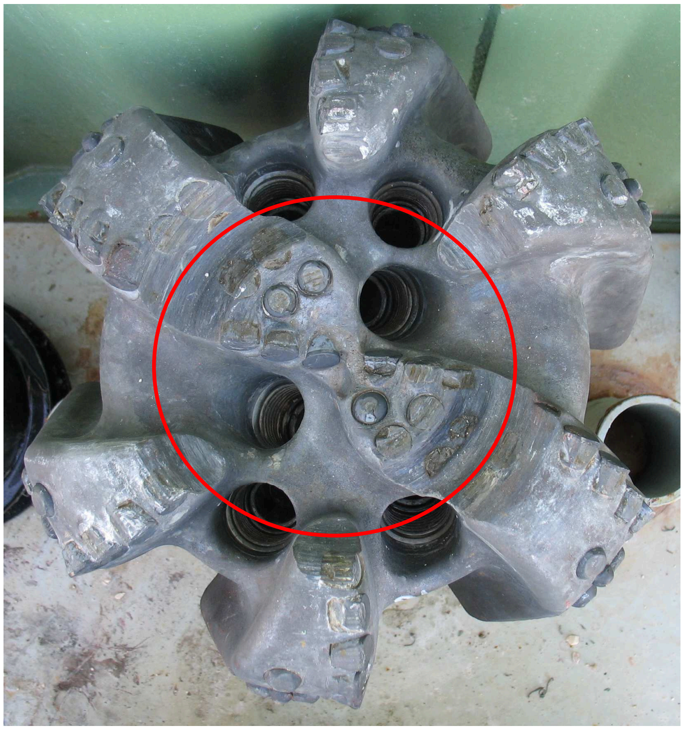


Figure 9.1 – OKSP-002 run #1: ring out after first conglomerate layers; no protection by tome-topped inserts

9.1.2 Run 2 – GF 15 BODVCPS

Regarding OKSP-001 run #2's dull grading, the GF 12 BVECPS showed flat crested wear and broken cutters and as a consequence, a less aggressive bit design was chosen. The Gemini TCI GF 15 BODVCPS has an IADC grading of 447X and thus, should keep the cutting structure longer. Gauge-protection was included as well.

9.1.2.1 Operational Parameters

With a flow-bypass for the roller cone operations the revolutions transmitted by the PDM were reduced again, but else only one feature has been updated.

Due to findings on OKSP-001's run #12, a vibration and torque reduction can be achieved with the installation of a roller reamer. The previous BHA configuration was not changed significantly, only the top stabilizer over the filter sub was exchanged, because during OKSP-001 this stabilizer showed severe wear. Additionally, a pivot-bearing would have the advantage of less counter-torque.

Directional drillers were not pleased with the change in the conventional PDM BHA. 2 main concerns were apparent for Baker Hughes Inteq when changes in the BHA were introduced:

- A pivotable bearing and
- a full-gauge reamer in an under-gauge bottom hole assembly.

First, the rotatable stabilizer would not counteract against torque generated from the bit/BHA. Regular stabilizers are supposed to keep the tool face orientated, but without a fixed point of application, the string can run through and more time would be needed in sliding drilling for orientating. Another disadvantage would be that in sliding drilling, a pivotable roller reamer would miss its purpose. Only during rotary drilling, a roller reamer brings advantages.

The second point of view, which BHI's was concerned about, was the tool's diameter. The conventional PDM bottom hole assembly after BHI guidelines is under-gauge. For the 12 ¼ inch hole, the string stabilizers are 11 $^{15}/_{32}$“ of diameter and thus, a clearance of more than ¾ inch is achieved. This considerable clearance is needed to successfully build up. The roller reamer though was equipped with a diameter of 12 $^{7}/_{32}$” and was considered full-gauge. The directional drillers feared not to be able to build up properly with the top stabilizer being “packed” in the hole.

9.1.2.2 Performance and performance-related problems

The deliberate design of the BHA and the bit did not have results as anticipated. Both, bit design and BHA changes were counterproductive. The rate of penetration dropped significantly during sliding and rotary drilling. The less aggressive bit design was not able to perform at a competitive level. Whilst the GF 12 BVECPS drilled more than 15 m/h average in the beginning, the GF 15 BODVCPS did not make 10 m/h.

Besides, the feared issue with the BHA having an X-like shape, meaning a smaller diameter stabilizer in the center of the BHA and a full-gauge diameter on top of it, demanded longer directional phases to orientate and drill with the desired build up rate. As suspected, the “packed” roller reamer had severe effects on the BHA's geometry.

9.1.2.3 Summary

With only 160 meters drilled (from 1746 m MD to 1906 m MD), the GF 15 BODVCPS fell significantly behind the comparable GF 12 BVECPS, also represented in 5.9 m/h ROP to OKSP-001's 8.5 m/h. In matchable conglomerate layers, and in supposedly the same clay marl layers, the rate of penetration was at least 1.5 m/h lower than before.

Another restriction was the addressed additional time lost for orientation and directional control. 39 % sliding time of the same section at OKSP-001 were outreached with 55 % of time spent without rotating the string.

9.1.2.4 IADC dull grading

3 8 BT H F 5 WT PR

With broken teeth in the heel row, a wear pattern was observed at the GF 15 BODVCPS, similar to OKSP-001's. Yet, the inner cutting structure stayed in good shape. A problem coming along with a worn heel row is the inability to cut sideways and thus, build up. This wear signs describe strong forces on the cones, but mainly for the side and so, with 50.5 hours on bottom, a bearing failure was inevitable.

9.1.3 Run 3 – GF 20 BVCPS

In line with the findings of OKSP-001, a hierarchy for bit selections was decided to go along with the increasing compressive strength. Therefore, a GF 20 BVCPS was picked; the same has already been in use on well #1.

9.1.3.1 Operational parameters

With beginning wear on the motor's bearing stabilizer, a new one was installed in the BHA. With concerns of a bad build up rate, the bent was increased to 1.3° (previous: 1.2°). Yet, the roller reamer was kept in the configuration for further testing. The near-bit stabilizer was left out though, due to signs of wear and with a shorter section from the bent to the bit, it was assumed that the heel row's teeth would face less erosive force.

9.1.3.2 Performance and performance related problems

Even though it was easier to stay on the planned well trajectory and sliding times were reduced, the average ROP fell again. Conglomerate layers did not fit the GF 20 BVCPS's cutter structure as they did the GFi 28 BODVCPS where penetration rates between 7 m/h and 11 m/h were reached. As mentioned, problems with directional drilling were not faced and directional drillers reported less troubles concerning tool face. Presumably, the negative influence of the roller reamer was reduced at 25° inclination.

9.1.3.3 Summary

With only 112 m the GF 20 BVCPS turned out having drilled the lowest meterage, if not pulled due to reaching TD. With a sliding percentage of 56 % across this run, a low ROP was predetermined leaving only 4.2 m/h.

9.1.3.4 IADC dull grading

4 4 WT A E 1 NO PR

With a regular dull grading, the roller cone was pulled out of hole because of the low ROP. With low hours on bottom, 36.5 h, there was no danger of a bearing breakage and all cone bearings were effective.

The initially assumed wrong grading of the bit being too aggressive was corrected after the inspection on surface. A severe dulling was the first impression, when the penetration rate was hardly higher than 3 m/h, but with a dull grading of 4, the cutting structure was still effective.

The weight applied on the bit was constant throughout the run, as far as possible. Downhole measurements would have allowed a close lock to the actually applied force, but costs would have exceeded the budget by far.

A low dull grading in combination with the low penetration rate, allows concluding that an increased friction force significantly reduced the WOB. This means that the force to generate the hole was drastically reduced before reaching the bit and therefore, too little weight acted on the bit itself. Only 2 changes were made from OKSP-001 to OKSP-002 in this depth:

- Installing a PDM with a bent of 1.3° and
- installing RedBack's full-gauge roller reamer.

The additional 0.1° of the bent housing can be neglected leaving the full-gauge roller reamer the reason for the reduction of ROP. Especially during sliding operations, the roller reamer missed its point. Axial movements are not supported by the reamer and consequently without rotations, the reamer increased the friction additionally.

9.1.4 Run 4 – GFS 15 BVCPS

After the first inspection of run #3's TCI dullness, the impression that the GF 20 BODVCPS was too little aggressive was apparent and the decision to run a more aggressive bit was made quickly. The effect of the roller reamer as mentioned in Chapter 9.1.3 was not considered and so a GFS 15 BVCPS was run to achieve better results

9.1.4.1 Operational Parameters

The roller reamer and the trust put into its vibration-reduction were still getting ahead. The BHA was not changed besides the new bit.

9.1.4.2 Performance and performance-related problems

During run #4, the trend prolonged and ROP was low. Steerability (ease to orientate and hold the tool face) though seemed better. An untypical appearance was the increased vibration measured during the whole run. Axial, lateral and stick-slip levels were increased, but only observed after the 12 ¼ inch section.

9.1.4.3 Summary

120 m (from 2018 m MD to 2138 m MD) did not represent a good performance and 3.9 m/h were below average. Directional control was improved though and did not give a reason to change. Main consideration for the low ROP was the formation with a big percentage of clay marl.

9.1.4.4 IADC dull grading

3 4 FC A 7 1 NO HR

The GFS 15 BVCPS was pulled due to hours on bottom (49.5 h), but low signs of wear were observable. Flat crested wear across all cutting structures seem that the depth of cut was not at its optimum. This conclusion leads to the same reason as in the previous run, where additional friction was reducing the WOB significantly and the 15 tons were not reached.

9.1.5 Run 5 – GFi 23 BODVCPS

With an expected large percentage of coarse sandstone, the choice for run #5 fell onto a GFi 23 BODVCPS with an IADC grading of 517X. But the bit’s grade was not only chosen because of the expected sandstone, it was also considered a testing run. The result should provide an alternative solution to the GFi 28 BODVCPS with a higher ROP.

9.1.5.1 Operational Parameters

No changes were made, neither in the BHA nor in the parameters, because after consulting with the directional drillers, steerability was satisfying and the performance-drop was not yet pinned down to a specific problem.

9.1.5.2 Performance and performance-related problems

Encountering a high alternation of lithologies, the main beddings drilled were sandstone. No problems were faced in this run, and the choice was good. Only one big layer of clay marl was encountered generating difficulties to perform. Other smaller interbeddings were easily coped with, and the majority of conglomerates and sandstone were fitting the bit’s grade. Constant penetration rates throughout the whole run were reassuring.

9.1.5.3 Summary

After having drilled 157 meters, from 2138 m MD to 2295 m MD, the meterage was seen as an upward trend. With 4 m/h, equally distributed over the bit’s lifetime, the cutters design of the bit was considered appropriate for the lithologies encountered. 57 % of sliding did not significantly lower the performance and only the massive clay marl layer with 72 % sliding allowed a performance drop that was noticeable with an ROP of only 2.6 m/h.

9.1.5.4 IADC dull grading

2 3 WT A 7 1 NO HR

Low signs of wear and the stable shape of the cutters reassure the constant rate of penetration. Being pulled due to hours also goes conform to the bearing wear of 7. No spring back and easily movable cones picture the grading. Yet, flat wear at the cutters allow a parallel assumption to the previous run, where an insufficient weight on bit reached the bit. Presumably, the appointed 15 tons did not reach the bit to their fullest.

9.1.6 Run 6 – GFS 20 BVCPS

With low signs of dullness on the GFi 23 BODVCPS cutter, the GFS 20 BVCPS was chosen to achieve a higher ROP. Also, there was no other choice on site.

9.1.6.1 Operational Parameters

To see the effect of the roller reamer through, no adjustments in the BHA were made. The post-job analysis was planned to break the effect down.

9.1.6.2 Performance and performance-related problems

With a very little sliding time, high rotary percentages would suggest a proper ROP, yet only in a sandstone package the bit was able to keep up with the expectations. Other layers were drilled with a constantly low penetration rate.

9.1.6.3 Summary

Besides the outstanding 7.5 m/h in the sandstone package, the GFS 20 BVCPS hardly reached 3.5 m/h. With 90% drilled in rotary, the bad ROP was surprising. With no reported problems, there was no ad hoc explanation for a low penetration rate. With only 140 meters drilled, casing setting depth was not reached and an additional bit run needed to be done.

9.1.6.4 IADC dull grading

3 3 WT A 4 1 BT HR

The wear, documented at the bit, was flat and slight gauge rounding was apparent. Still, with comparatively little wear, a more aggressive bit design seemed applicable.

On behalf of the similar signs of wear, the problem later appeared not to be the bit's grading and more the insufficient weight reaching the bit.

9.1.7 Run 7 – GFS 20 BVCPS

An additional run was needed to reach the casing setting depth due to the insufficient meterage of all roller cone runs. The GFS 20 BVCPS was the last bit on site and thus, chosen to drill the missing 30 meters.

9.1.7.1 Operational Parameters

No changes were made for the fill-in run.

9.1.7.2 Performance and performance-related problems

With the goal of reaching casing setting depth and not drilling through the impermeable clay marl layer, performance was not the highest priority hence, the ROP was low.

9.1.7.3 Summary

As already mentioned, the bit run #7 was needed because of the loss of meterage in the previous runs. 30 meters to the casing setting depth of 2465 m MD were drilled slowly. Only 2.75 m/h in mainly clay marl formations are evidence of a careful hole generation.

9.1.7.4 IADC dull grading

2 2 NO A 2 1 NO TD

With merely 30 meters drilled, and being pulled due to reaching total depth, no real dulling happened.

9.2. 8 ½ inch section

A necessary cost reduction due to the overshoot of OKSP-001, implied a different strategic concerning the RSS section being the biggest cost driver. BHI's steering element with the combined X-treme Modular motor, a positive displacement motor, in the horizontal section for reservoir navigation increased the costs drastically. For an onshore operation daily costs (neglecting standby and maintenance costs) 12,260 € for the AutoTrak steering element and 5,190 € for the PDM were a bold down hole configuration, neglecting the necessary navigational MWD/LWD tools. With a need for cutting down costs, the 8 ½ inch section was divided into 3 subdivisions:

- Conventional directional BHA (PDM with a bent housing),
- RSS without the PDM and
- RSS with both, steering and power unit.

The conventional section was planned to be drilled out of the casing shoe since no reservoir-dependent directional drilling was needed. The casing shoe, set at 75° inclination, demanded only a similar trajectory, build and azimuthal direction, to the 12 ¼ inch section, hence the build up to horizontal can be easily performed by a conventional directional bottom hole assembly with a PDM with a bent housing.

For reservoir navigation (inclination and azimuth) and even more to get a smooth well path, the RSS was needed. So, as seen in OKSP-001 the torque issues were not faced until reaching a large offset. Therefore, the needed PDM behind the steering unit was expandable. The BHA was planned to be powered only by the top drive.

When the offset tends to increase torque to a level not applicable by both, top drive and drill pipes, the Modular motor is needed to absorb part of the induced torque, especially the one coming from the bit. But since this version of the BHA is the most expensive one, it was planned to be only used for the last sections.

9.2.1 Run 8 – MSF 616 M-A2B

Expecting long distances drilled in clay marl layers, a PDC bit was the best choice. Reed's six-blader with the dome-topped inserts was picked up and run because of its impact resistance if minor conglomerate layers are encountered. For run #8, OKSP-001's MSF 616 M-A2B was repaired and reused (double-checked with the serial number).

9.2.1.1 Operational Parameters

As mentioned in Chapter 9.2, the BHA was designed conventionally for the reason of cost reduction. The PDM, which was installed, added 0.1 revolutions per liter pumped.

But, a for the pump range in this section, 640 liters were bypassed by a valve. Consequently, 120 to 160 rpm's were added to the top drive's 60 to 70 revolutions per minute. As usual for a PDC, a weight on bit of about 5 to 10 tons was applied. Yet, frequent peaks of 15 tons were recorded as well. A roller reamer was not integrated into the BHA,

9.2.1.2 Performance and performance-related problems

With long distances in clay marl packages, the PDC was performing decently. The penetration rate decreased constantly though, but conglomerates did not seem to break the cutting structure significantly. The assumption for clasts having decreased in size and showing sandstone-like properties was fortified. The longer section in conglomerate was considered the minor reservoir with conglomerate/sandstone properties.

The change from the powered RSS to the conventional directional assembly did not have any bad influence. In combination with the PDC, no restrictions were limiting the time on bottom. Further, the build rate needed to hit the horizontal reservoir path was easy to reach. With only minor sliding sections long rotary times were possible.

9.2.1.3 Summary

26% sliding time display the little build rate remaining, which was needed in the first subdivision, and supported the change of the BHA. 236 meters drilled with an average ROP of 7 m/h were considered satisfying. The long sections in clay marl were drilled with more than 8 m/h on average and even conglomerates were drilled with 5 m/h. The MSF 616 M-A2B proved being impact resistant in coarse sandstone, respectively conglomerate, and perform adequately in clay marl layers.

9.2.1.4 IADC dull grading

4 7 NO A X 2 NO PR

After more than 70 meters in conglomerate, the bit showed expected signs of wear. The long distance in the minor layer (conglomerate/sandstone) wore off the cutters significantly reducing the penetration rate drastically. Hence, when the ROP dropped to about 2 m/h, the bit was pulled.

9.2.2 Run 9 – FH 35 VPS

Being consistent with the cost reduction plan, the rotary steerable system was assembled for run #9 without the power unit (X-treme Modular motor). The top drive was allocated to transmit the RPM and the torque. With good experiences from OKSP-001, the FH 35 VPS was picked.

9.2.2.1 Operational Parameters

Without the PDM providing the majority of RPM, the top drive was run with 120 revolutions per minute. Reservoir navigation was secured by BHI's RSS. Other parameters, such as the pump pressure, pump rate or WOB, were kept similar to previous runs, respectively roller cones in the 8 ½ inch section. Only the roller reamer has been integrated into the BHA again.

9.2.2.2 Performance and performance-related problems

The first and most interesting revelations was that with less revolutions at the bit, bit life was significantly increased without losing penetration rate. Despite the fact that the majority of the distance drilled in this run was in clay marl, comparable penetration rates were achieved, considering offset values of OKSP-001, where the RSS was used combined with the PDM power unit. Yet, a torque increase was noticeable with the BHA modification from run #8 to run #9, despite the change from a PDC to a roller cone and the additional pivot bearing of the roller reamer.

Another benefit of the modified BHA was the possibility of a faster MWD/LWD. While in the reservoir navigation tool was about 12 meters behind the bit in the "old" assembly, the left out PDM allowed measurements closer to the bit, at around 5 meters. Consequently, faster reacting to lithological changes was enabled.

When considering VSS measurements, two things were obvious. On the one hand, axial vibration was reduced after implementing the roller cone and on the other hand, lateral movements were reduced as well (Figure 9.2). Both phenomena can be linked to the lithological change from coarse sandstone to clay marl, but also the offset of the bent housing in run #8 added irregularities in the string. With an RSS, the bit stands straight on bottom.

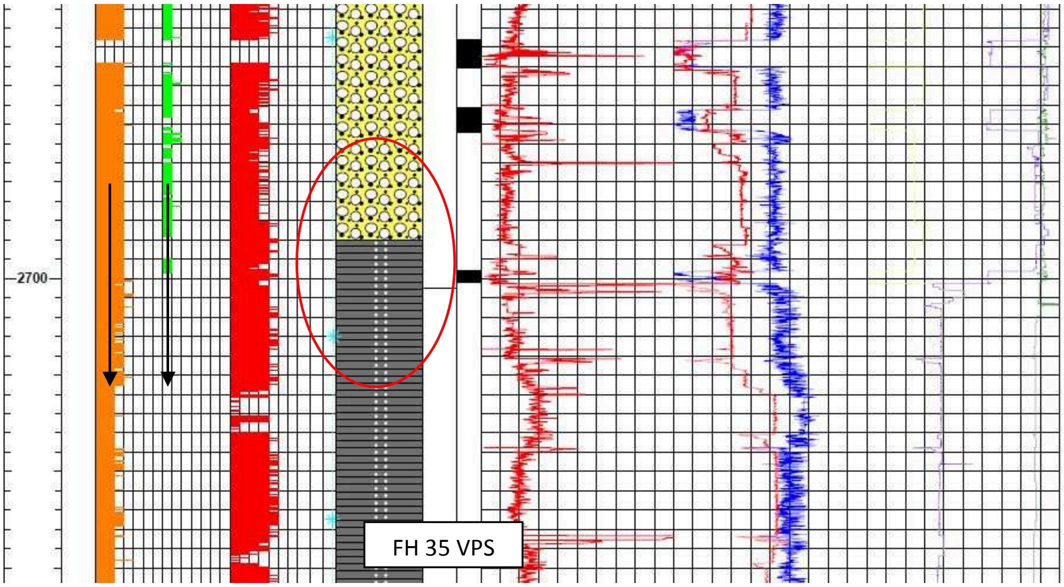


Figure 9.2 – OKSP-002 run #9: change in VSS after installing BHI's RSS head

9.2.2.3 Summary

From 2702 m MD to 2949 m MD, the FH 35 VPS made 247 meters (11 m more than during run #8). A rate of penetration of 4.7 m/h is comparable to OKSP-001's 5 m/h (run #7), respectively 6.6 m/h (run #9). But while during the two runs of OKSP-001 mainly conglomerates were encountered, OKSP-002's run #9 faced nearly 240 meters clay marl.

9.2.2.4 IADC dull grading

1 1 NO A E 1 NO HR

The long distances covered in clay marl rarely had any effects on the bit's cutting structure. The bit was pulled due to hours, but effective bearings suggest a longer bit run would have been possible.

9.2.3 Run 10 – MSF 6161 M-A2B

Since during run #9 the majority of distance was drilled in clay marl layers, the well site geologist strongly recommended the implementation of another PDC after the evaluation of cuttings and the seismic data. With an inclination of 93° the same clay marl package was expected.

9.2.3.1 Operational Parameters

Parameters for this run were not changed, since experiences from the previous run did not demand for adaption.

9.2.3.2 Performance and performance-related problems

Unexpectedly, the clay marl layer was already near to being drilled through, and thus, the PDC hit an abrasive conglomerate layer. The penetration rate fell immediately. After the problems encountered in the conglomerate layer, the PDC was pulled out of hole, just when hitting another clay marl package.

9.2.3.3 Summary

With only 93 meters drilled (from 2949 m MD to 3042 m MD), the MSF 616 M-A2B was clearly misapplied. Being pulled before severe dullness would occur, run #10 was considered failed. Yet, as to be found out later, two larger clay marl packages were about to be encountered. Pulling out of hole was the conservative option to avoid damage beyond repair.

9.2.3.4 IADC dull grading

1 1 NO A E 1 NO HR

The low meterage was also reflected on the bit's dull grading, when only minor wear was visible. The 45 m conglomerate section had no bad influence on the cutting structure and further use would have been promising.

9.2.4 Run 11 – FHi 28 ODV

After the presumed misapplication of the PDC, a roller cone bit was pushed into the focus again. With the low IADC dull grading of the FH 35 VPS, a more aggressive TCI was chosen to increase the rate of penetration. IADC grading of 527X represent a soft TCI designed for high ROP's.

9.2.4.1 Operational parameters

With only minor changes (different nozzles reduced the HSI by 0.1), drilling parameters were basically untouched.

9.2.4.2 Performance and performance-related problems

As previously mentioned, the lithology encountered first, was clay marl. And after a conglomerate section and another clay marl layer, the reservoir layer of conglomerate was drilled. In conglomerate, the TCI performed as well as expected. After all, the aggressive roller cone was an adequate pick.

9.2.4.3 Summary

With 293 m drilled, the FH 28 ODV reached the highest meterage, where 200 meters were conglomerate. During 68 hours on bottom, this bit allowed a ROP of about 5.1 m/h. With the need of reservoir navigation and thus drill through both reservoir sections, inclination changed between 89° and 93°, but no problems were caused by the chosen well path.

9.2.4.4 IADC dull grading

3 4 BT H E 2 FC HR

With a soft grade, the FH 28 ODV achieved a high meterage and was pulled due to hours. Besides, the dull grading showed that the soft IADC grade was right. Broken teeth on the bit's heel and flat crested wear were only minor dulling considering the abrasiveness of the conglomerate encountered during drilling other sections.

9.2.5 Run 12 – FH 35 ODV

Due to the amount of bits ordered, Smith bit's FH 28 ODV was not available anymore and the FH 35 ODV was run. The appealing performance from OKSP-001 induced planning to stack more of them.

9.2.5.1 Operational parameters

With torque peaks not exceeding the pipe's limitations, another run without the power unit was possible. 38,000 Nm were the limit for the pipe.

9.2.5.2 Performance and performance-related problems

Long sections in the conglomerate reservoir layer combined with the low revolutions at the bit allowed high meterage. The only clay marl encountered was because of navigating to the upper minor reservoir.

9.2.5.3 Summary

Little losings in the rate of penetration with a considerably longer bit life enabled the FH 35 ODV to drill 228 meters. An average of above 4 m/h was achieved with the two long sections, which were 37 m and respectively 120 m, in the coarse sandstone or conglomerate of the reservoirs.

9.2.5.4 IADC dull grading

3 3 FC A 7 1 NO HR

Minor signs of wear reflect the assumption that the FH 35 ODV's grade was too high and that a more aggressive bit would have achieved better results. Yet, the performance can be regarded as good.

9.2.6 Run 13 – FH 35 ODV

Similar restrictions on behalf of the stored bits governed the bit selection for run #13.

9.2.6.1 Operational parameters

With torque values reaching the 38,000 Nm limit, the X-treme Modular motor was installed in the bottom hole assembly again. MWD/LWD tools were put back again and reservoir navigation was more difficult. Yet, the power unit was needed to provide the revolutions at the bit and carry part of the loads. With the PDM, additional rpm's were generated, 0.05 revolutions per liter pumped.

9.2.6.2 Performance and performance-related problems

The maximum allowable torque was not reached anymore. The PDM worked as planned and ROP was increased as well. But, a limiting factor returned – the number of total revolutions and with additional 100 revolutions per minute, the bit lasted less long.

9.2.6.3 Summary

The additional rpm's enabled the bit to drill on average 1 m/h faster than in the previous run (5.2 m/h), but with additional 100 revolutions per minute, its life time was drastically reduced from 71 hours (run #12) to 37 hours. Consequently, the total distance drilled was reduced to 159 meters (from 3563 m MD to 3722 m MD). This finding will be issued later to lead to one of the main improvements.

9.2.6.4 IADC dull grading

3 3 FC A 7 2 NO HR

In the same lithology, the FH 35 ODV showed similar signs of wear, besides the higher rpm's. The minor dulling allows the assumption, parallel to run #12, that a lower grade a higher ROP would have been possible.

9.2.7 Run 14 – FH 30

The final run was done to gain more knowledge about the reservoir. The last remaining bit was used which was not equipped with diamond gauge protection (ODV).

9.2.7.1 Operational parameters

In the last run, parameters were kept the same.

9.2.7.2 Performance and performance-related problems

The main purpose for run #14 was to discover the extents of the storage layer. The reached offset was the biggest one ever drilled within RAG. Unfortunately, the reservoir section pointed out quickly and the majority of the meterage was performed in a tight clay marl layer.

9.2.7.3 Summary

After 158 meters drilled, TD was reached at 3880 m measure depth. With nearly 4.8 m/h, the FH 30's penetration rate was reduced by the large clay marl section. The more aggressive design (IADC grade of 537X) would have reached a high ROP in conglomerates with 6.4 m/h.

9.2.7.4 IADC dull grading

2 2 NO A E 1 NO HR

After drilling 115 meters in clay marl, the dulling was not as progressed as in previous runs. The cutting structure and bearings were still effective and the reason pulled besides hours, were torque peaks of 38,000 Nm despite the use of the X-treme Modular motor.

9.3. Lessons learned from OKSP-002

Similar tools (Chapter 7) as for OKSP-001 have been used for the interpretation of OKSP-002. In both sections, the 12 ¼ inch and the 8 ½ inch section, seven bit runs were necessary to reach target depth, neglecting the milling runs as done at the OKSP-001.

Oberkling well #2 revealed new challenges and proved previous assumptions wrong. With an additional run in the 12 ¼ inch section, the improvement that was hoped for was missed. A new angle for an optimization was found during the 8 ½ inch section of OKSP-002, where a segmenting into three different divisions illustrated the revised performance enhancement for upcoming wells.

9.3.1 Summary of the 12 ¼ inch section

A similar trajectory of the well (Chapter 3) with only minor changes did not imply strong changes of the BHA. Moderate build rates allowed the use of the conventional directional assembly. As mentioned in Chapter 8.3.3, the PDC for the top section with nearly exclusively clay marl was equipped with dome-topped impact inserts to withstand the abrasive conglomerate interbeddings. Yet, the result was not as expected and a similar ring out destroyed the bit beyond repair.

One problem defined during evaluation OKSP-001 was vibration. Installing a RedBack roller reamer was a try to allow smooth running of the bit and a significant torque reduction. A negative side effect of a full-gauge reamer within the BHA has not been considered and therefore, the change flopped and caused an additional run. The pivotable bearing increased steerability and reduced torque, but the full-gauge nature of the roller reamer fixed the bearing and disabled proper build rates. As a consequence, a higher sliding percentage reduced the meterage significantly in run #2 and run #3. The lost meters were not to be retrieved in the upcoming runs and a seventh run was needed.

Further, the bit hierarchy (Chapter 8.3.3) was not followed. A try-and-error procedure was used and so, “15-20-15-23-20-20” regime displays the imbalance and troubles with the lithology. Run #3 (“20”) and run #5 (“23”) show that harder formations were expected, but softer grading in the succeeding runs illustrate only minor signs of wear and low penetration rates.

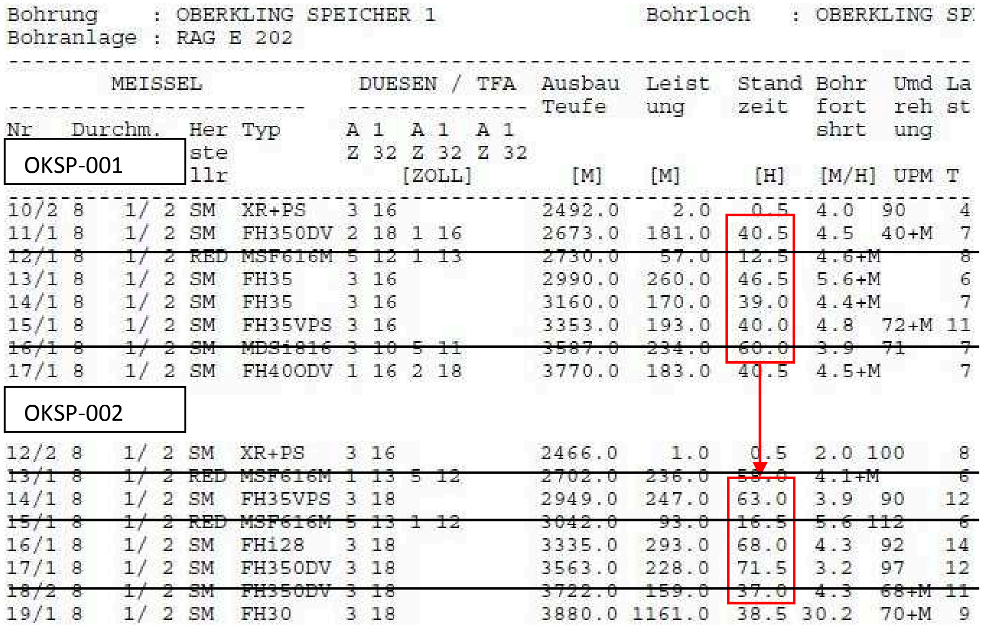
9.3.2 Summary of the 8 ½ inch section

With the rotary steerable system being a major cost driver, an alternative solution was found to drill the horizontal section. Three subdivisions were formed with each different bottom hole assemblies.

The first assembly was a conventional PDM assembly and combined with a PDC, no life time restrictions were apparent. The low costs of the conventional system were the main decision criteria. The build rate required to reach 90° inclination was easily accomplished.

The second division would be the one with the biggest influence on future recommendations. The implementation of the RSS head without the PDM power unit revealed a quality that started a new way of thinking in the Oberkling Speicher project. Originally, the X-treme Modular motor was left out, due to its considerable day rate. With the possibility to rotate the string by the top drive without restraints, the “reduced” RSS was a feasible alternative.

Soon it was clear, that without the additional downhole revolutions by the PDM, the average life time of a TCI roller cone (Figure 9.3 - red rectangle) was increased by more than 60 % without a significant decrease in ROP leading to an increased meterage per run.



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Bohrung     : OBERKLING SPEICHER 1              Bohrloch    : OBERKLING SP
Bohranlage  : RAG E 202
------------------------------------------------------------------------
        MEISSEL              DUESEN / TFA  Ausbau  Leist  Stand Bohr  Umd La
-----------------------    --------------- Teufe   ung    zeit  fort  reh st
Nr   Durchm.     Her Typ     A 1  A 1  A 1                      shrt  ung
OKSP-001         ste         Z 32 Z 32 Z 32
                 llr              [ZOLL]       [M]     [M]     [H]  [M/H] UPM T
------------------------------------------------------------------------
10/2 8    1/ 2 SM  XR+PS   3 16            2492.0    2.0   0.5  4.0  90    4
11/1 8    1/ 2 SM  FH350DV 2 18 1 16       2673.0  181.0  40.5  4.5  40+M  7
~~12/1 8    1/ 2 RED MSF616M 5 12 1 13       2730.0   57.0  12.5  4.6+M       8~~
13/1 8    1/ 2 SM  FH35    3 16            2990.0  260.0  46.5  5.6+M       6
14/1 8    1/ 2 SM  FH35    3 16            3160.0  170.0  39.0  4.4+M       7
15/1 8    1/ 2 SM  FH35VPS 3 16            3353.0  193.0  40.0  4.8  72+M 11
~~16/1 8    1/ 2 SM  MDSi816 3 10 5 11       3587.0  234.0  60.0  3.9  71    7~~
17/1 8    1/ 2 SM  FH40ODV 1 16 2 18       3770.0  183.0  40.5  4.5+M       7
OKSP-002

12/2 8    1/ 2 SM  XR+PS   3 16            2466.0    1.0   0.5  2.0 100    8
~~13/1 8    1/ 2 RED MSF616M 1 13 5 12       2702.0  236.0  58.0  4.1+M       6~~
14/1 8    1/ 2 SM  FH35VPS 3 18            2949.0  247.0  63.0  3.9  90   12
~~15/1 8    1/ 2 RED MSF616M 5 13 1 12       3042.0   93.0  16.5  5.6 112    6~~
16/1 8    1/ 2 SM  FHi28   3 18            3335.0  293.0  68.0  4.3  92   14
17/1 8    1/ 2 SM  FH350DV 3 18            3563.0  228.0  71.5  3.2  97   12
~~18/2 8    1/ 2 SM  FH350DV 3 18            3722.0  159.0  37.0  4.3  68+M 11~~
19/1 8    1/ 2 SM  FH30    3 18            3880.0 1161.0  38.5 30.2  70+M  9
```

Figure 9.3 – Comparison of the 8 ½ inch bit life times from OKSP-001 and OKSP-002

The final section, run #13 and run #14, required the power unit, because the drill pipe's yield did not allow exceeding 38,000 Nm. But, with only 2 runs with the complete rotary steerable system, cost reduction was effective.

9.3.3 Recommendations

As mentioned, the installation of the roller reamer in the 12 ¼ inch section is considered failed, because the effect was an additional trip. Yet, the 8 ½ inch section split-up ended in a cost reduction and gave insight into a new approach to increase the roller cones' performance. Baker Hughes Inteq's rotary steerable system was disjointed on behalf of cost reduction but the concluding results display a success on top of it. As already mentioned, the RSS without the power unit was considered a success.

For the other wells planned in the Oberkling area and the Pfaffstätt campaign, a bottom hole assembly with the "reduced" RSS should be taken into consideration. The increased bit life and the higher meterage as a consequence allow contemplating the more expensive solution. Another benefit of using the RSS powered by the top drive is the straight loads acting on the bit. Without the bent housing of the conventional directional system, side loads on the bearings reduce the risk of breakage and increase the number of total revolutions additionally (Chapter 10.1.3).

The increased costs of a RSS in comparison to the conventional PDM assembly need to be reviewed. The additional charge of the highly sophisticated steering head needs to break even with the low costs of the other BHA. Comparing the two possibilities is performed in Chapter 10.1.4, where the rig rate needed by additional trips is opposed to the day rates of BHI’s RSS service.

10. Conclusion

The hands-on character of this thesis asked for quick results to be easily applied. As mentioned, a tight budget also prohibited more detailed down hole evaluations. As discussed below, the detailed evaluation of down hole data was crossed out with extensive costs for BHI's CoPilot tool. Nevertheless, with given means applicable results have been realized and have found approval by the engineers in charge.

10.1. Discussion

10.1.1 Data quality

In times, where computers become more and more part of drilling operations, data acquisition in a manner to satisfy demands of a drilling engineer must not be for discussion. Measurement, interpretation and storage should be easily realizable. Relevant data measured at the rig should be of a high density to fully understand operations and allow improvement. In order to measure down hole activities thoroughly, tools such as BHI's CoPilot can be of great value for a precise evaluation of processes acting on our equipment.

Still, such tools, for an exact analysis of drilling performance, are very expensive and thus, rarely applicable in onshore operations. The value added by evaluating detailed data does not economically break even with the aligned costs coming along with renting the needed tools. The monetary cost-benefit calculation did not suggest a try run in the Oberkling gas storage campaign.

An offer by Baker Hughes Inteq was considered but turned down, due to insufficient funds available. For both sections, the 12 ¼ and the 8 ½ inch section, BHI offered the CoPilot tool for € 5,980.00.- per day. With average rig costs of € 35,000.00.- per day, including day rates and services, energy costs and drilling mud, the benefit of applying the tool does simply not exceed its costs.

10.1.2 Parameters considered, but neglected

During the work on this thesis, several parameters have been reviewed and considered to play a role in the evaluation of the bits' performances. The ones applied have been discussed throughout this thesis, but this does not mean, that no other options were taken into consideration. But with the stated problems encountered as mentioned in Chapter 10.1.1 and the non-consideration of an accurate down hole measurement tools, mechanical specific energy (MSE) did not play any role. The computation of MSE demanded accurate values of weight on bit (WOB) and down hole torque at the bit. Neither was possible to be computed and thus, the inevitable lack of correctness led to neglecting this opportunity, especially, because a computed correlation between the MSE and the penetration rate could not be achieved.[14]

$$MSE = \frac{4 \times WOB}{\pi \times D^2} + \frac{480 \times (N + K_N \times Q) \times \left(\left(\frac{T_{Max}}{\Delta P_{Max}} \right) \times \frac{\Delta P}{1000} \right)}{D^2 \times ROP}$$

Equation 10.1 – Mechanical Specific Energy with a mud motor in use[6]

- MSE - Mechanical Specific Energy [ksi]
- WOB - weight on bit [klbs]
- D - bit diameter [in]
- N - rotary speed [RPM]
- T - torque [kft-lb]
- ROP - penetration rate [ft/hr]
- K_N - mud motor ratio [rev/gal]
- Q - total mud flow rate [gal/min]
- T_{Max} - maximum rated torque (motor) [ft-lb]
- P_{Max} - maximum differential pressure (motor) [psi]
- P - differential pressure [psi]

Even though WOB is represented in the two generated logs, its channel needs to be considered carefully. The inevitable inaccuracy when re-setting the measurements is a human factor which must not be underestimated. Hence, the channel gives a general trend, yet computations on its basis are not recommended. Torque and drag have been provided by BHI, but without the input on the friction factor from the neglected pick-up and slack-off tests, the computation provided did not play any role in the thesis' scope. A consistent monitoring of valuable parameters was not given and thus, a lot of information lost. The engineering approach was in this case neglected and substantial knowledge on friction and WOB was lost.

Drilling is still an operation performed by humans and the oil industry is known to be a conservative one. To find the optimum WOB, a drill-off-test (DOT) gives a clear indication. With the inaccuracy of WOB and directional drillers' "best practice" guidelines for BHI's down hole tools, a DOT was not performed.

The hydraulic horse power per square inch (HSI) was indeed considered throughout the entire thesis. Any significant optimization was prohibited though by the system's restrictions. The two pumps were not able to improve the pressure losses at the bit and increase the HSI. As mentioned in Chapter 8.1.1.1, 260 bar per pump limited the system significantly and especially in the 12 ¼ inch section an HSI of only 1.5 (average) was achieved.

10.1.3 Induced side forces on the bit

A bent housing in a conventional BHA composition bears another problem, rarely addressed to. With problems at hand of seal failure and loose cones, an additional parameter must exist. After disassembling the bit in Smith bits' reliability center and discussing the seal breakage with the reliability engineer, another question arose. Vibration induced by the clasts of coarse sandstone / conglomerate increase wear, but patterns in which cones get lifted off their legs led to investigating the side forces acting on the bit.

With average 15 tons WOB (pre-set by the driller), even small angles might bear excessive loads on each cone and accelerating damage. As discussed earlier in this chapter, the actual weight acting on the bit was not known because of neglecting an approach where detailed torque and drag evaluation would have been considered.

Especially, if weight on bit varies strongly and vibration faced as in conglomerates enables highly fluctuating loads - not to speak of loads in a deviated well, where the well's geometry and stabilizers act as a fulcrum and increase the loads even more. A simple trigonometric evaluation shows how the WOB in a bent housing BHA applies loads on the bit's side.

With the sinusoidal-function the percentage of load acting on the bit's side can be computed. Without considering shock-induced fluctuations or an inclined well deflecting the WOB even more, these loads acting side-ways can be an additional cause of early bit-breakage.

$$F_{side} = F_{vertical} \times \sin\theta_{bent}$$

Equation 10.2 – Trigonometrically computed side force

The interesting parameter is θ_{bent} and with a pre-set bent housing of 1.2° or 1.3°, the resulting force is a small, but not negligible fraction of the vertical loading of the WOB. With a bent housing of

- 1.2° => 2.1% act sideways,
- 1.3° => 2.3% act sideways.

Now, as said, roughly 2% are not too much, but with shocks, where the average WOB is exceeded, and the constant average of 300 N as estimated (referring to 15 tons WOB), wear and especially seal breakage is accelerated.

Comparison of conventionally applied bits and bits used with a rotary steerable system shows that seal breakage is more likely in the first application.

10.1.4 Financial Evaluation

An omnipresent factor in every drilling campaign is budget. With very little or no room for additional costs, an evaluation of the financial situation is inevitable. With the hands-on character of the thesis a *quick* evaluation is needed to allow a quick implementation of the result. In both options, cost effectiveness must have the highest priority and therefore, comparing the day rates is performed. The conventional way with a PDM with a bent housing is opposed to the suggested solution with the RSS steering unit. In the latter case, the power unit is left out, because as witnessed in

OKSP-002’s 8 ½ inch section (Chapter 9.3.2) the lower downhole RPM allow longer bit runs without reducing the penetration rate significantly.

Costs and day rates are taken from Baker Hughes Inteq’s offer for their directional drilling services. As for the day rate of RAG’s E 202 rig, an average value is used which is suggested by the project leader’s operating experience. Additional rates for servicing and standby can be neglected due to contractual agreements with the service provider.

Day rates:

- Rig - € 35,000.00.-
- BHI’s conventional PDM BHA incl. NaviGamma MWD - € 8,400.00.-
- BHI’s RSS steering unit incl. NaviGamma MWD - € 16,000.00.-
- BHI’s OnTrak MWD/LWD - € 4,300.00.-

The different options are evaluated for the 12 ¼ inch section, and durations of roller cones for the section were 21 and respectively 23 days. For a conservative approach, an ideal duration of 20 days is used for the conventional assembly and the TCI application. Standby rates and service rates are neglected, since the costs are assumed minor compared to the day rates. The first PDC run is not considered in the evaluation process due to its application in the both scenarios. The OnTrak tool with its azimuthal gamma ray measurements is planned to be run in the last 250 meters for finding the right casing setting depth.

Another assumption made is the drilling hours per day. In both situations, 6 hours per shift are assumed being below average of OKSP-001 and OKSP-002 and thus conservative. Hence, the bits’ life is seen to be over after 3 days with 54 hours drilling. This is considered above average for the conventional case. Tripping time is anticipated with 1 day per run. With 5 runs (3 with NaviGamma and 2 with OnTrak) casing setting depth is planned to be reached and costs are computed as follows.

$$Costs_{conventional} = 20 \times rate_{rig} + 12 \times rate_{PDM\,\&\,NaviGamma} + 8 \times rate_{PDM\,\&\,OnTrak} \approx \text{€}902{,}400.00.-$$

Equation 10.3 – Rough estimate of costs for conventional BHA

Without the additional revolutions and RPM only provided by the top drive, the bit's life is supposed to be increased up to 78 hours, whilst still being conservative (< 450,000 total revolutions). Penetration rates for the estimate of the RSS option are used from average values of OKSP-001 and OKSP-002 to begin with. The average value then is decreased with the ongoing drilling by 0.5 m/h per day. Average values are used as starting values for the RSS computation:

- Run 1 - 5 m/h
- Run 2 - 3.5 m/h
- Run 3 - 3.5 m/h

With a lower benchmark of 2.5 m/h which should not be under run, 3 runs are expected to be sufficient to make the required 780 meters. Similar to the prior option, 1 day is anticipated for tripping.

$$Costs_{RSS-option} = 15 \times rate_{rig} + 10 \times rate_{RSS\,\&\,NaviGamma} + 5 \times rate_{RSS\,\&\,OnTrak} \approx €786{,}500.00.-$$

Equation 10.4 – Rough estimate of costs for the RSS-BHA

After a quick evaluation of the costs in both options, the conservative approach suggests the try of the reduced rotary steerable option. Possible savings of ~ €115,000.00.- imply the step to change the PDM for the more expensive RSS tool. Potential savings of fewer bits in use have not yet been considered and an increase of total revolutions to Smith bits' specifications of the bit due to loads acting axial is yet to be found.

Nevertheless, the nature of the estimate is to give a quick overview of the expected costs and must not be seen as a detailed financial evaluation, since the complexity of cost planning in drilling projects exceeds the scope of this thesis.

10.2. Recommendation

In succeeding projects in comparable regions, the first bit run can be done conventionally with Smith bits' five-bladed PDC. Reed's dome-topped inserts could not withstand the conglomerates and the penetration rate was lower than with Smith bits' SDSi 519.

As for the roller cones' IADC grade, a more aggressive bit design is advisable. The dulling of OKSP-001's GFi 12 BVECPS (Chapter 8.1.2) is acceptable and the high ROP is favorable. There is no need for a bit pulled out of hole, where the cutting structure is in good condition, but the run lacks meterage.

As a recommendation, softer TCI's should bring high penetration rates and are to be preferred. With an IADC grade of 517X, the GFi 20 BODVCPS should be the toughest bit, which did not face any problems with the conglomerate throughout any of the runs and clay marl layers have been drilled moderately.

The 8 ½ inch section is considered optimized, especially because the upcoming wells will not have an offset as long as OKSP-002. For example, OKSP-003 with 3500 m MD will not require the last division and the X-treme Modular motor can be spared. The combination of the classical directional assembly with a PDC can also be considered as good, since high running speeds of the motor do not affect the life time of a PDC. The RSS without the power unit should be used for roller cone bit runs in order to reach long running times and a high meterage.

The FH 35 ODV bits performed well and thus, can be run again. But, on behalf of the intact cutting structure, a softer TCI should be tried and revised for a higher ROP. Smith bits' FH 28 ODV is a bit with an IADC grade of 527X and is advisable for a test run.

Considering the advantages of a rotary steerable system where RPM is provided by the top drive, roller cones' applications shall be run with such a BHA configuration. The PDM option is favorable for PDC runs, where no limitations due to the number of total revolutions are present. Even with a conservative approach, the more expensive option shows can be considered more cost-effective in the end, still neglecting other advantages, such as preferable loading of the bit (axial).

List of Figures

List of Equations

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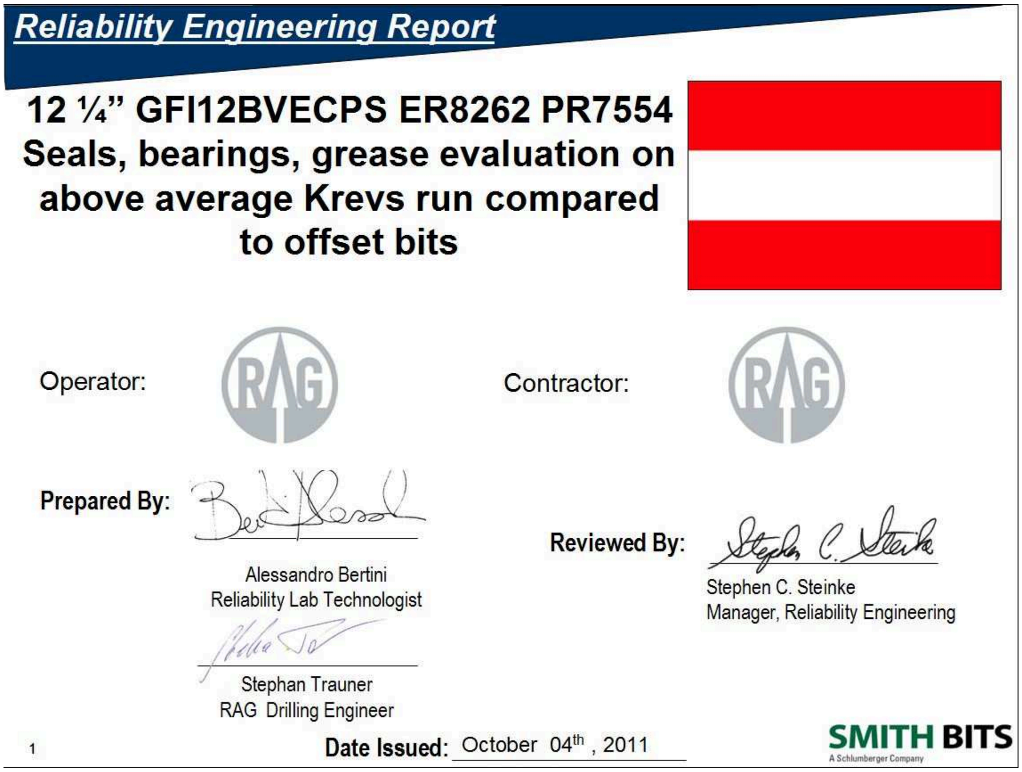
APPENDIX A – Smith Bits’ Reliability Engineering Report



Reliability Engineering Report

12 ¼” GFI12BVECPS ER8262 PR7554 Seals, bearings, grease evaluation on above average Krevs run compared to offset bits

Operator: RAG

Contractor: RAG

Prepared By:

Alessandro Bertini
Reliability Lab Technologist

Stephan Trauner
RAG Drilling Engineer

Reviewed By:

Stephen C. Steinke
Manager, Reliability Engineering

Date Issued: October 04th , 2011

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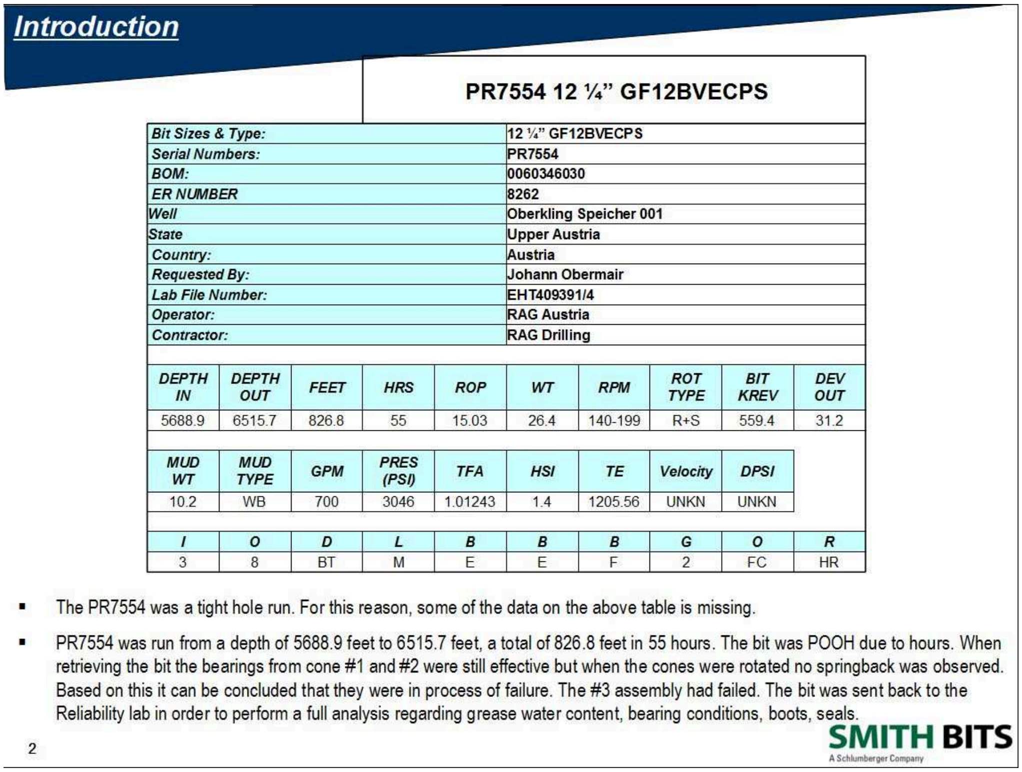

Introduction

PR7554 12 ¼” GF12BVECPS

Bit Sizes & Type:	12 ¼” GF12BVECPS
Serial Numbers:	PR7554
BOM:	0060346030
ER NUMBER	8262
Well	Oberkling Speicher 001
State	Upper Austria
Country:	Austria
Requested By:	Johann Obermair
Lab File Number:	EHT409391/4
Operator:	RAG Austria
Contractor:	RAG Drilling

DEPTH IN	DEPTH OUT	FEET	HRS	ROP	WT	RPM	ROT TYPE	BIT KREV	DEV OUT
5688.9	6515.7	826.8	55	15.03	26.4	140-199	R+S	559.4	31.2

MUD WT	MUD TYPE	GPM	PRES (PSI)	TFA	HSI	TE	Velocity	DPSI
10.2	WB	700	3046	1.01243	1.4	1205.56	UNKN	UNKN

I	O	D	L	B	B	B	G	O	R
3	8	BT	M	E	E	F	2	FC	HR

- The PR7554 was a tight hole run. For this reason, some of the data on the above table is missing.
- PR7554 was run from a depth of 5688.9 feet to 6515.7 feet, a total of 826.8 feet in 55 hours. The bit was POOH due to hours. When retrieving the bit the bearings from cone #1 and #2 were still effective but when the cones were rotated no springback was observed. Based on this it can be concluded that they were in process of failure. The #3 assembly had failed. The bit was sent back to the Reliability lab in order to perform a full analysis regarding grease water content, bearing conditions, boots, seals.

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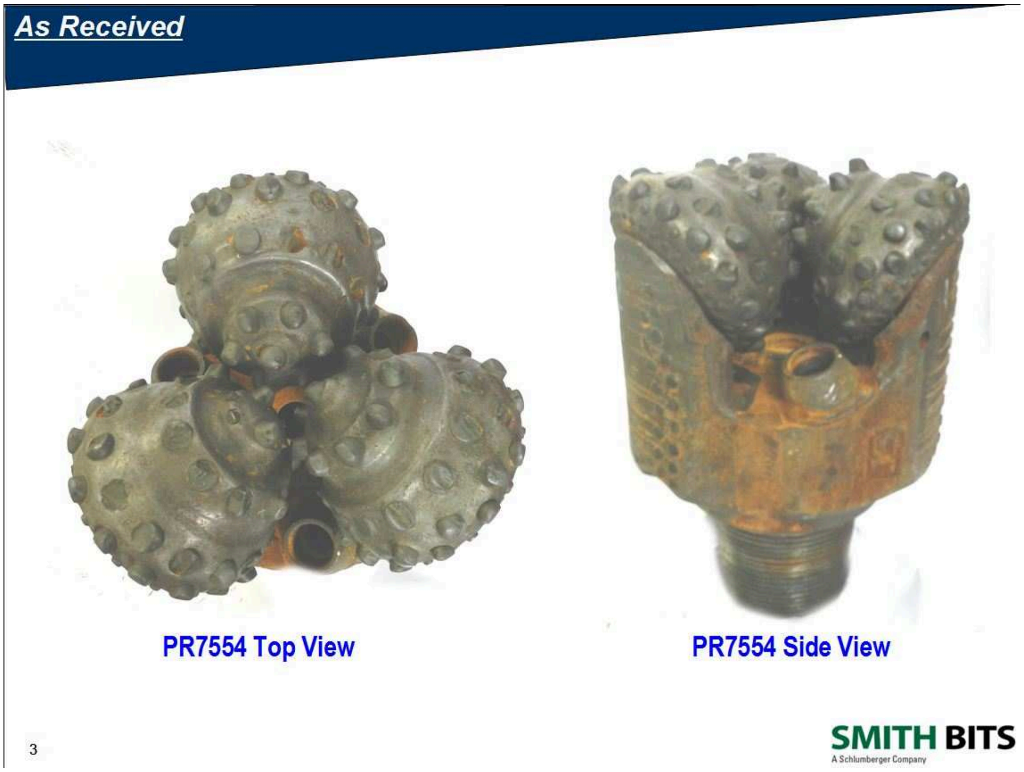

As Received

PR7554 Top View

PR7554 Side View

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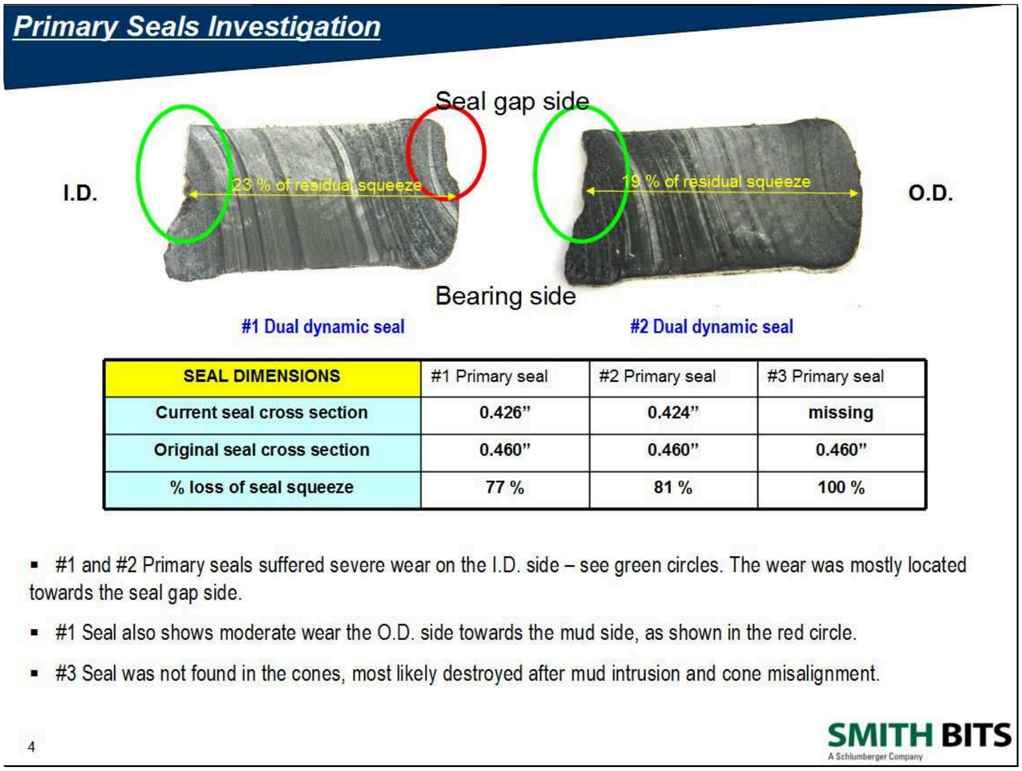

Primary Seals Investigation

Seal gap side

I.D.

23 % of residual squeeze

19 % of residual squeeze

O.D.

Bearing side

#1 Dual dynamic seal

#2 Dual dynamic seal

SEAL DIMENSIONS	#1 Primary seal	#2 Primary seal	#3 Primary seal
Current seal cross section	**0.426”**	**0.424”**	**missing**
Original seal cross section	**0.460”**	**0.460”**	**0.460”**
% loss of seal squeeze	**77 %**	**81 %**	**100 %**

- #1 and #2 Primary seals suffered severe wear on the I.D. side – see green circles. The wear was mostly located towards the seal gap side.
- #1 Seal also shows moderate wear the O.D. side towards the mud side, as shown in the red circle.
- #3 Seal was not found in the cones, most likely destroyed after mud intrusion and cone misalignment.

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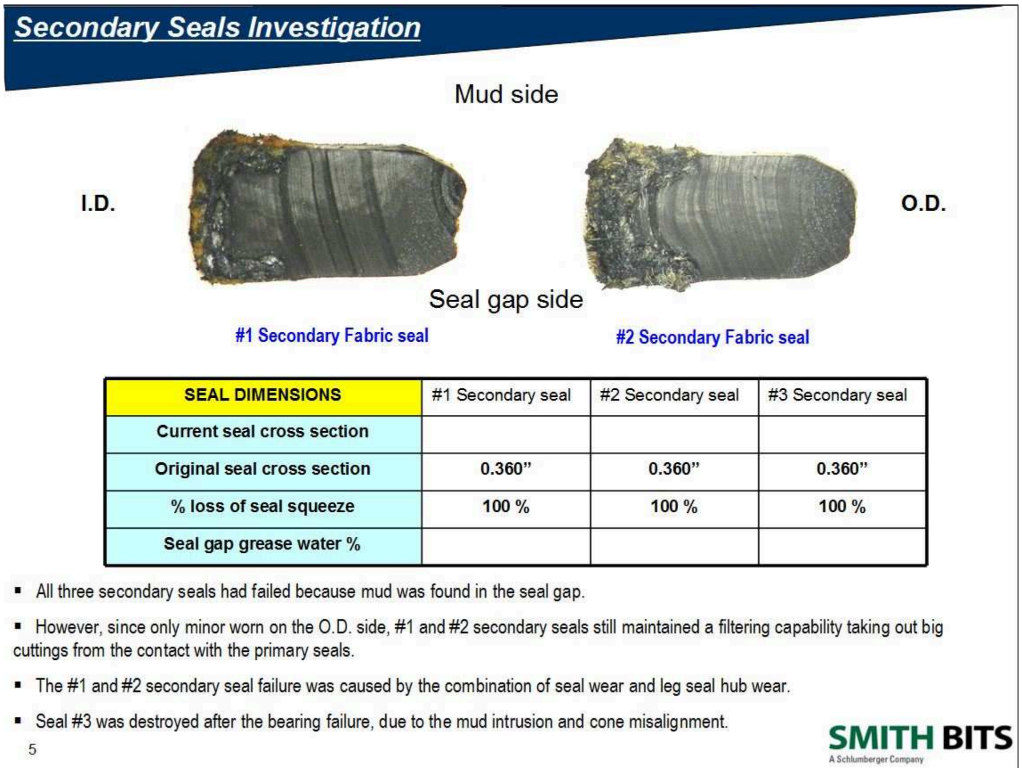

Secondary Seals Investigation

Mud side

I.D.

O.D.

Seal gap side

#1 Secondary Fabric seal

#2 Secondary Fabric seal

SEAL DIMENSIONS	#1 Secondary seal	#2 Secondary seal	#3 Secondary seal
Current seal cross section			
Original seal cross section	0.360"	0.360"	0.360"
% loss of seal squeeze	100 %	100 %	100 %
Seal gap grease water %			

- All three secondary seals had failed because mud was found in the seal gap.
- However, since only minor worn on the O.D. side, #1 and #2 secondary seals still maintained a filtering capability taking out big cuttings from the contact with the primary seals.
- The #1 and #2 secondary seal failure was caused by the combination of seal wear and leg seal hub wear.
- Seal #3 was destroyed after the bearing failure, due to the mud intrusion and cone misalignment.

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Legs Investigation

#1 leg bearing

#2 leg bearing

#3 leg bearing

- #1 and #2 legs were in good condition and suffered no wear.
- When #1 and #2 legs were measured, all the dimensions were found to be within the required specification.
- **#3 leg suffered severe wear on the loading side due to cone misalignment after seal/bearing failure.**
- **Legs #1 and #2 suffered moderate wear on the secondary seal hub, caused by sliding action of the secondary seals fabric embedded with cutting particles.**

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Cone Bearings Investigation

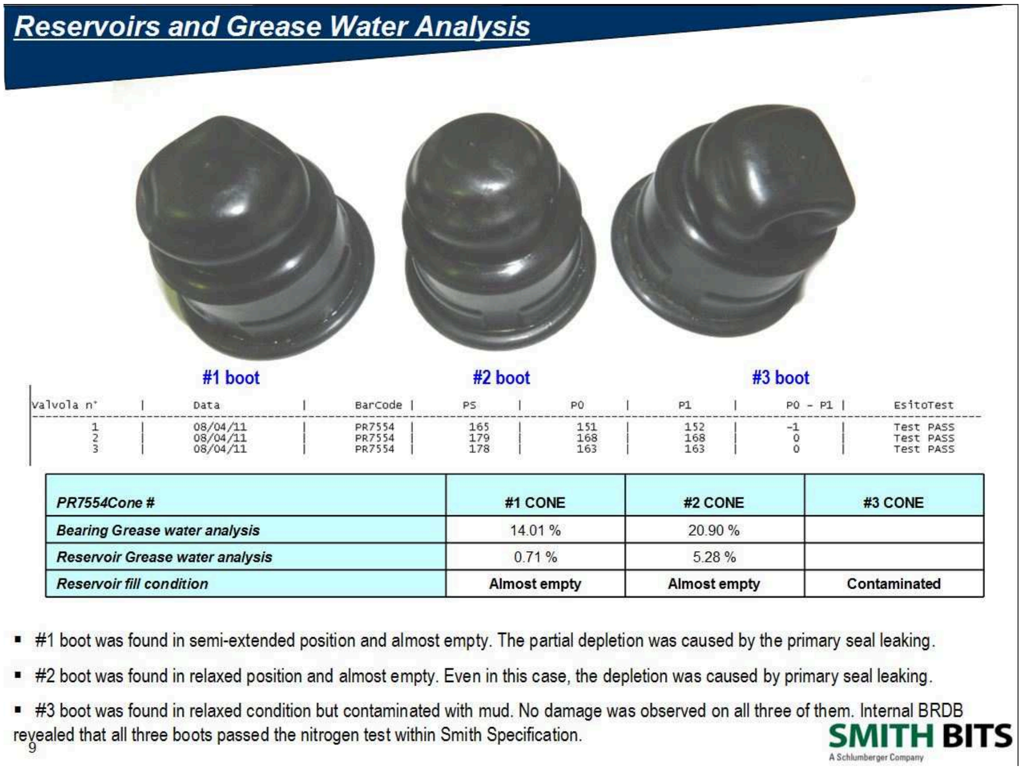
#1 cone bearing **#2 cone bearing** **#3 cone bearing**

- #1 and #2 cone bearings were in good condition and suffered no wear.
- Measured dimensions on cones #1 and #2 revealed no wear. All the dimensions were within the required specification.
- **#3 cone showed minor wear due to cone misalignment and mud intrusion.**

Thrust Washers Investigation

#1 internal components **#2 internal components** **#3 internal components**

- #1 and #2 cone internal components showed no signs of wear.
- #3 bearing sleeve was not found in the bearing because it was destroyed after the seal failure due to mud intrusion and cone misalignment.



Reservoirs and Grease Water Analysis

```
Valvola n°    |    Data     |   BarCode |   PS   |   P0   |   P1   |  P0 - P1 |   EsitoTest
-------------------------------------------------------------------------------------------
         1    |  08/04/11   |   PR7554  |  165   |  151   |  152   |    -1    |   Test PASS
         2    |  08/04/11   |   PR7554  |  179   |  168   |  168   |     0    |   Test PASS
         3    |  08/04/11   |   PR7554  |  178   |  163   |  163   |     0    |   Test PASS
```

PR7554Cone #	#1 CONE	#2 CONE	#3 CONE
Bearing Grease water analysis	14.01 %	20.90 %	
Reservoir Grease water analysis	0.71 %	5.28 %	
Reservoir fill condition	**Almost empty**	**Almost empty**	**Contaminated**

- #1 boot was found in semi-extended position and almost empty. The partial depletion was caused by the primary seal leaking.
- #2 boot was found in relaxed position and almost empty. Even in this case, the depletion was caused by primary seal leaking.
- #3 boot was found in relaxed condition but contaminated with mud. No damage was observed on all three of them. Internal BRDB revealed that all three boots passed the nitrogen test within Smith Specification.

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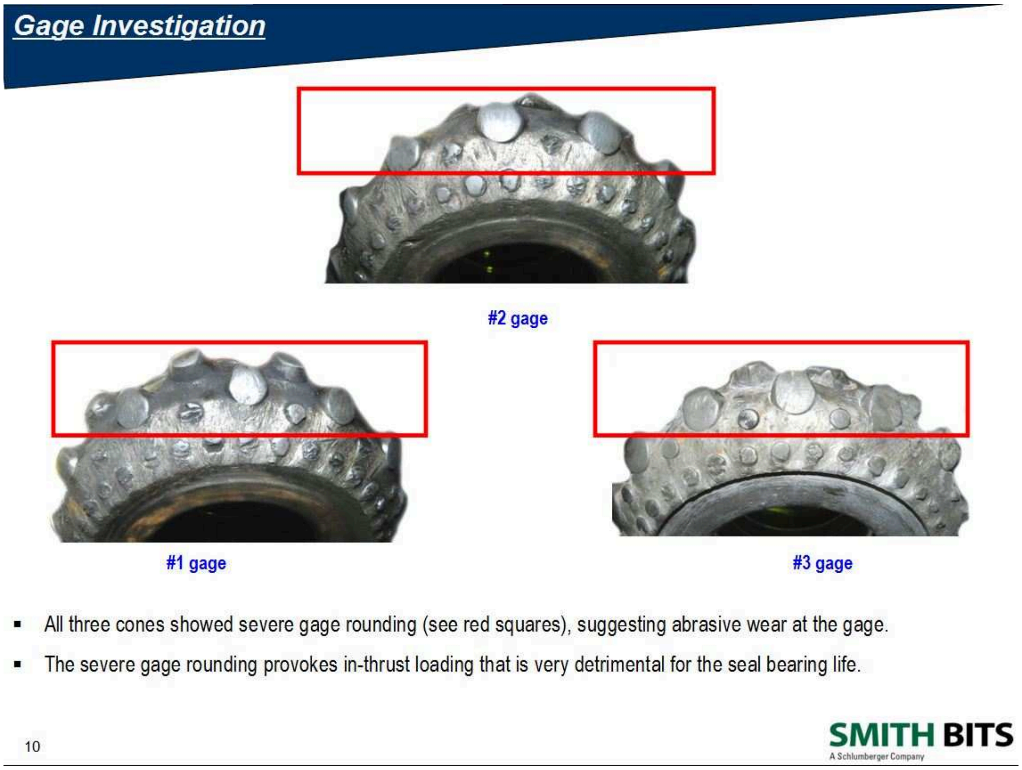

Gage Investigation

- All three cones showed severe gage rounding (see red squares), suggesting abrasive wear at the gage.
- The severe gage rounding provokes in-thrust loading that is very detrimental for the seal bearing life.

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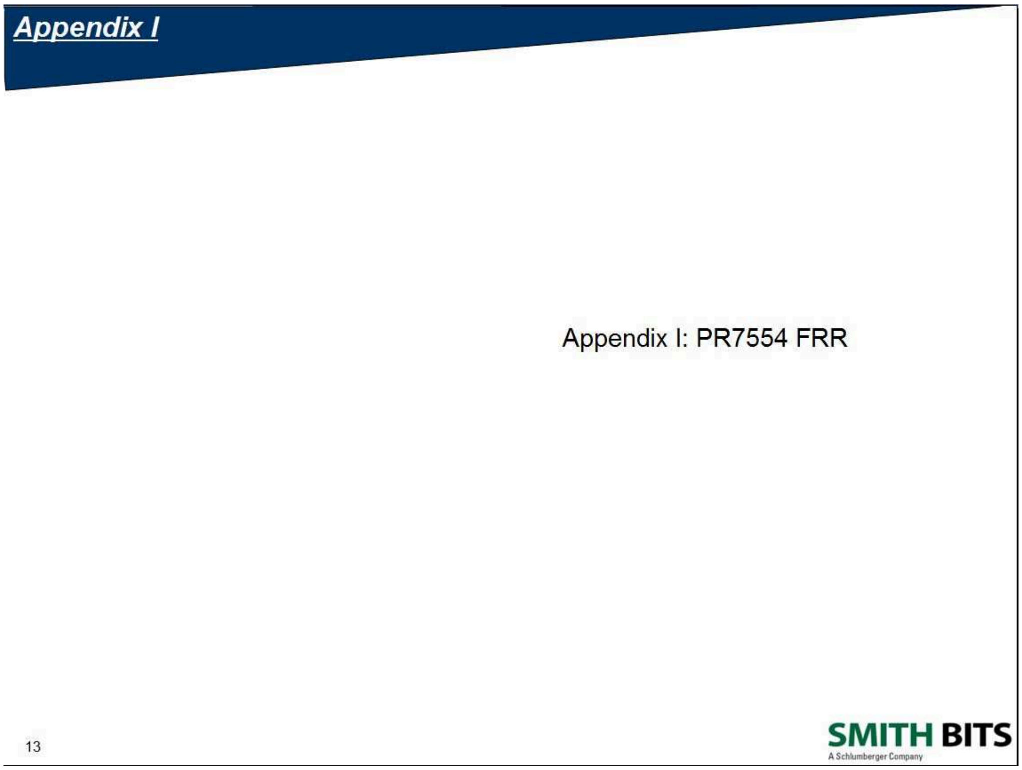
Cutting Structure Investigation

- Inner row cutting structure was severely broken.
- Severe breakage was most likely caused by vibration and bouncing due to drilling in conglomerate formation.

Conclusion

- **Based on the results of this investigation and on the past experience, one can conclude that the #3 assembly failure was caused by primary seal wear.**
- **The #3 seal bearing failure was accelerated by gage rounding, inner cutting structure breakage and low HSI.**
- **The #1 and #2 assemblies still have grease in the bearings, but since high water % was found during the grease water analysis, they were in process of failure.**
- **Based on the results of this investigation, no material or manufacturing non conformances were found to be related to the #3 seal/bearing failure.**
- **All three legs have deep grooves worn between the p-feature inserts. This was most likely caused by the bit lying on its side in the 31 degree deviation, abrasive formation.**



Appendix I

Appendix I: PR7554 FRR

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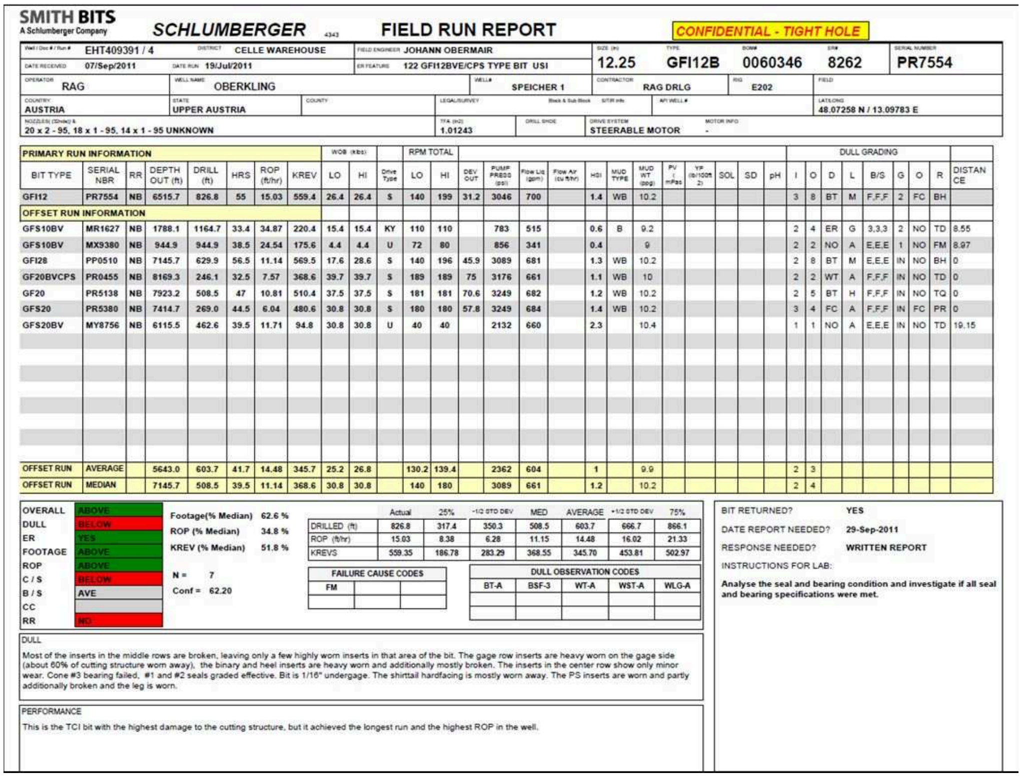


SMITH BITS A Schlumberger Company **SCHLUMBERGER** 4343 **FIELD RUN REPORT** **CONFIDENTIAL - TIGHT HOLE**

Well / Doc # / Run #	EHT409391 / 4	DISTRICT	CELLE WAREHOUSE	FIELD ENGINEER	JOHANN OBERMAIR	SIZE (in)	TYPE	BOM#	ER#
DATE RECEIVED	07/Sep/2011	DATE RUN	19/Jul/2011	ER FEATURE	122 GFI12BVE/CPS TYPE BIT USI	12.25	GFI12B	0060346	8262

SERIAL NUMBER: PR7554

OPERATOR	RAG	WELL NAME	OBERKLING	WELL#	SPEICHER 1	CONTRACTOR	RAG DRLG	RIG	E202

FIELD:

COUNTRY: AUSTRIA
STATE: UPPER AUSTRIA
COUNTY:
LEGAL/SURVEY: Block & Sub Block S/T/R info
API WELL #:
LAT/LONG: 48.07258 N / 13.09783 E
NOZZLES (32nds) &: 20 x 2 - 95, 18 x 1 - 95, 14 x 1 - 95 UNKNOWN
TFA (in2): 1.01243
DRILL SHOE:
DRIVE SYSTEM: STEERABLE MOTOR
MOTOR INFO: -

PRIMARY RUN INFORMATION								WOB (klbs)			RPM TOTAL														DULL GRADING								
BIT TYPE	SERIAL NBR	RR	DEPTH OUT (ft)	DRILL (ft)	HRS	ROP (ft/hr)	KREV	LO	HI	Drive Type	LO	HI	DEV OUT	PUMP PRESS (psi)	Flow Liq (gpm)	Flow Air (cu ft/hr)	HSI	MUD TYPE	MUD WT (ppg)	PV (mPas	YP (lb/100ft 2)	SOL	SD	pH	I	O	D	L	B/S	G	O	R	DISTANCE
GFI12	PR7554	NB	6515.7	826.8	55	15.03	559.4	26.4	26.4	S	140	199	31.2	3046	700		1.4	WB	10.2						3	8	BT	M	F,F,F	2	FC	BH	
OFFSET RUN INFORMATION																																	
GFS10BV	MR1627	NB	1788.1	1164.7	33.4	34.87	220.4	15.4	15.4	KY	110	110		783	515		0.6	B	9.2						2	4	ER	G	3,3,3	2	NO	TD	8.55
GFS10BV	MX9380	NB	944.9	944.9	38.5	24.54	175.6	4.4	4.4	U	72	80		856	341		0.4		9						2	2	NO	A	E,E,E	1	NO	FM	8.97
GFI28	PP0510	NB	7145.7	629.9	56.5	11.14	569.5	17.6	28.6	S	140	196	45.9	3089	681		1.3	WB	10.2						2	8	BT	M	E,E,E	IN	NO	BH	0
GF20BVCPS	PR0455	NB	8169.3	246.1	32.5	7.57	368.6	39.7	39.7	S	189	189	75	3176	661		1.1	WB	10						2	2	WT	A	F,F,F	IN	NO	TD	0
GF20	PR5138	NB	7923.2	508.5	47	10.81	510.4	37.5	37.5	S	181	181	70.6	3249	682		1.2	WB	10.2						2	5	BT	H	F,F,F	IN	NO	TQ	0
GFS20	PR5380	NB	7414.7	269.0	44.5	6.04	480.6	30.8	30.8	S	180	180	57.8	3249	684		1.4	WB	10.2						3	4	FC	A	F,F,F	IN	FC	PR	0
GFS20BV	MY8756	NB	6115.5	462.6	39.5	11.71	94.8	30.8	30.8	U	40	40		2132	660		2.3		10.4						1	1	NO	A	E,E,E	IN	NO	TD	19.15
OFFSET RUN	AVERAGE		5643.0	603.7	41.7	14.48	345.7	25.2	26.8		130.2	139.4		2362	604		1		9.9						2	3							
OFFSET RUN	MEDIAN		7145.7	508.5	39.5	11.14	368.6	30.8	30.8		140	180		3089	661		1.2		10.2						2	4							

OVERALL	ABOVE
DULL	BELOW
ER	YES
FOOTAGE	ABOVE
ROP	ABOVE
C / S	BELOW
B / S	AVE
CC	
RR	NO

Footage(% Median)	62.6 %
ROP (% Median)	34.8 %
KREV (% Median)	51.8 %
N =	7
Conf =	62.20

	Actual	25%	-1/2 STD DEV	MED	AVERAGE	+1/2 STD DEV	75%
DRILLED (ft)	826.8	317.4	350.3	508.5	603.7	666.7	866.1
ROP (ft/hr)	15.03	8.38	6.28	11.15	14.48	16.02	21.33
KREVS	559.35	186.78	283.29	368.55	345.70	453.81	502.97

FAILURE CAUSE CODES		
FM		

DULL OBSERVATION CODES				
BT-A	BSF-3	WT-A	WST-A	WLG-A

BIT RETURNED?	YES
DATE REPORT NEEDED?	29-Sep-2011
RESPONSE NEEDED?	WRITTEN REPORT

INSTRUCTIONS FOR LAB:

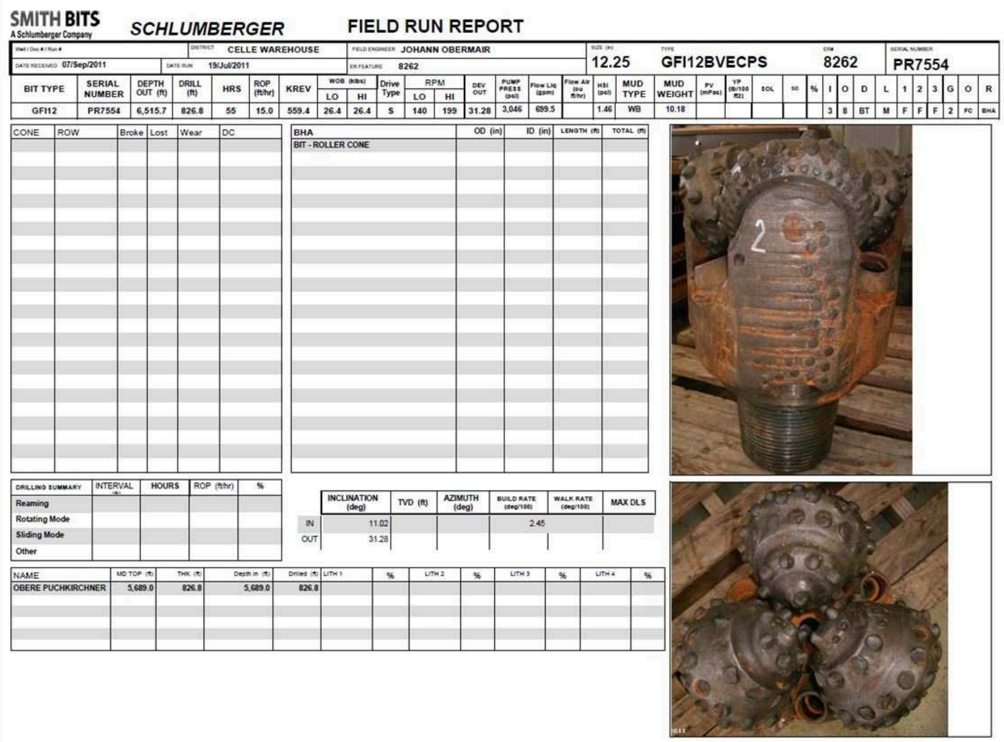
Analyse the seal and bearing condition and investigate if all seal and bearing specifications were met.

DULL

Most of the inserts in the middle rows are broken, leaving only a few highly worn inserts in that area of the bit. The gage row inserts are heavy worn on the gage side (about 60% of cutting structure worn away), the binary and heel inserts are heavy worn and additionally mostly broken. The inserts in the center row show only minor wear. Cone #3 bearing failed, #1 and #2 seals graded effective. Bit is 1/16" undergage. The shirttail hardfacing is mostly worn away. The PS inserts are worn and partly additionally broken and the leg is worn.

PERFORMANCE

This is the TCI bit with the highest damage to the cutting structure, but it achieved the longest run and the highest ROP in the well.



SMITH BITS
A Schlumberger Company

SCHLUMBERGER

FIELD RUN REPORT

Well / Doc # / Run #
DISTRICT CELLE WAREHOUSE
FIELD ENGINEER JOHANN OBERMAIR
DATE RECEIVED 07/Sep/2011
DATE RUN 19/Jul/2011
ER FEATURE 8262
SIZE (in) 12.25
TYPE GFI12BVECPS
ER# 8262
SERIAL NUMBER PR7554

BIT TYPE	SERIAL NUMBER	DEPTH OUT (ft)	DRILL (ft)	HRS	ROP (ft/hr)	KREV	WOB (klbs)		Drive Type	RPM		DEV OUT	PUMP PRESS (psi)	Flow Liq (gpm)	Flow Air (cu ft/hr)	HSI (psi)	MUD TYPE	MUD WEIGHT	PV (mPas)	YP (lb/100 ft2)	SOL	SD	%	I	O	D	L	1	2	3	G	O	R
							LO	HI		LO	HI																						
GFI12	PR7554	6,515.7	826.8	55	15.0	559.4	26.4	26.4	S	140	199	31.28	3,046	699.5		1.46	WB	10.18						3	8	BT	M	F	F	F	2	FC	BHA

CONE	ROW	Broke	Lost	Wear	DC

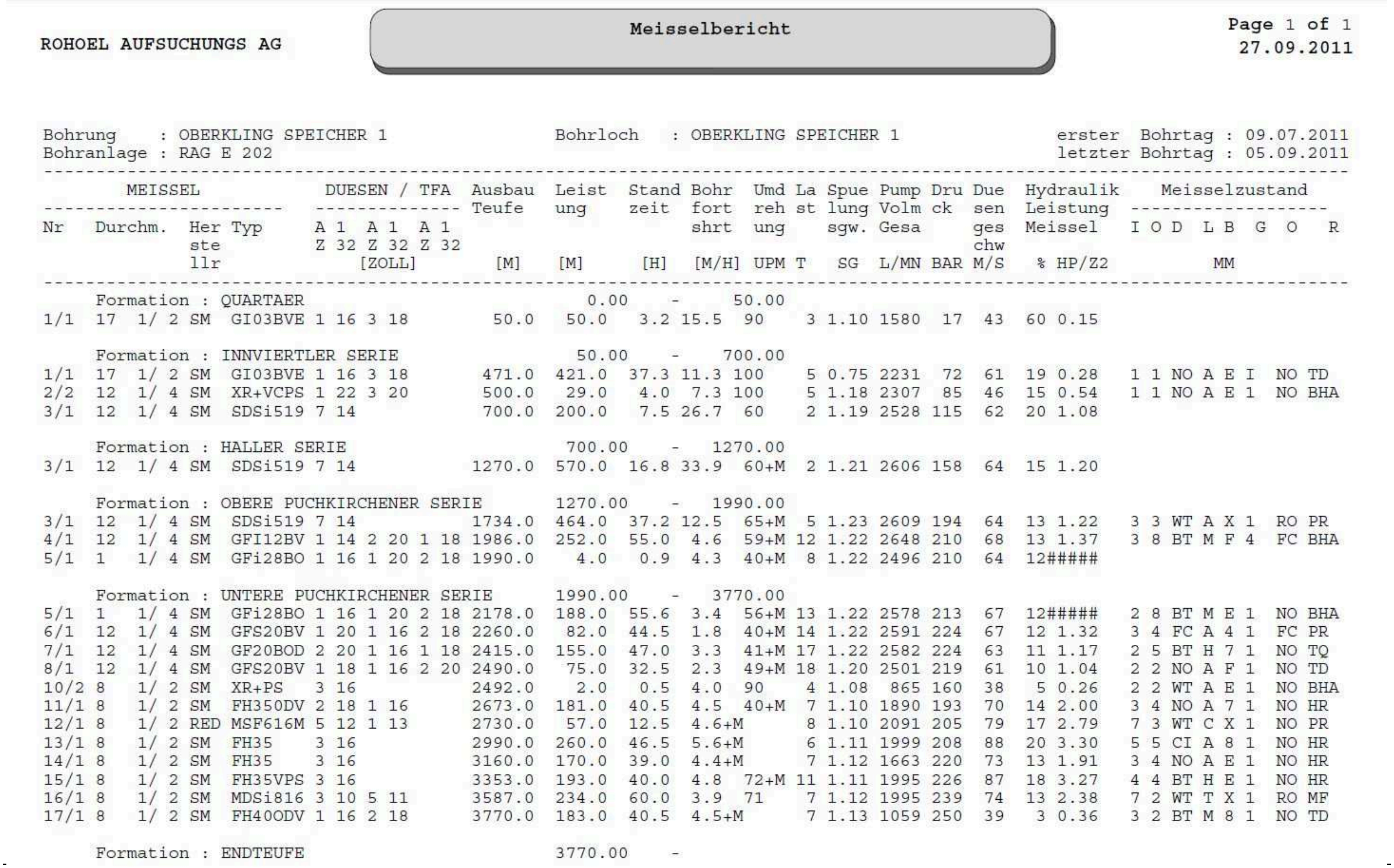
BHA	OD (in)	ID (in)	LENGTH (ft)	TOTAL (ft)
BIT - ROLLER CONE				

DRILLING SUMMARY	INTERVAL (ft)	HOURS	ROP (ft/hr)	%
Reaming				
Rotating Mode				
Sliding Mode				
Other				

	INCLINATION (deg)	TVD (ft)	AZIMUTH (deg)	BUILD RATE (deg/100)	WALK RATE (deg/100)	MAX DLS
IN	11.02			2.45		
OUT	31.28					

NAME	MD TOP (ft)	THK (ft)	Depth in (ft)	Drilled (ft)	LITH 1	%	LITH 2	%	LITH 3	%	LITH 4	%
OBERE PUCHKIRCHNER	5,689.0	826.8	5,689.0	826.8								

APPENDIX B – RAG’s PVSS bit reports - OKSP-001 & OKSP-002



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ROHOEL AUFSUCHUNGS AG                 Meisselbericht                          Page 1 of 1
                                                                               27.09.2011

Bohrung     : OBERKLING SPEICHER 1              Bohrloch    : OBERKLING SPEICHER 1           erster  Bohrtag : 09.07.2011
Bohranlage : RAG E 202                                                                        letzter Bohrtag : 05.09.2011
------------------------------------------------------------------------------------------------------------------------------
        MEISSEL              DUESEN / TFA Ausbau  Leist   Stand Bohr  Umd La Spue Pump Dru Due  Hydraulik    Meisselzustand
----------------------    -------------- Teufe   ung     zeit  fort  reh st lung Volm ck  sen  Leistung   -------------------
Nr   Durchm.  Her Typ     A 1  A 1  A 1                         shrt  ung    sgw. Gesa     ges  Meissel    I O D  L B  G  O   R
              ste         Z 32 Z 32 Z 32                                                   chw
              llr             [ZOLL]       [M]   [M]      [H]  [M/H] UPM T   SG  L/MN BAR M/S   % HP/Z2           MM
------------------------------------------------------------------------------------------------------------------------------
     Formation : QUARTAER                         0.00     -     50.00
1/1  17  1/ 2 SM  GI03BVE 1 16 3 18       50.0   50.0   3.2 15.5  90    3 1.10 1580  17  43   60 0.15

     Formation : INNVIERTLER SERIE               50.00     -    700.00
1/1  17  1/ 2 SM  GI03BVE 1 16 3 18      471.0  421.0  37.3 11.3 100    5 0.75 2231  72  61   19 0.28   1 1 NO A E I  NO TD
2/2  12  1/ 4 SM  XR+VCPS 1 22 3 20      500.0   29.0   4.0  7.3 100    5 1.18 2307  85  46   15 0.54   1 1 NO A E 1  NO BHA
3/1  12  1/ 4 SM  SDSi519 7 14           700.0  200.0   7.5 26.7  60    2 1.19 2528 115  62   20 1.08

     Formation : HALLER SERIE                   700.00     -   1270.00
3/1  12  1/ 4 SM  SDSi519 7 14          1270.0  570.0  16.8 33.9  60+M  2 1.21 2606 158  64   15 1.20

     Formation : OBERE PUCHKIRCHENER SERIE     1270.00     -   1990.00
3/1  12  1/ 4 SM  SDSi519 7 14          1734.0  464.0  37.2 12.5  65+M  5 1.23 2609 194  64   13 1.22   3 3 WT A X 1  RO PR
4/1  12  1/ 4 SM  GFI12BV 1 14 2 20 1 18 1986.0 252.0  55.0  4.6  59+M 12 1.22 2648 210  68   13 1.37   3 8 BT M F 4  FC BHA
5/1  1   1/ 4 SM  GFi28BO 1 16 1 20 2 18 1990.0   4.0   0.9  4.3  40+M  8 1.22 2496 210  64   12#####

     Formation : UNTERE PUCHKIRCHENER SERIE    1990.00     -   3770.00
5/1  1   1/ 4 SM  GFi28BO 1 16 1 20 2 18 2178.0 188.0  55.6  3.4  56+M 13 1.22 2578 213  67   12#####   2 8 BT M E 1  NO BHA
6/1  12  1/ 4 SM  GFS20BV 1 20 1 16 2 18 2260.0  82.0  44.5  1.8  40+M 14 1.22 2591 224  67   12 1.32   3 4 FC A 4 1  FC PR
7/1  12  1/ 4 SM  GF20BOD 2 20 1 16 1 18 2415.0 155.0  47.0  3.3  41+M 17 1.22 2582 224  63   11 1.17   2 5 BT H 7 1  NO TQ
8/1  12  1/ 4 SM  GFS20BV 1 18 1 16 2 20 2490.0  75.0  32.5  2.3  49+M 18 1.20 2501 219  61   10 1.04   2 2 NO A F 1  NO TD
10/2 8   1/ 2 SM  XR+PS   3 16          2492.0    2.0   0.5  4.0  90    4 1.08  865 160  38    5 0.26   2 2 WT A E 1  NO BHA
11/1 8   1/ 2 SM  FH350DV 2 18 1 16     2673.0  181.0  40.5  4.5  40+M  7 1.10 1890 193  70   14 2.00   3 4 NO A 7 1  NO HR
12/1 8   1/ 2 RED MSF616M 5 12 1 13     2730.0   57.0  12.5  4.6+M       8 1.10 2091 205  79   17 2.79   7 3 WT C X 1  NO PR
13/1 8   1/ 2 SM  FH35    3 16          2990.0  260.0  46.5  5.6+M       6 1.11 1999 208  88   20 3.30   5 5 CI A 8 1  NO HR
14/1 8   1/ 2 SM  FH35    3 16          3160.0  170.0  39.0  4.4+M       7 1.12 1663 220  73   13 1.91   3 4 NO A E 1  NO HR
15/1 8   1/ 2 SM  FH35VPS 3 16          3353.0  193.0  40.0  4.8  72+M 11 1.11 1995 226  87   18 3.27   4 4 BT H E 1  NO HR
16/1 8   1/ 2 SM  MDSi816 3 10 5 11     3587.0  234.0  60.0  3.9  71    7 1.12 1995 239  74   13 2.38   7 2 WT T X 1  RO MF
17/1 8   1/ 2 SM  FH40ODV 1 16 2 18     3770.0  183.0  40.5  4.5+M       7 1.13 1059 250  39    3 0.36   3 2 BT M 8 1  NO TD

     Formation : ENDTEUFE                      3770.00     -
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ROHOEL AUFSUCHUNGS AG

Meisselbericht

29.11.2011

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Bohrung    : OBERKLING SPEICHER 2                Bohrloch   : OBERKLING SPEICHER 2               erster  Bohrtag : 23.09.2011
Bohranlage : RAG E 202                                                                           letzter Bohrtag : 23.11.2011
------------------------------------------------------------------------------------------------------------------------------
        MEISSEL            DUESEN / TFA  Ausbau  Leist  Stand Bohr  Umd La Spue Pump Dru Due  Hydraulik    Meisselzustand
-----------------------   -------------- Teufe   ung    zeit  fort  reh st lung Volm ck  sen  Leistung  -------------------
Nr   Durchm.  Her Typ     A 1  A 1  A 1                       shrt  ung    sgw. Gesa     ges  Meissel   I O D  L B  G  O   R
              ste         Z 32 Z 32 Z 32                                                 chw
              llr             [ZOLL]       [M]   [M]     [H]  [M/H] UPM T   SG  L/MN BAR M/S   % HP/Z2          MM
------------------------------------------------------------------------------------------------------------------------------
     Formation : INNVIERTLER SERIE                 48.00    -    700.00
1/1  17  1/ 2 SM  GI03BVE 3 18 1 16        54.0    6.0   0.3 22.0  80    3 1.09 1422  13  39  63 0.11   1 1 NO A E 1  NO FM
2/1  17  1/ 2 SM  XR+VEC  3 18 1 16       472.0  418.0  31.0 13.5  96    6 1.10 2619  73  72  38 0.68   1 1 NO A E 1  NO TD
3/2  12  1/ 4 SM  XR+     3 22             480.0    8.0   1.5  5.3  80    4 1.18 2496  87  58  22 0.92   1 1 NO A E 1  NO BHA
4/1  12  1/ 4 RED MSF616M 6 15             700.0  220.0  13.5 16.3  69+M  1 1.17 1547 158  39   5 0.25

     Formation : HALLER SERIE                     700.00    -   1267.00
4/1  12  1/ 4 RED MSF616M 6 15            1267.0  567.0  21.4 26.4  68+M  4 1.19 2043 190  51   8 0.59

     Formation : OBERE PUCHKIRCHENER SERIE       1267.00    -   1983.00
4/1  12  1/ 4 RED MSF616M 6 15            1746.0  479.0  51.5  9.3  46+M  7 1.21 2496 157  62  15 1.09   8 6 WT A X 1  RO PR
5/1  12  1/ 4 SM  GF15BOD 1 16 2 20 1 18 1906.0  160.0  50.5  3.2  44+M 11 1.21 2688 209  66  12 1.30   3 8 BT H F 5  WT PR
6/1  12  1/ 4 SM  GF20BVC 1 18 2 20 1 16 1983.0   77.0  29.9  2.6  40+M 11 1.22 2554 217  62  11 1.12

     Formation : UNTERE PUCHKIRCHENER SERIE      1983.00    -   3880.00
6/1  12  1/ 4 SM  GF20BVC 1 18 2 20 1 16 2018.0   35.0  16.6  2.1  40+M 10 1.21 2513 203  61  11 1.06   4 4 WT A E 1  NO PR
7/1  12  1/ 4 SM  GFS15BV 1 18 1 16 2 20 2138.0  120.0  49.5  2.4  44+M 15 1.21 2528 209  62  11 1.09   3 4 FC A 7 1  NO HR
8/1  12  1/ 4 SM  GFi23BO 1 16 2 20 1 18 2295.0  157.0  56.0  2.8  42+M 14 1.21 2050 208  50   7 0.58   2 3 WT A 7 1  NO HR
9/1  12  1/ 4 SM  GF20BVC 4 18           2435.0  140.0  51.0  2.7  40+M 15 1.21 2137 204  56   9 0.74   3 3 WT A 4 1  BT HR
10/1 12  1/ 4 SM  GF20BVC 4 18           2465.0   30.0  16.5  1.8  40+M 19 1.21 2180 205  57   9 0.79   2 2 NO A 2 1  NO TD
12/2 8   1/ 2 SM  XR+PS   3 16           2466.0    1.0   0.5  2.0 100    8 1.10 1729 130  76  24 2.11   3 3 NO A E 1  NO BHA
13/1 8   1/ 2 RED MSF616M 1 13 5 12      2702.0  236.0  58.0  4.1+M       6 1.10 2141 232  81  15 2.99   4 7 NO A X 2  NO PR
14/1 8   1/ 2 SM  FH35VPS 3 18           2949.0  247.0  63.0  3.9  90   12 1.11 2128 227  74  13 2.49   1 1 NO A E 1  NO HR
15/1 8   1/ 2 RED MSF616M 5 13 1 12      3042.0   93.0  16.5  5.6 112    6 1.13 1225 243  42   4 0.47   1 1 NO A X 1  NO PR
16/1 8   1/ 2 SM  FHi28   3 18           3335.0  293.0  68.0  4.3  92   14 1.13 2125 235  74  13 2.51   3 4 BT H E 2  FC HR
17/1 8   1/ 2 SM  FH350DV 3 18           3563.0  228.0  71.5  3.2  97   12 1.13 2040 253  71  11 2.22   3 3 FC A 7 1  NO HR
18/2 8   1/ 2 SM  FH350DV 3 18           3722.0  159.0  37.0  4.3  68+M 11 1.12 1915 248  66  10 1.82   3 3 FC A 7 2  NO HR
19/1 8   1/ 2 SM  FH30    3 18           3880.0 1161.0  38.5 30.2  70+M  9 1.12 1916 250  66  10 1.83   2 2 NO A E 1  NO HR

     Formation : ENDTEUFE                        3880.00    -
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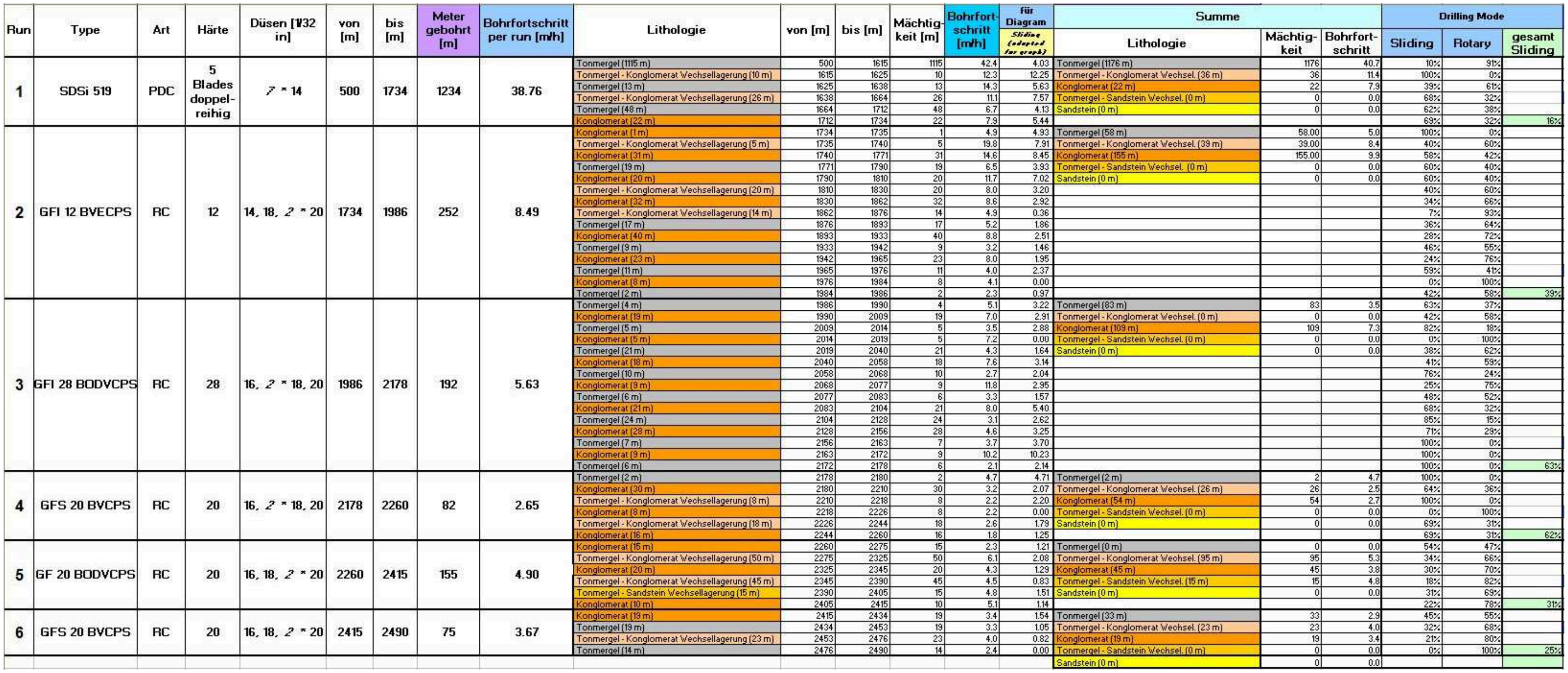
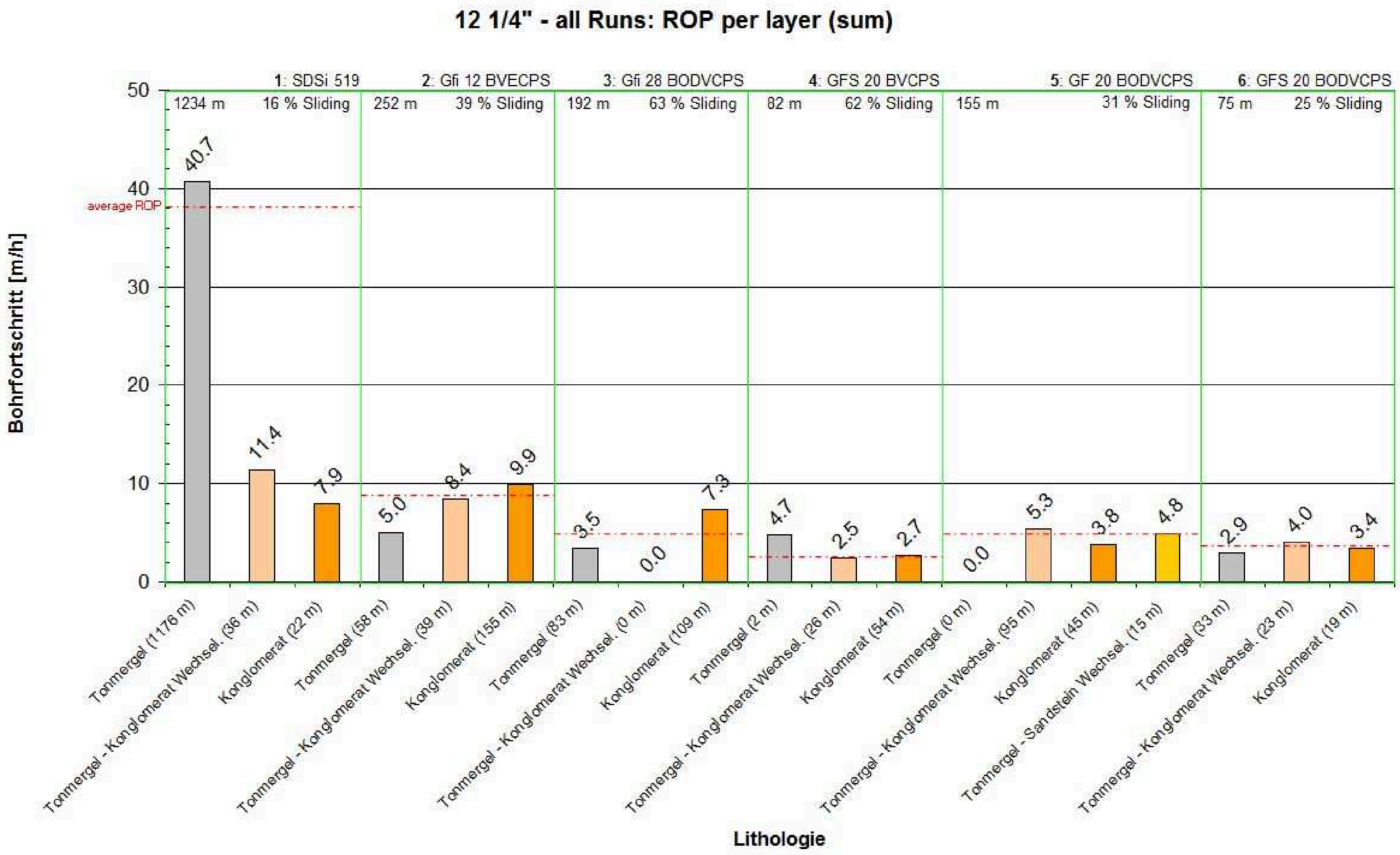
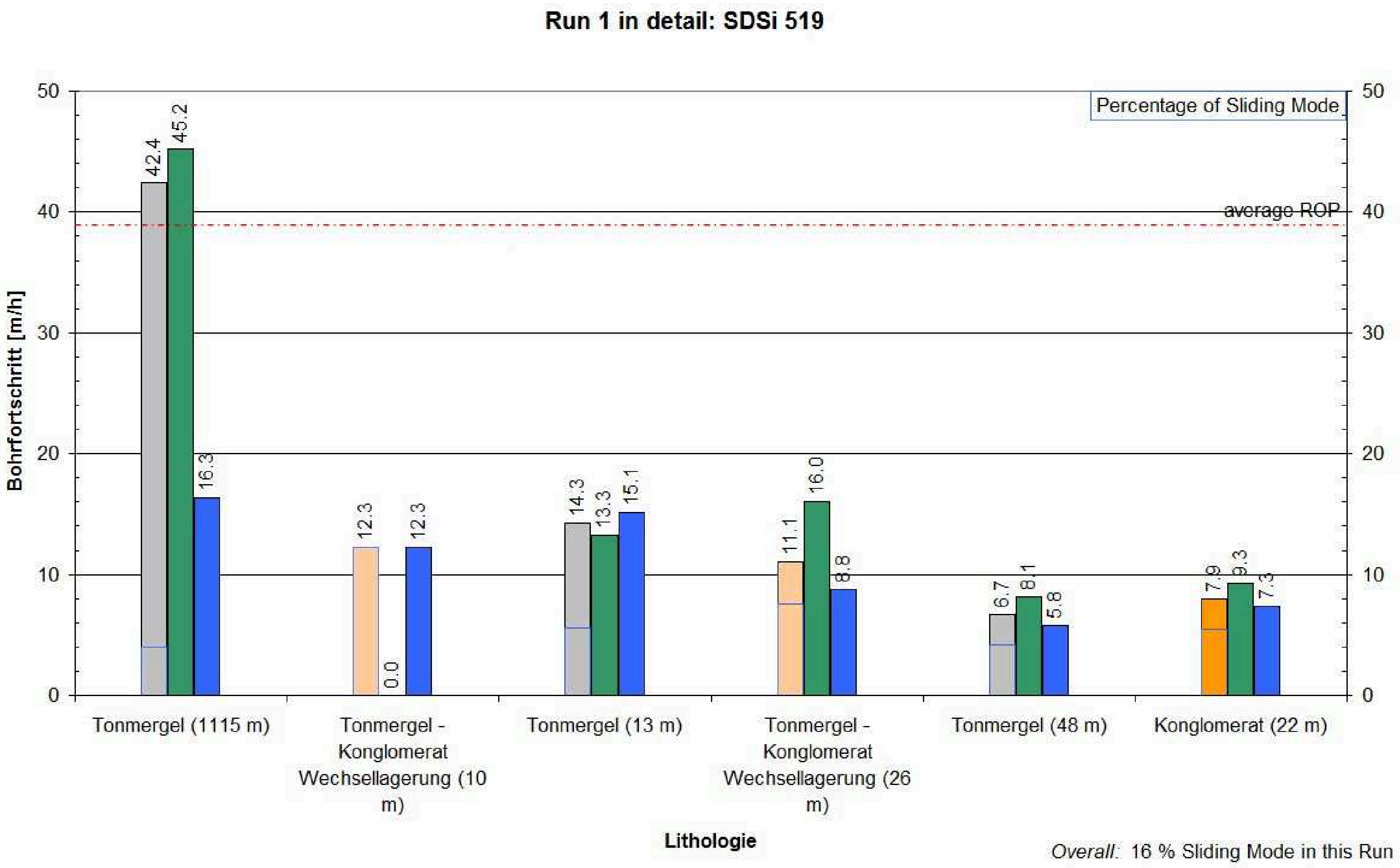
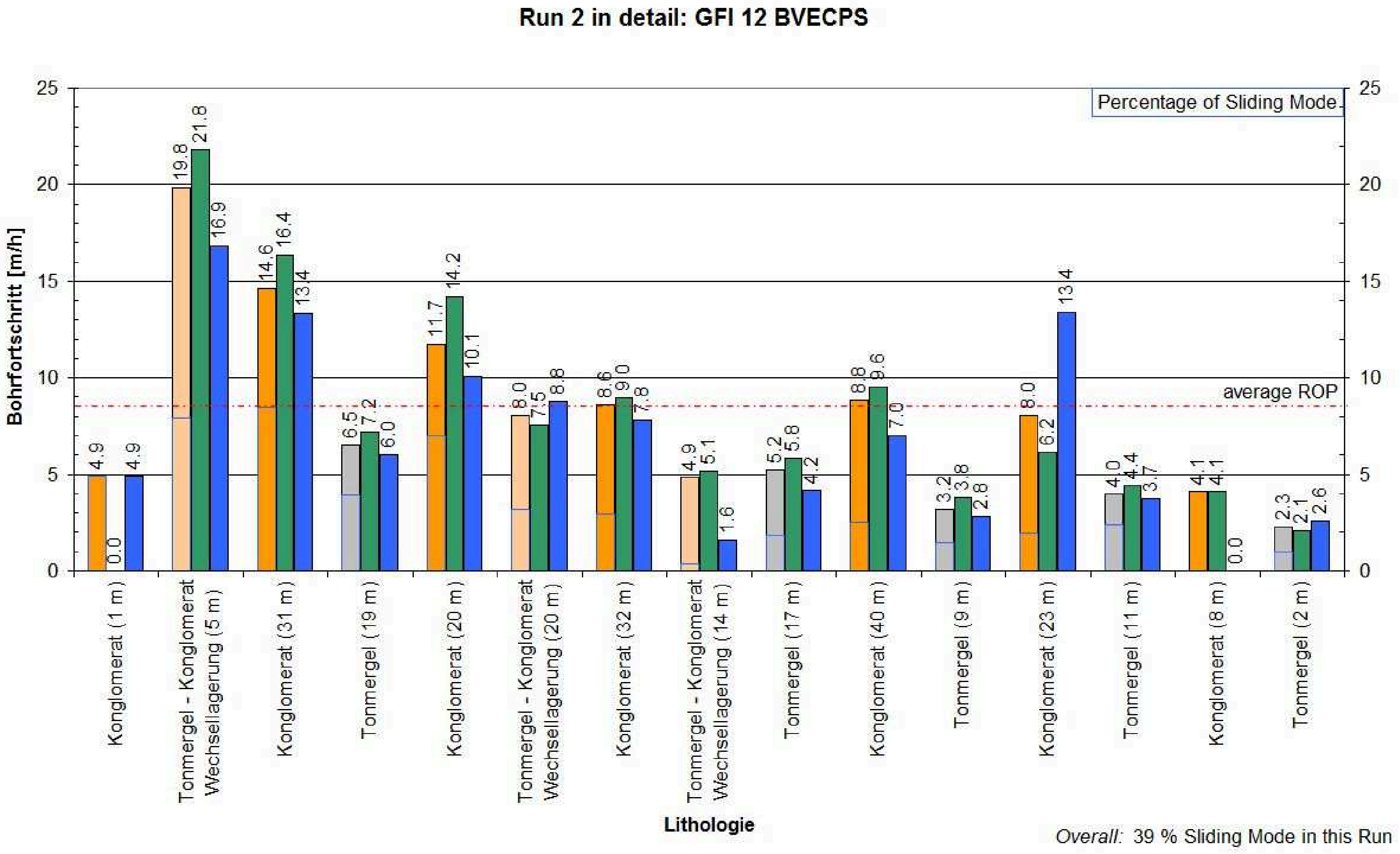
APPENDIX C - Excel sheet for OKSP-001

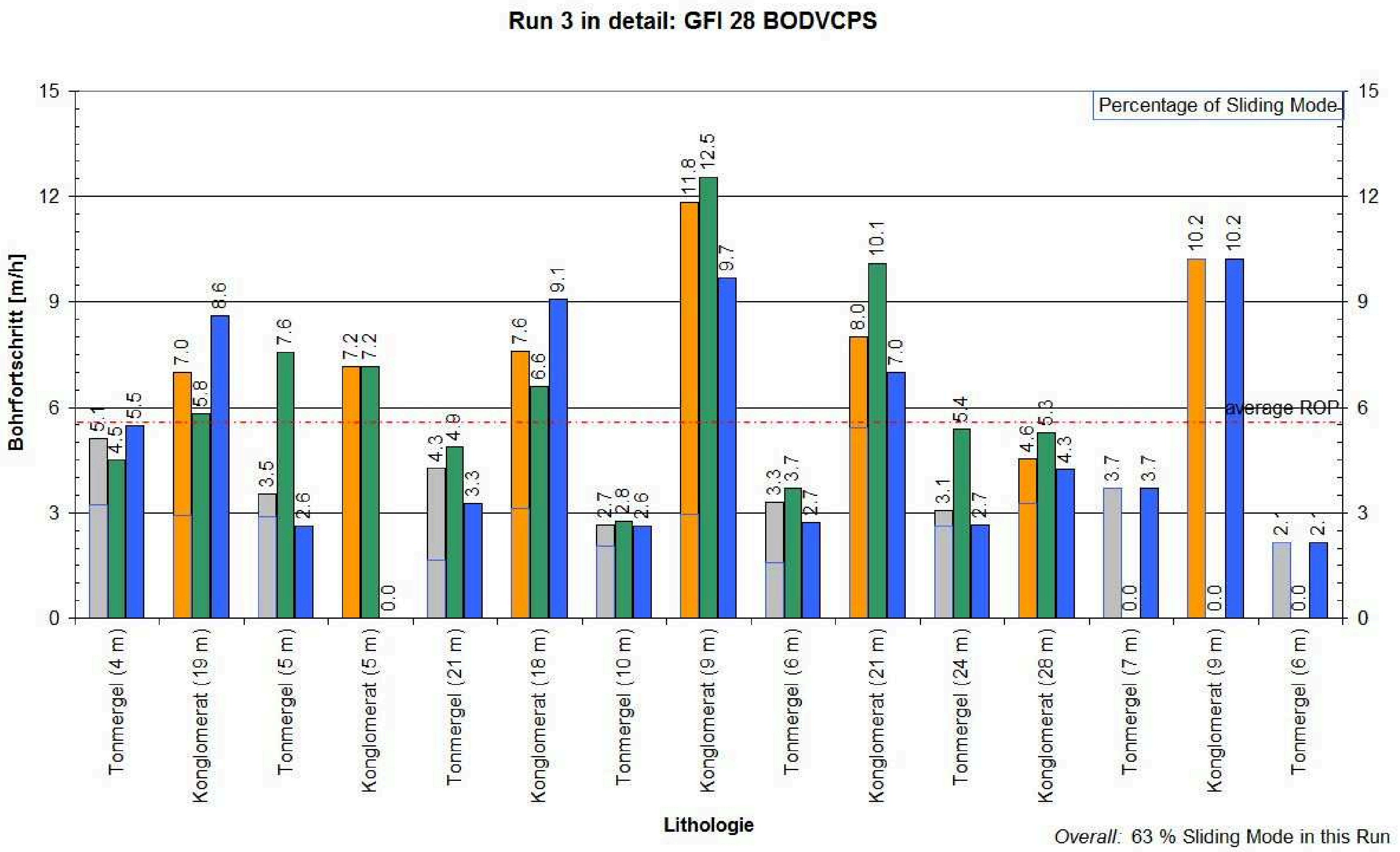


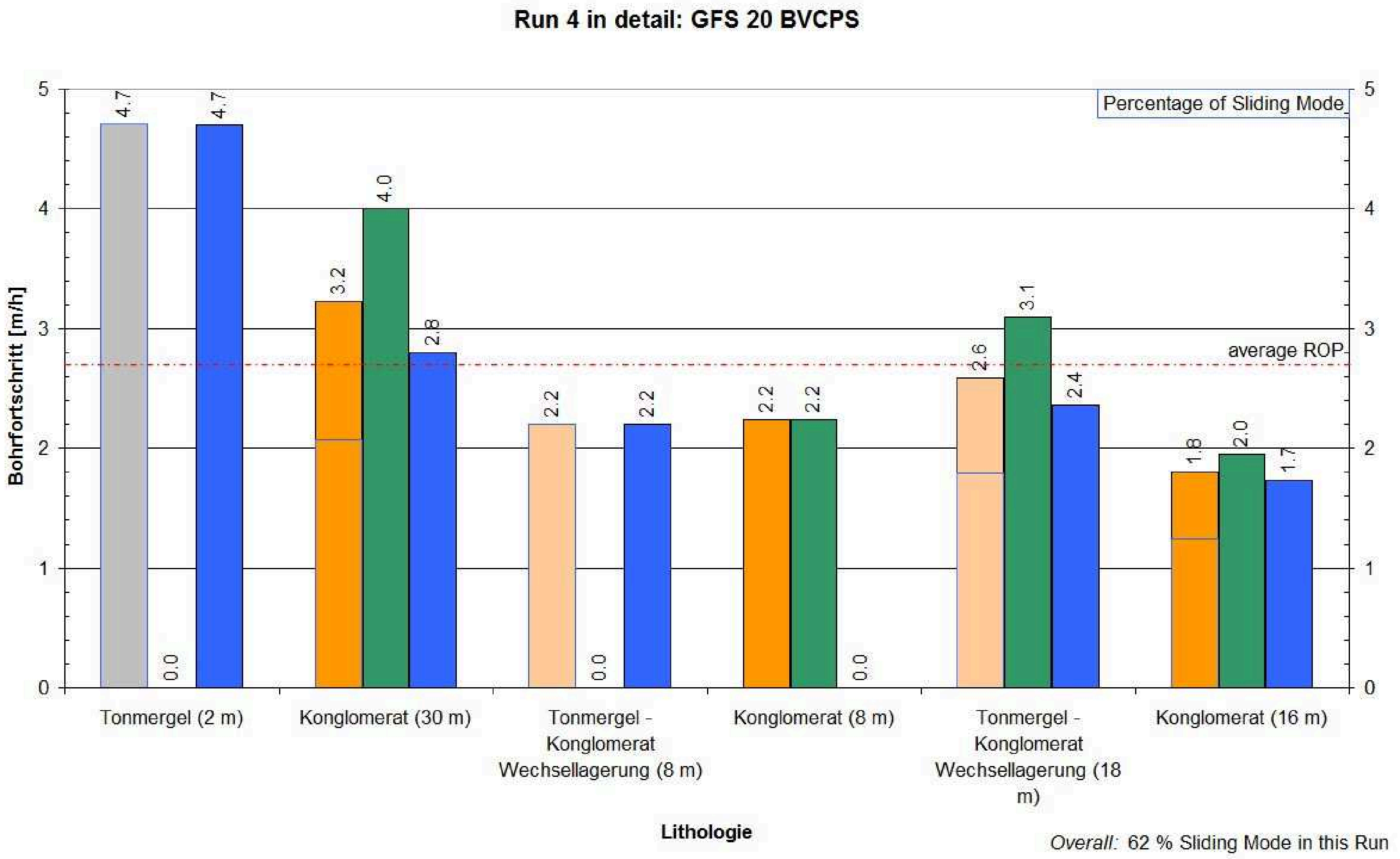
Run	Type	Art	Härte	Düsen [1/32 in]	von [m]	bis [m]	Meter gebohrt [m]	Bohrfortschritt per run [m/h]	Lithologie	von [m]	bis [m]	Mächtigkeit [m]	Bohrfortschritt [m/h]	für Diagram	Summe			Drilling Mode		
														Sliding (adapted for graph)	Lithologie	Mächtigkeit	Bohrfortschritt	Sliding	Rotary	gesamt Sliding
1	SDSi 519	PDC	5 Blades doppelreihig	7 * 14	500	1734	1234	38.76	Tonmergel (1115 m)	500	1615	1115	42.4	4.03	Tonmergel (1176 m)	1176	40.7	10%	91%	
									Tonmergel - Konglomerat Wechsellagerung (10 m)	1615	1625	10	12.3	12.25	Tonmergel - Konglomerat Wechsel. (36 m)	36	11.4	100%	0%	
									Tonmergel (13 m)	1625	1638	13	14.3	5.63	Konglomerat (22 m)	22	7.9	39%	61%	
									Tonmergel - Konglomerat Wechsellagerung (26 m)	1638	1664	26	11.1	7.57	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	68%	32%	
									Tonmergel (48 m)	1664	1712	48	6.7	4.13	Sandstein (0 m)	0	0.0	62%	38%	
									Konglomerat (22 m)	1712	1734	22	7.9	5.44				69%	32%	16%
2	GFI 12 BVECPS	RC	12	14, 18, 2 * 20	1734	1986	252	8.49	Konglomerat (1 m)	1734	1735	1	4.9	4.93	Tonmergel (58 m)	58.00	5.0	100%	0%	
									Tonmergel - Konglomerat Wechsellagerung (5 m)	1735	1740	5	19.8	7.91	Tonmergel - Konglomerat Wechsel. (39 m)	39.00	8.4	40%	60%	
									Konglomerat (31 m)	1740	1771	31	14.6	8.45	Konglomerat (155 m)	155.00	9.9	58%	42%	
									Tonmergel (19 m)	1771	1790	19	6.5	3.93	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	60%	40%	
									Konglomerat (20 m)	1790	1810	20	11.7	7.02	Sandstein (0 m)	0	0.0	60%	40%	
									Tonmergel - Konglomerat Wechsellagerung (20 m)	1810	1830	20	8.0	3.20				40%	60%	
									Konglomerat (32 m)	1830	1862	32	8.6	2.92				34%	66%	
									Tonmergel - Konglomerat Wechsellagerung (14 m)	1862	1876	14	4.9	0.36				7%	93%	
									Tonmergel (17 m)	1876	1893	17	5.2	1.86				36%	64%	
									Konglomerat (40 m)	1893	1933	40	8.8	2.51				28%	72%	
									Tonmergel (9 m)	1933	1942	9	3.2	1.46				46%	55%	
									Konglomerat (23 m)	1942	1965	23	8.0	1.95				24%	76%	
									Tonmergel (11 m)	1965	1976	11	4.0	2.37				59%	41%	
									Konglomerat (8 m)	1976	1984	8	4.1	0.00				0%	100%	
									Tonmergel (2 m)	1984	1986	2	2.3	0.97				42%	58%	39%
3	GFI 28 BODVCPS	RC	28	16, 2 * 18, 20	1986	2178	192	5.63	Tonmergel (4 m)	1986	1990	4	5.1	3.22	Tonmergel (83 m)	83	3.5	63%	37%	
									Konglomerat (19 m)	1990	2009	19	7.0	2.91	Tonmergel - Konglomerat Wechsel. (0 m)	0	0.0	42%	58%	
									Tonmergel (5 m)	2009	2014	5	3.5	2.88	Konglomerat (109 m)	109	7.3	82%	18%	
									Konglomerat (5 m)	2014	2019	5	7.2	0.00	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	0%	100%	
									Tonmergel (21 m)	2019	2040	21	4.3	1.64	Sandstein (0 m)	0	0.0	38%	62%	
									Konglomerat (18 m)	2040	2058	18	7.6	3.14				41%	59%	
									Tonmergel (10 m)	2058	2068	10	2.7	2.04				76%	24%	
									Konglomerat (9 m)	2068	2077	9	11.8	2.95				25%	75%	
									Tonmergel (6 m)	2077	2083	6	3.3	1.57				48%	52%	
									Konglomerat (21 m)	2083	2104	21	8.0	5.40				68%	32%	
									Tonmergel (24 m)	2104	2128	24	3.1	2.62				85%	15%	
									Konglomerat (28 m)	2128	2156	28	4.6	3.25				71%	29%	
									Tonmergel (7 m)	2156	2163	7	3.7	3.70				100%	0%	
									Konglomerat (9 m)	2163	2172	9	10.2	10.23				100%	0%	
									Tonmergel (6 m)	2172	2178	6	2.1	2.14				100%	0%	63%
4	GFS 20 BVCPS	RC	20	16, 2 * 18, 20	2178	2260	82	2.65	Tonmergel (2 m)	2178	2180	2	4.7	4.71	Tonmergel (2 m)	2	4.7	100%	0%	
									Konglomerat (30 m)	2180	2210	30	3.2	2.07	Tonmergel - Konglomerat Wechsel. (26 m)	26	2.5	64%	36%	
									Tonmergel - Konglomerat Wechsellagerung (8 m)	2210	2218	8	2.2	2.20	Konglomerat (54 m)	54	2.7	100%	0%	
									Konglomerat (8 m)	2218	2226	8	2.2	0.00	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	0%	100%	
									Tonmergel - Konglomerat Wechsellagerung (18 m)	2226	2244	18	2.6	1.79	Sandstein (0 m)	0	0.0	69%	31%	
									Konglomerat (16 m)	2244	2260	16	1.8	1.25				69%	31%	62%
5	GF 20 BODVCPS	RC	20	16, 18, 2 * 20	2260	2415	155	4.90	Konglomerat (15 m)	2260	2275	15	2.3	1.21	Tonmergel (0 m)	0	0.0	54%	47%	
									Tonmergel - Konglomerat Wechsellagerung (50 m)	2275	2325	50	6.1	2.08	Tonmergel - Konglomerat Wechsel. (95 m)	95	5.3	34%	66%	
									Konglomerat (20 m)	2325	2345	20	4.3	1.29	Konglomerat (45 m)	45	3.8	30%	70%	
									Tonmergel - Konglomerat Wechsellagerung (45 m)	2345	2390	45	4.5	0.83	Tonmergel - Sandstein Wechsel. (15 m)	15	4.8	18%	82%	
									Tonmergel - Sandstein Wechsellagerung (15 m)	2390	2405	15	4.8	1.51	Sandstein (0 m)	0	0.0	31%	69%	
									Konglomerat (10 m)	2405	2415	10	5.1	1.14				22%	78%	31%
6	GFS 20 BVCPS	RC	20	16, 18, 2 * 20	2415	2490	75	3.67	Konglomerat (19 m)	2415	2434	19	3.4	1.54	Tonmergel (33 m)	33	2.9	45%	55%	
									Tonmergel (19 m)	2434	2453	19	3.3	1.05	Tonmergel - Konglomerat Wechsel. (23 m)	23	4.0	32%	68%	
									Tonmergel - Konglomerat Wechsellagerung (23 m)	2453	2476	23	4.0	0.82	Konglomerat (19 m)	19	3.4	21%	80%	
									Tonmergel (14 m)	2476	2490	14	2.4	0.00	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	0%	100%	25%
															Sandstein (0 m)	0	0.0			

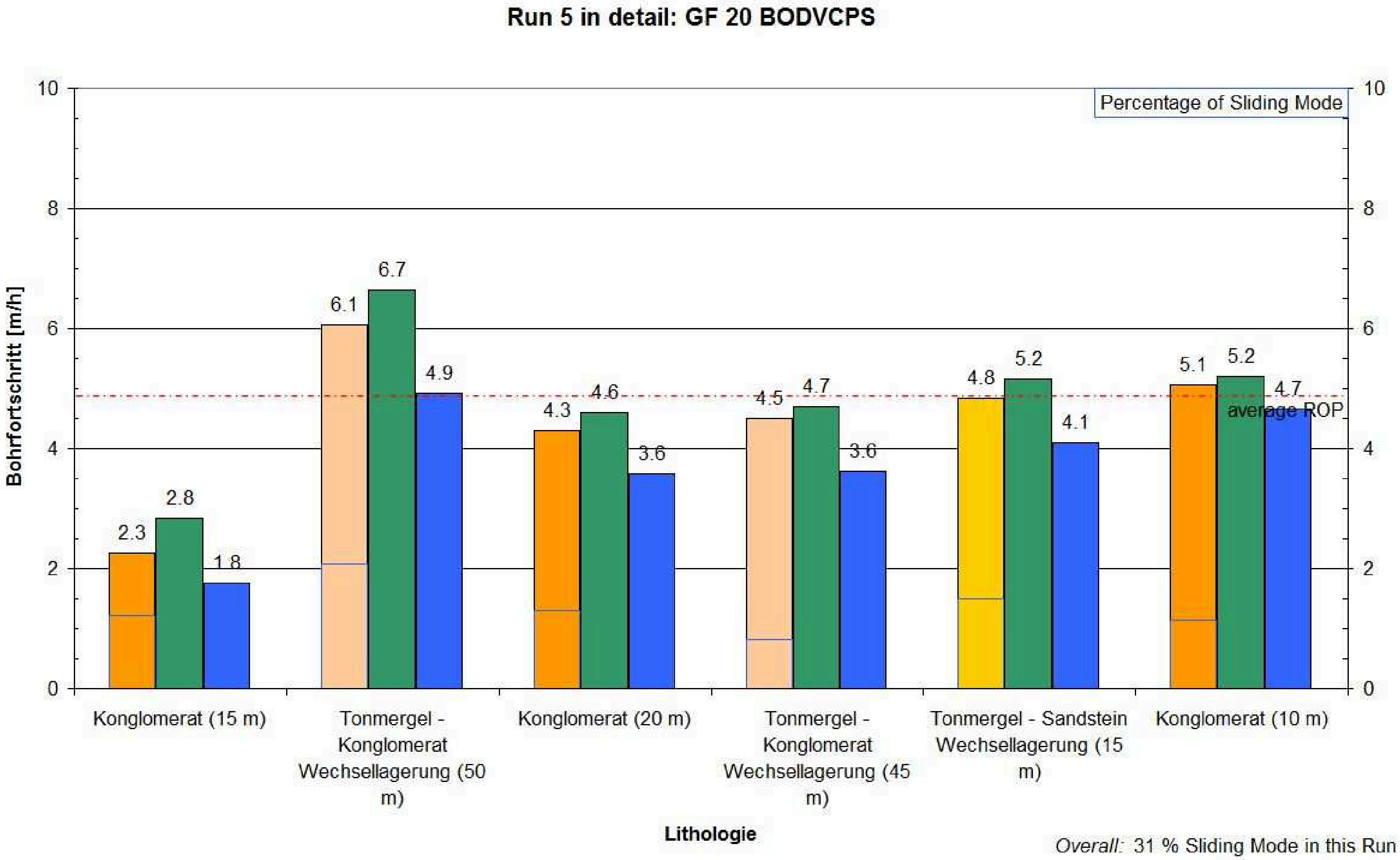

12 1/4" - all Runs: ROP per layer (sum)
1: SDSi 519
1234 m
16 % Sliding
2: Gfi 12 BVECPS
252 m
39 % Sliding
3: Gfi 28 BODVCPS
192 m
63 % Sliding
4: GFS 20 BVCPS
82 m
62 % Sliding
5: GF 20 BODVCPS
155 m
31 % Sliding
6: GFS 20 BODVCPS
75 m
25 % Sliding
average ROP
Bohrfortschritt [m/h]
0
10
20
30
40
50
40.7
11.4
7.9
5.0
8.4
9.9
3.5
0.0
7.3
4.7
2.5
2.7
0.0
5.3
3.8
4.8
2.9
4.0
3.4
Tonmergel (1176 m)
Tonmergel - Konglomerat Wechsel. (36 m)
Konglomerat (22 m)
Tonmergel (58 m)
Tonmergel - Konglomerat Wechsel. (39 m)
Konglomerat (155 m)
Tonmergel (83 m)
Tonmergel - Konglomerat Wechsel. (0 m)
Konglomerat (109 m)
Tonmergel (2 m)
Tonmergel - Konglomerat Wechsel. (26 m)
Konglomerat (54 m)
Tonmergel (0 m)
Tonmergel - Konglomerat Wechsel. (95 m)
Konglomerat (45 m)
Tonmergel - Sandstein Wechsel. (15 m)
Tonmergel (33 m)
Tonmergel - Konglomerat Wechsel. (23 m)
Konglomerat (19 m)
Lithologie


Run 1 in detail: SDSi 519
Percentage of Sliding Mode
average ROP
Bohrfortschritt [m/h]
50
40
30
20
10
0
42.4
45.2
16.3
12.3
0.0
12.3
14.3
13.3
15.1
11.1
16.0
8.8
6.7
8.1
5.8
7.9
9.3
7.3
Tonmergel (1115 m)
Tonmergel - Konglomerat Wechsellagerung (10 m)
Tonmergel (13 m)
Tonmergel - Konglomerat Wechsellagerung (26 m)
Tonmergel (48 m)
Konglomerat (22 m)
Lithologie
Overall: 16 % Sliding Mode in this Run

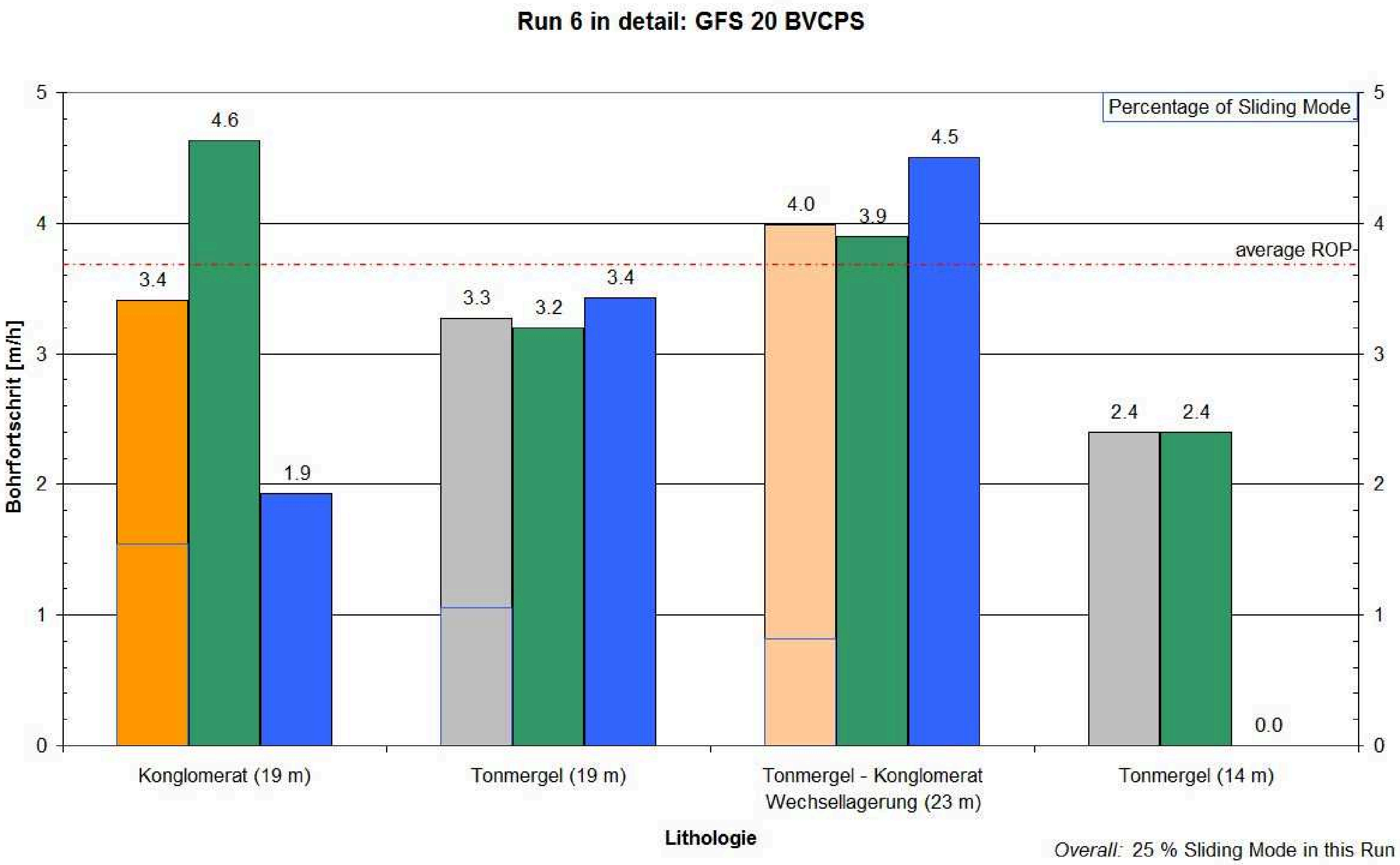

Run 2 in detail: GFI 12 BVECPS
Bohrfortschritt [m/h]
0
5
10
15
20
25
Percentage of Sliding Mode
average ROP
4.9
0.0
4.9
19.8
21.8
16.9
14.6
16.4
13.4
6.5
7.2
6.0
11.7
14.2
10.1
8.0
7.5
8.8
8.6
9.0
7.8
4.9
5.1
1.6
5.2
5.8
4.2
8.8
9.6
7.0
3.2
3.8
2.8
8.0
6.2
13.4
4.0
4.4
3.7
4.1
4.1
0.0
2.3
2.1
2.6
Konglomerat (1 m)
Tonmergel - Konglomerat Wechsellagerung (5 m)
Konglomerat (31 m)
Tonmergel (19 m)
Konglomerat (20 m)
Tonmergel - Konglomerat Wechsellagerung (20 m)
Konglomerat (32 m)
Tonmergel - Konglomerat Wechsellagerung (14 m)
Tonmergel (17 m)
Konglomerat (40 m)
Tonmergel (9 m)
Konglomerat (23 m)
Tonmergel (11 m)
Konglomerat (8 m)
Tonmergel (2 m)
Lithologie
Overall: 39 % Sliding Mode in this Run

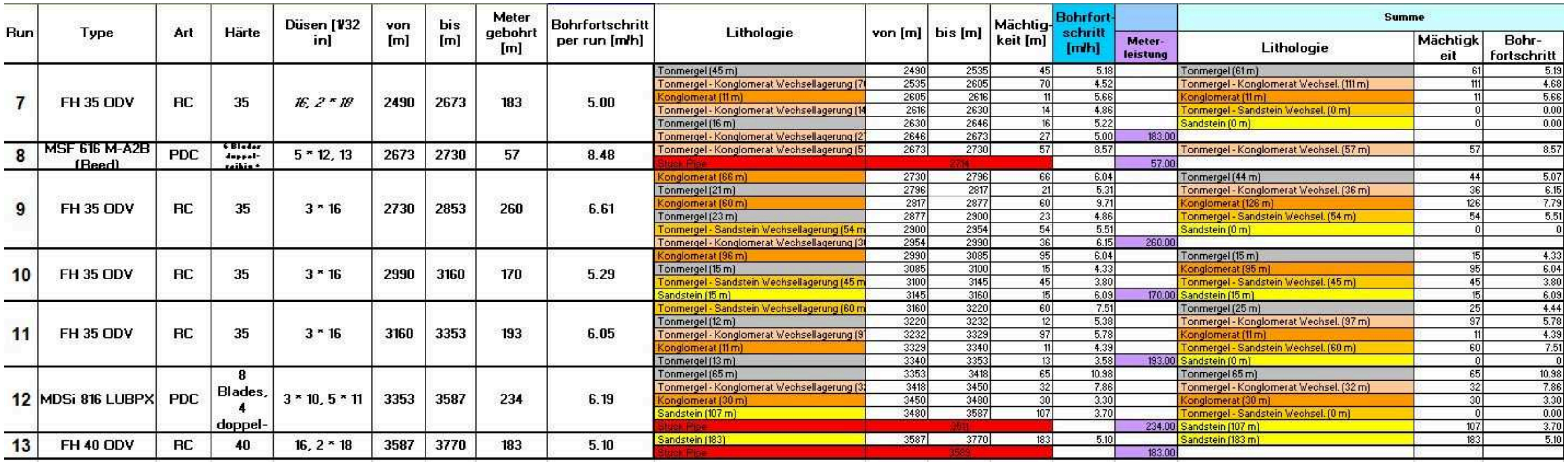

Run 3 in detail: GFI 28 BODVCPS
Bohrfortschritt [m/h]
15
12
9
6
3
0
Percentage of Sliding Mode
average ROP
5.1
4.5
5.5
7.0
5.8
8.6
3.5
7.6
2.6
7.2
7.2
0.0
4.3
4.9
3.3
7.6
6.6
9.1
2.7
2.8
2.6
11.8
12.5
9.7
3.3
3.7
2.7
8.0
10.1
7.0
3.1
5.4
2.7
4.6
5.3
4.3
3.7
0.0
3.7
10.2
0.0
10.2
2.
0.0
2.
Tonmergel (4 m)
Konglomerat (19 m)
Tonmergel (5 m)
Konglomerat (5 m)
Tonmergel (21 m)
Konglomerat (18 m)
Tonmergel (10 m)
Konglomerat (9 m)
Tonmergel (6 m)
Konglomerat (21 m)
Tonmergel (24 m)
Konglomerat (28 m)
Tonmergel (7 m)
Konglomerat (9 m)
Tonmergel (6 m)
Lithologie
Overall: 63 % Sliding Mode in this Run

Run 4 in detail: GFS 20 BVCPS
Bohrfortschritt [m/h]
0
1
2
3
4
5
Percentage of Sliding Mode
average ROP
4.7
0.0
4.7
3.2
4.0
2.8
2.2
0.0
2.2
2.2
2.2
0.0
2.6
3.1
2.4
1.8
2.0
1.7
Tonmergel (2 m)
Konglomerat (30 m)
Tonmergel - Konglomerat Wechsellagerung (8 m)
Konglomerat (8 m)
Tonmergel - Konglomerat Wechsellagerung (18 m)
Konglomerat (16 m)
Lithologie
Overall: 62 % Sliding Mode in this Run

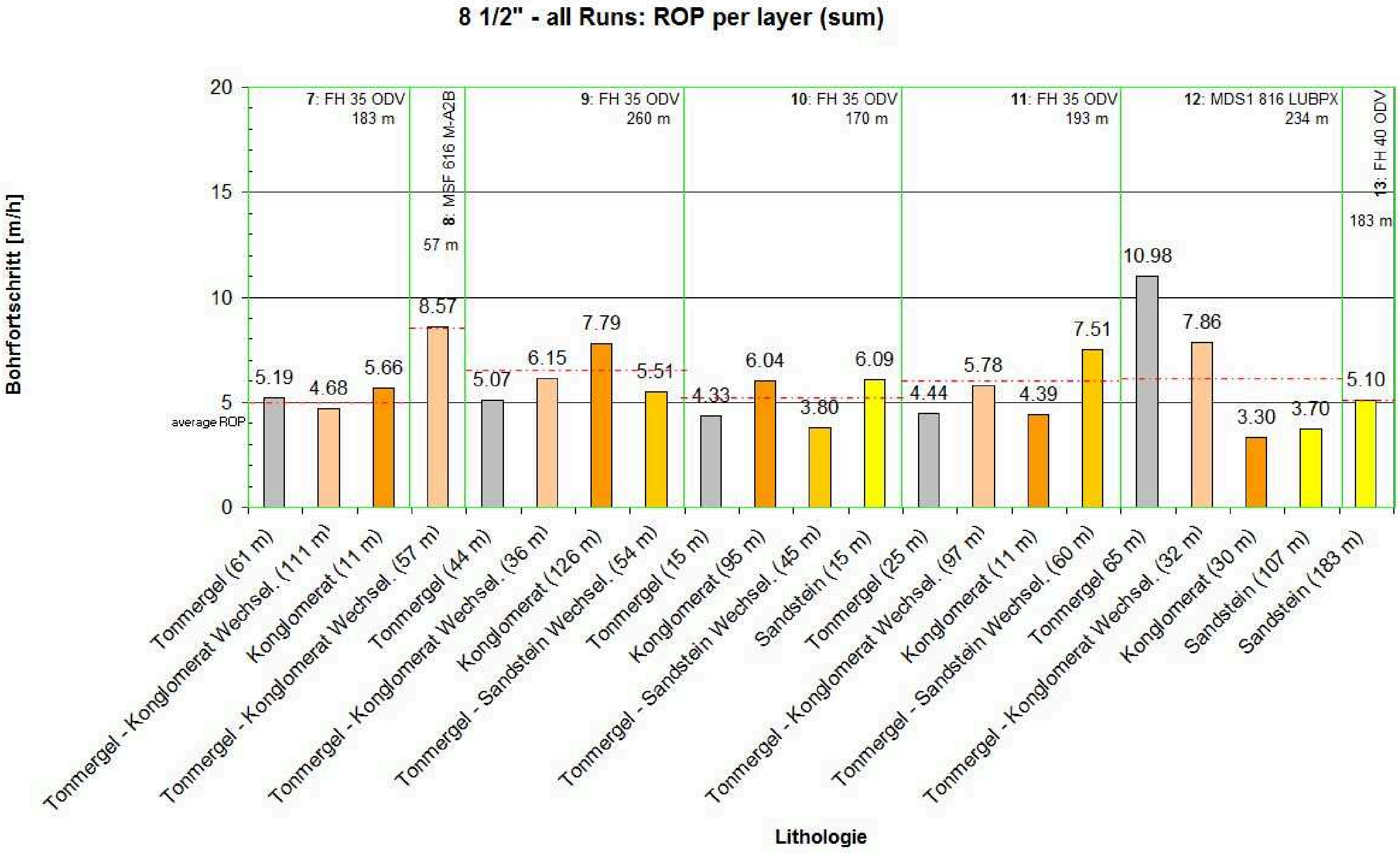


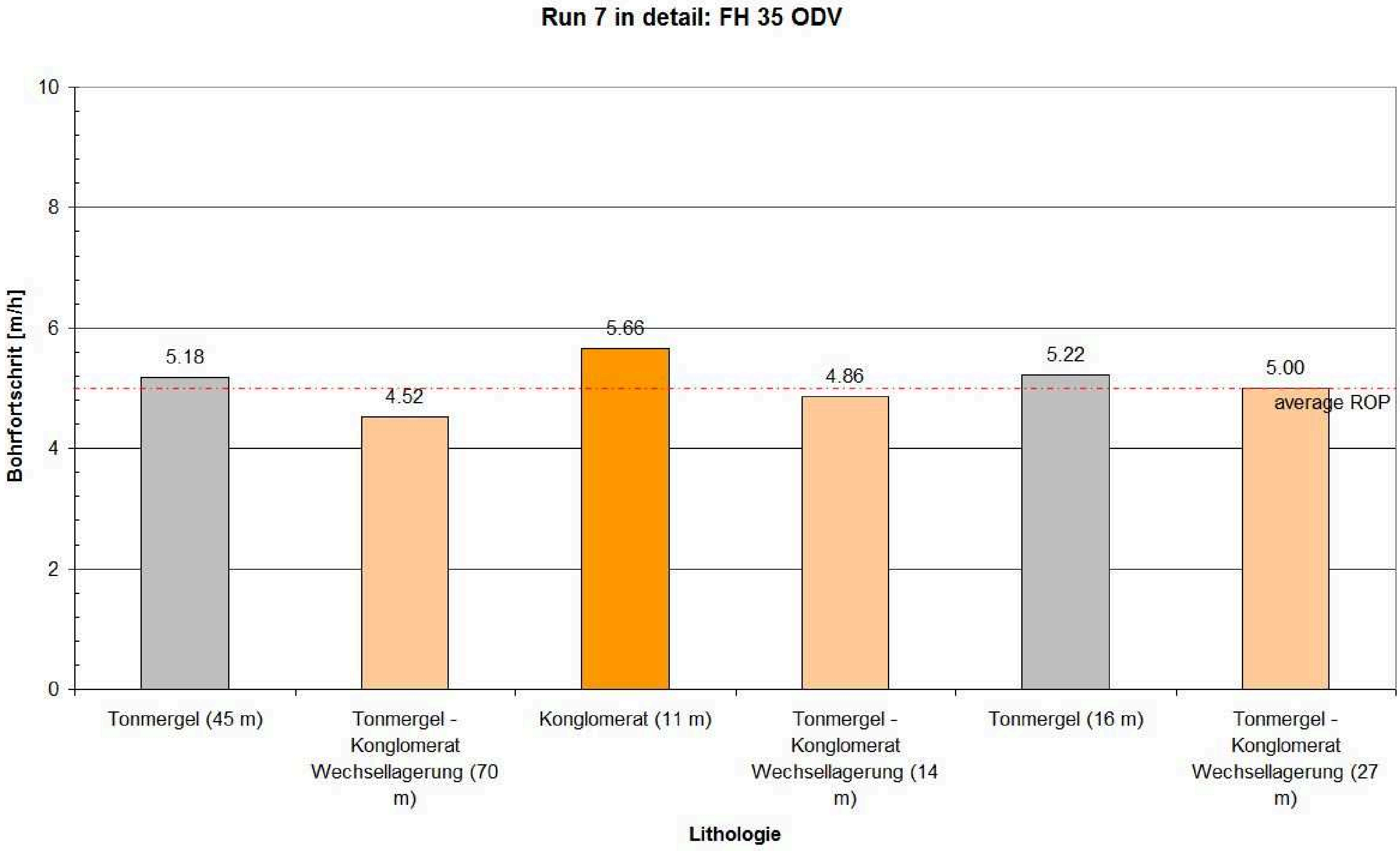
Run 5 in detail: GF 20 BODVCPS
Bohrfortschritt [m/h]
10
8
6
4
2
0
Percentage of Sliding Mode
2.3
2.8
1.8
6.1
6.7
4.9
4.3
4.6
3.6
4.5
4.7
3.6
4.8
5.2
4.1
5.1
5.2
4.7
average ROP
Konglomerat (15 m)
Tonmergel - Konglomerat Wechsellagerung (50 m)
Konglomerat (20 m)
Tonmergel - Konglomerat Wechsellagerung (45 m)
Tonmergel - Sandstein Wechsellagerung (15 m)
Konglomerat (10 m)
Lithologie
Overall: 31 % Sliding Mode in this Run

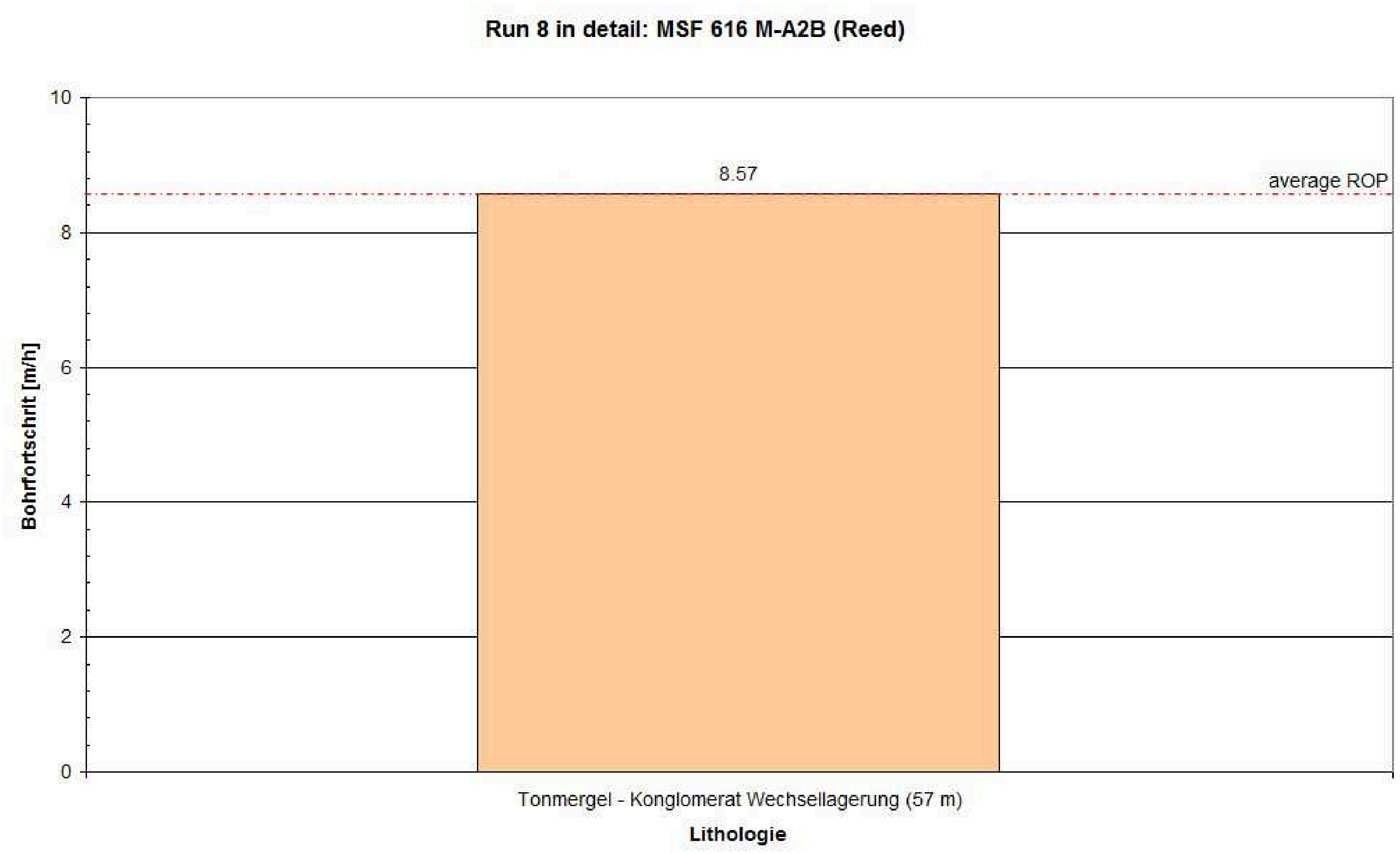

Run 6 in detail: GFS 20 BVCPS
Bohrfortschrit [m/h]
0
1
2
3
4
5
Percentage of Sliding Mode
average ROP
3.4
4.6
1.9
3.3
3.2
3.4
4.0
3.9
4.5
2.4
2.4
0.0
Konglomerat (19 m)
Tonmergel (19 m)
Tonmergel - Konglomerat Wechsellagerung (23 m)
Tonmergel (14 m)
Lithologie
Overall: 25 % Sliding Mode in this Run

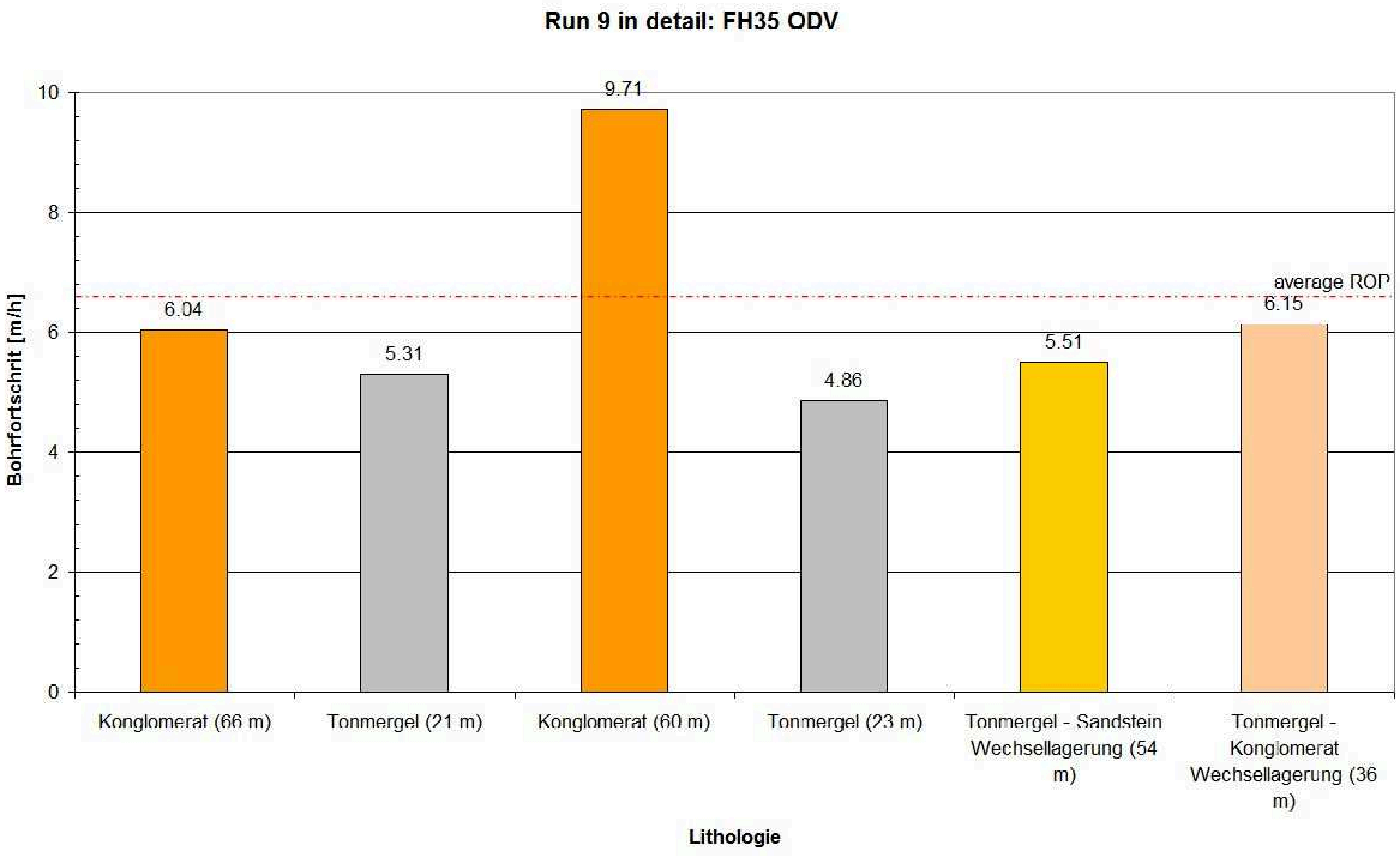


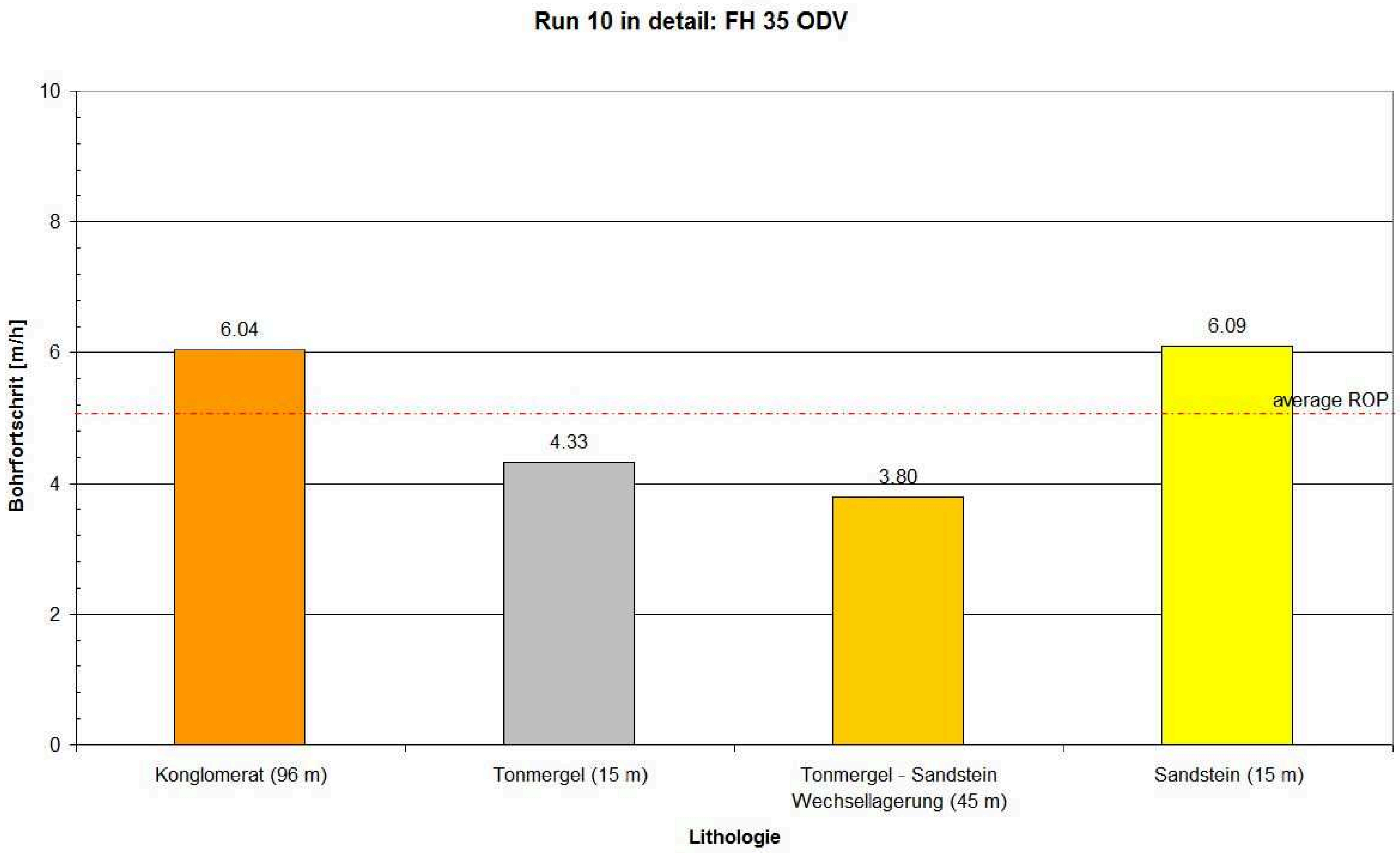
Run	Type	Art	Härte	Düsen [1/32 in]	von [m]	bis [m]	Meter gebohrt [m]	Bohrfortschritt per run [m/h]	Lithologie	von [m]	bis [m]	Mächtigkeit [m]	Bohrfort-schritt [m/h]		Summe		
														Meter-leistung	Lithologie	Mächtigkeit	Bohr-fortschritt
7	FH 35 ODV	RC	35	16, 2 * 18	2490	2673	183	5.00	Tonmergel (45 m)	2490	2535	45	5.18		Tonmergel (61 m)	61	5.19
									Tonmergel - Konglomerat Wechsellagerung (7	2535	2605	70	4.52		Tonmergel - Konglomerat Wechsel. (111 m)	111	4.68
									Konglomerat (11 m)	2605	2616	11	5.66		Konglomerat (11 m)	11	5.66
									Tonmergel - Konglomerat Wechsellagerung (14	2616	2630	14	4.86		Tonmergel - Sandstein Wechsel. (0 m)	0	0.00
									Tonmergel (16 m)	2630	2646	16	5.22		Sandstein (0 m)	0	0.00
									Tonmergel - Konglomerat Wechsellagerung (2	2646	2673	27	5.00	183.00			
8	MSF 616 M-A2B (Reed)	PDC	6 Blades doppel-reihig *	5 * 12, 13	2673	2730	57	8.48	Tonmergel - Konglomerat Wechsellagerung (5	2673	2730	57	8.57		Tonmergel - Konglomerat Wechsel. (57 m)	57	8.57
									Stuck Pipe		2714			57.00			
9	FH 35 ODV	RC	35	3 * 16	2730	2853	260	6.61	Konglomerat (66 m)	2730	2796	66	6.04		Tonmergel (44 m)	44	5.07
									Tonmergel (21 m)	2796	2817	21	5.31		Tonmergel - Konglomerat Wechsel. (36 m)	36	6.15
									Konglomerat (60 m)	2817	2877	60	9.71		Konglomerat (126 m)	126	7.79
									Tonmergel (23 m)	2877	2900	23	4.86		Tonmergel - Sandstein Wechsel. (54 m)	54	5.51
									Tonmergel - Sandstein Wechsellagerung (54 m	2900	2954	54	5.51		Sandstein (0 m)	0	0
									Tonmergel - Konglomerat Wechsellagerung (3	2954	2990	36	6.15	260.00			
10	FH 35 ODV	RC	35	3 * 16	2990	3160	170	5.29	Konglomerat (96 m)	2990	3085	95	6.04		Tonmergel (15 m)	15	4.33
									Tonmergel (15 m)	3085	3100	15	4.33		Konglomerat (95 m)	95	6.04
									Tonmergel - Sandstein Wechsellagerung (45 m	3100	3145	45	3.80		Tonmergel - Sandstein Wechsel. (45 m)	45	3.80
									Sandstein (15 m)	3145	3160	15	6.09	170.00	Sandstein (15 m)	15	6.09
11	FH 35 ODV	RC	35	3 * 16	3160	3353	193	6.05	Tonmergel - Sandstein Wechsellagerung (60 m	3160	3220	60	7.51		Tonmergel (25 m)	25	4.44
									Tonmergel (12 m)	3220	3232	12	5.38		Tonmergel - Konglomerat Wechsel. (97 m)	97	5.78
									Tonmergel - Konglomerat Wechsellagerung (9	3232	3329	97	5.78		Konglomerat (11 m)	11	4.39
									Konglomerat (11 m)	3329	3340	11	4.39		Tonmergel - Sandstein Wechsel. (60 m)	60	7.51
									Tonmergel (13 m)	3340	3353	13	3.58	193.00	Sandstein (0 m)	0	0
12	MDSi 816 LUBPX	PDC	8 Blades, 4 doppel-	3 * 10, 5 * 11	3353	3587	234	6.19	Tonmergel (65 m)	3353	3418	65	10.98		Tonmergel 65 m)	65	10.98
									Tonmergel - Konglomerat Wechsellagerung (3	3418	3450	32	7.86		Tonmergel - Konglomerat Wechsel. (32 m)	32	7.86
									Konglomerat (30 m)	3450	3480	30	3.30		Konglomerat (30 m)	30	3.30
									Sandstein (107 m)	3480	3587	107	3.70		Tonmergel - Sandstein Wechsel. (0 m)	0	0.00
									Stuck Pipe		3511			234.00	Sandstein (107 m)	107	3.70
13	FH 40 ODV	RC	40	16, 2 * 18	3587	3770	183	5.10	Sandstein (183)	3587	3770	183	5.10		Sandstein (183 m)	183	5.10
									Stuck Pipe		3589			183.00			

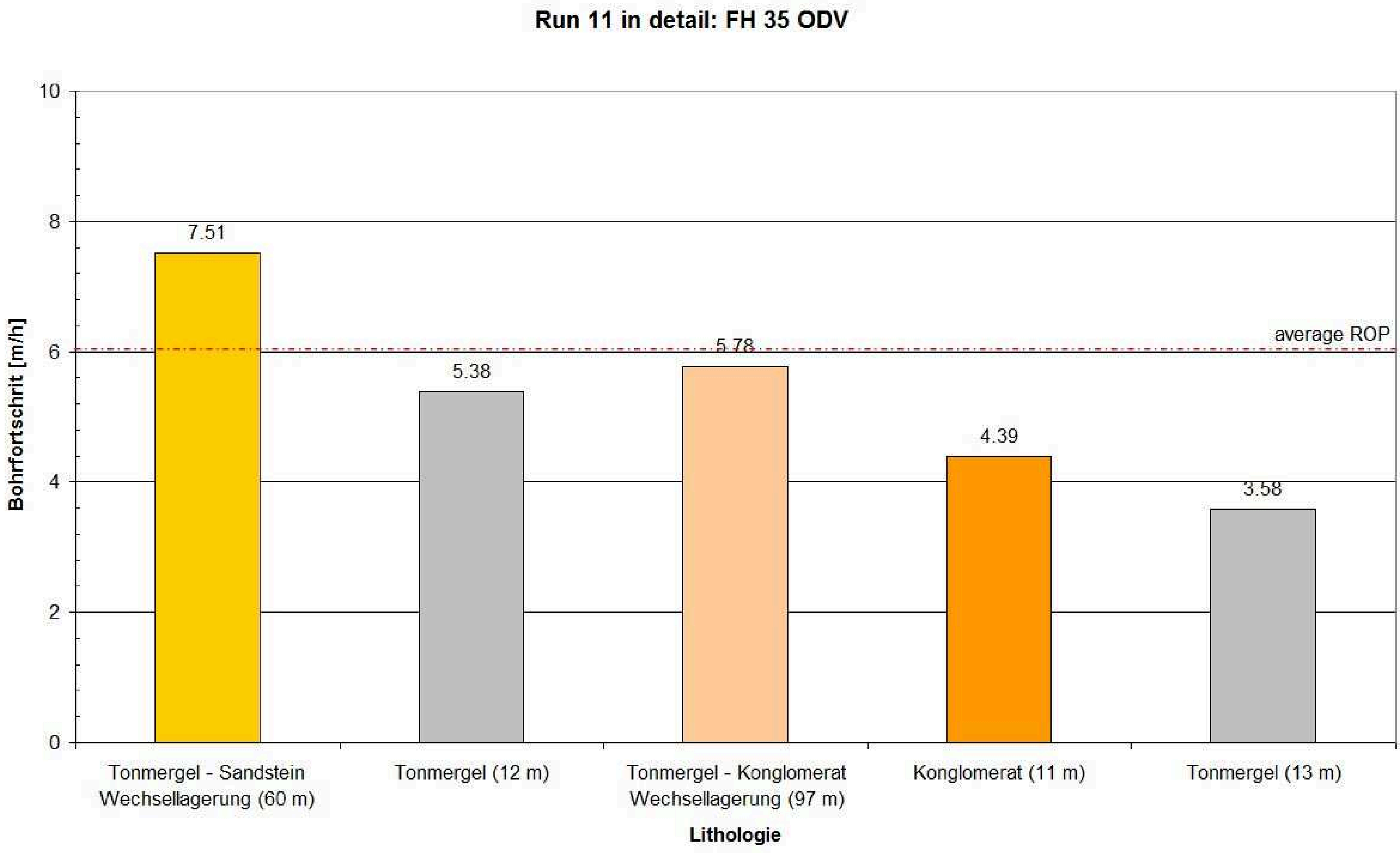

8 1/2" - all Runs: ROP per layer (sum)
Bohrfortschritt [m/h]
Lithologie
0
5
10
15
20
average ROP
7: FH 35 ODV
183 m
8: MSF 616 M-A2B
57 m
9: FH 35 ODV
260 m
10: FH 35 ODV
170 m
11: FH 35 ODV
193 m
12: MDS1 816 LUBPX
234 m
13: FH 40 ODV
183 m
5.19
4.68
5.66
8.57
5.07
6.15
7.79
5.51
4.33
6.04
3.80
6.09
4.44
5.78
4.39
7.51
10.98
7.86
3.30
3.70
5.10
Tonmergel (61 m)
Tonmergel - Konglomerat Wechsel. (111 m)
Konglomerat (11 m)
Tonmergel - Konglomerat Wechsel. (57 m)
Tonmergel (44 m)
Tonmergel - Konglomerat Wechsel. (36 m)
Konglomerat (126 m)
Tonmergel - Sandstein Wechsel. (54 m)
Tonmergel (15 m)
Konglomerat (95 m)
Tonmergel - Sandstein Wechsel. (45 m)
Sandstein (15 m)
Tonmergel (25 m)
Tonmergel - Konglomerat Wechsel. (97 m)
Konglomerat (11 m)
Tonmergel - Sandstein Wechsel. (60 m)
Tonmergel 65 m)
Tonmergel - Konglomerat Wechsel. (32 m)
Konglomerat (30 m)
Sandstein (107 m)
Sandstein (183 m)

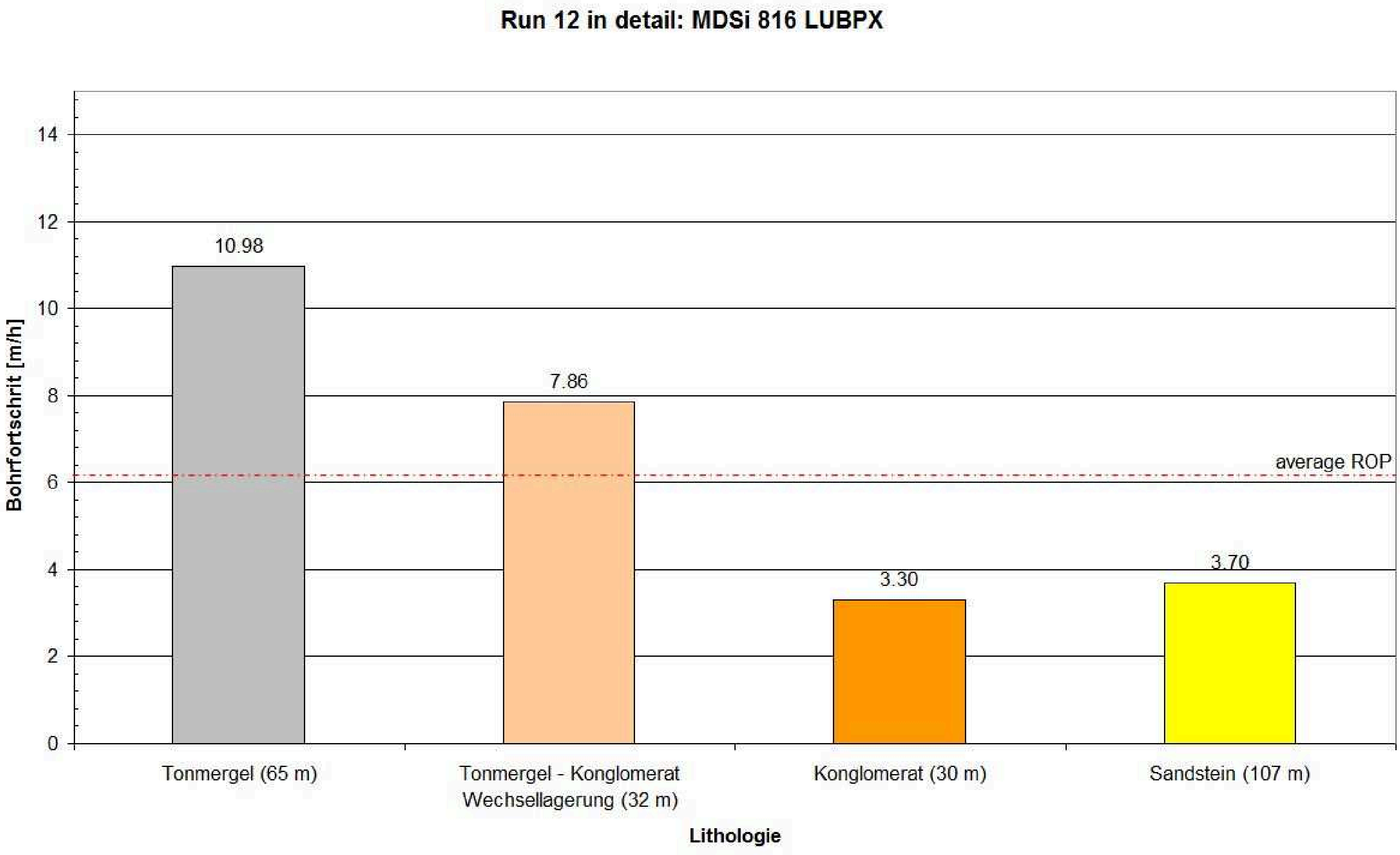

Run 7 in detail: FH 35 ODV
Bohrfortschrit [m/h]
10
8
6
4
2
0
5.18
4.52
5.66
4.86
5.22
5.00
average ROP
Tonmergel (45 m)
Tonmergel - Konglomerat Wechsellagerung (70 m)
Konglomerat (11 m)
Tonmergel - Konglomerat Wechsellagerung (14 m)
Tonmergel (16 m)
Tonmergel - Konglomerat Wechsellagerung (27 m)
Lithologie


Run 8 in detail: MSF 616 M-A2B (Reed)
10
8
6
4
2
0
Bohrfortschrit [m/h]
8.57
average ROP
Tonmergel - Konglomerat Wechsellagerung (57 m)
Lithologie

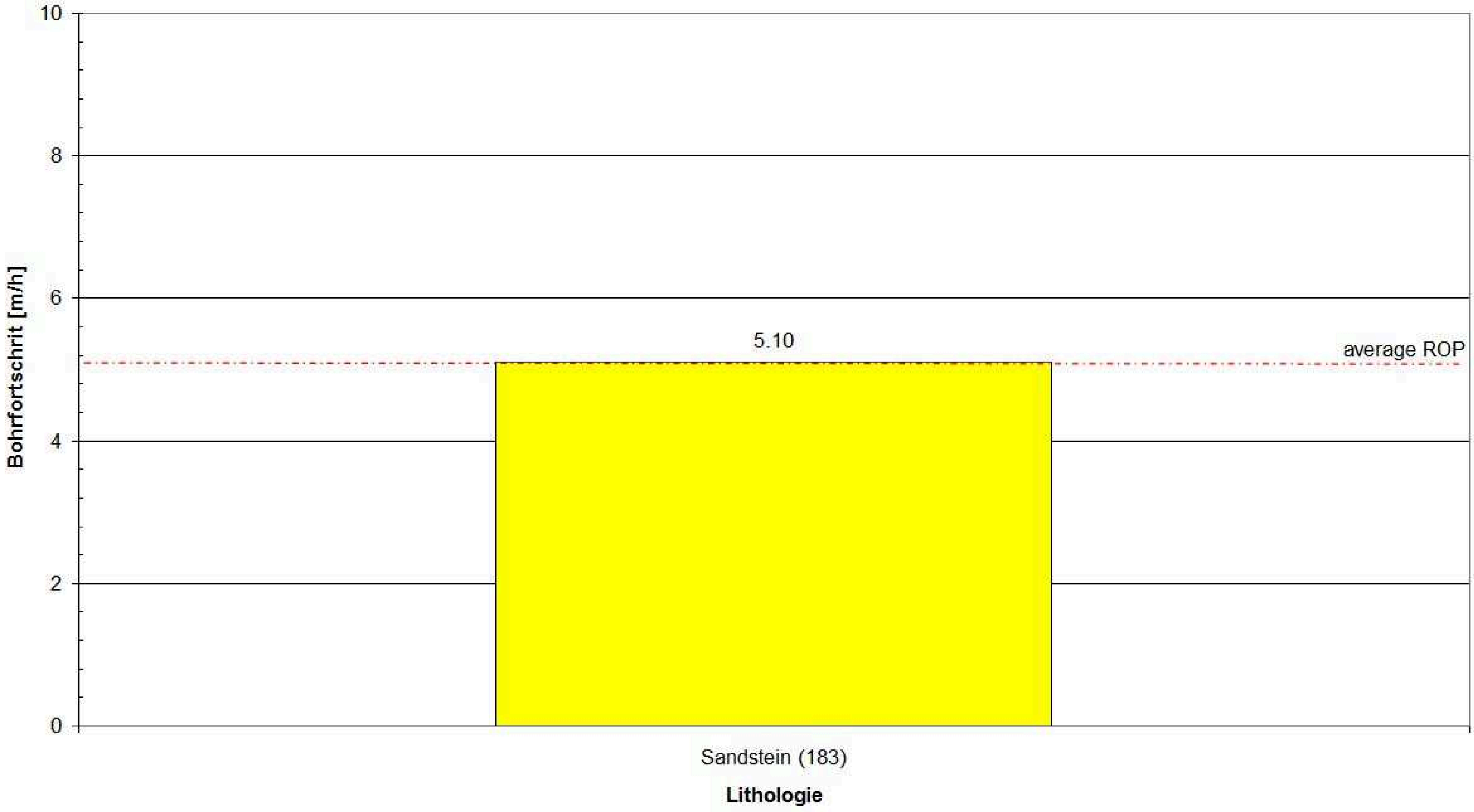

Run 9 in detail: FH35 ODV
10
8
6
4
2
0
Bohrfortschrit [m/h]
6.04
5.31
9.71
4.86
5.51
6.15
average ROP
Konglomerat (66 m)
Tonmergel (21 m)
Konglomerat (60 m)
Tonmergel (23 m)
Tonmergel - Sandstein Wechsellagerung (54 m)
Tonmergel - Konglomerat Wechsellagerung (36 m)
Lithologie


Run 10 in detail: FH 35 ODV
Bohrfortschrit [m/h]
10
8
6
4
2
0
6.04
4.33
3.80
6.09
average ROP
Konglomerat (96 m)
Tonmergel (15 m)
Tonmergel - Sandstein Wechsellagerung (45 m)
Sandstein (15 m)
Lithologie

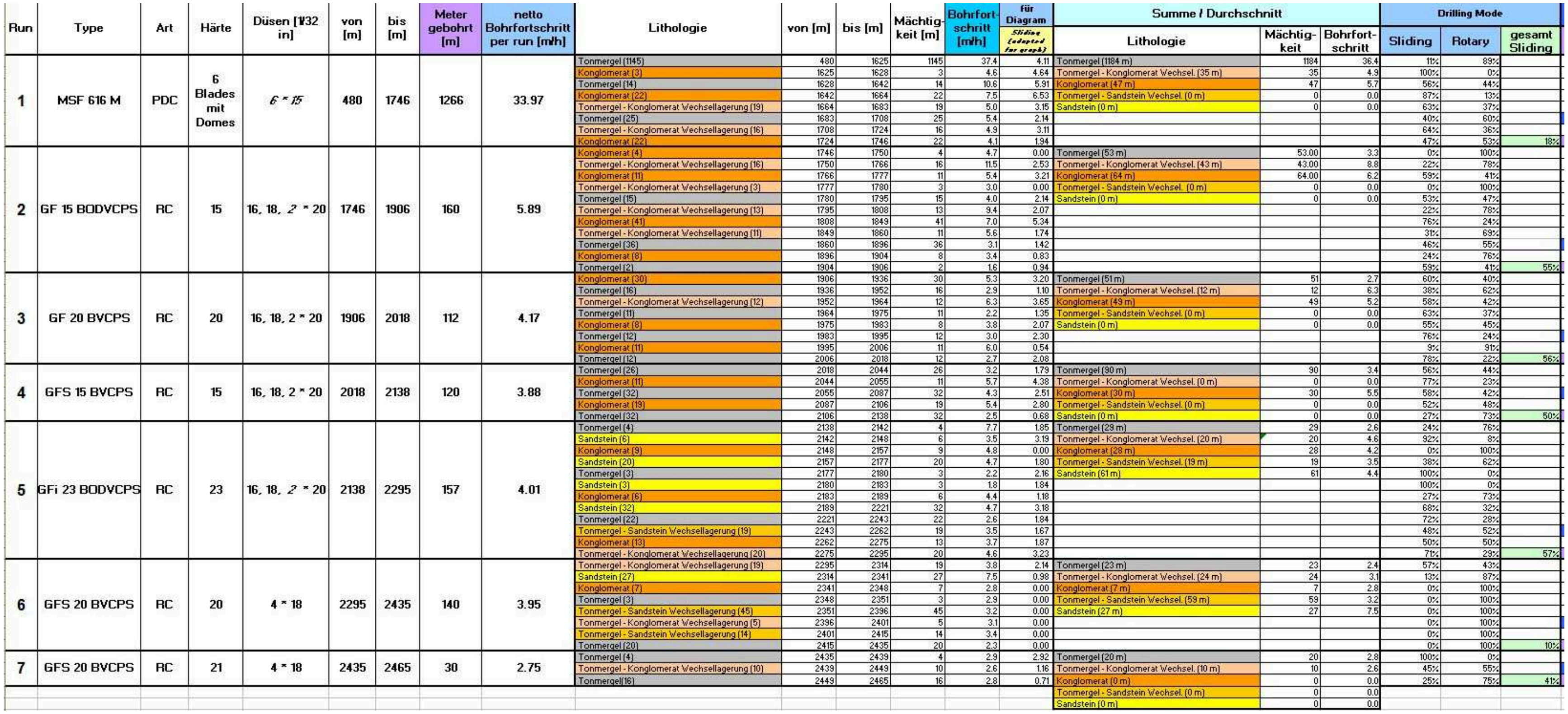

Run 11 in detail: FH 35 ODV
Bohrfortschrit [m/h]
10
8
6
4
2
0
7.51
5.38
5.78
4.39
3.58
average ROP
Tonmergel - Sandstein Wechsellagerung (60 m)
Tonmergel (12 m)
Tonmergel - Konglomerat Wechsellagerung (97 m)
Konglomerat (11 m)
Tonmergel (13 m)
Lithologie


Run 12 in detail: MDSi 816 LUBPX
Bohrfortschrit [m/h]
0
2
4
6
8
10
12
14
10.98
7.86
3.30
3.70
average ROP
Tonmergel (65 m)
Tonmergel - Konglomerat Wechsellagerung (32 m)
Konglomerat (30 m)
Sandstein (107 m)
Lithologie

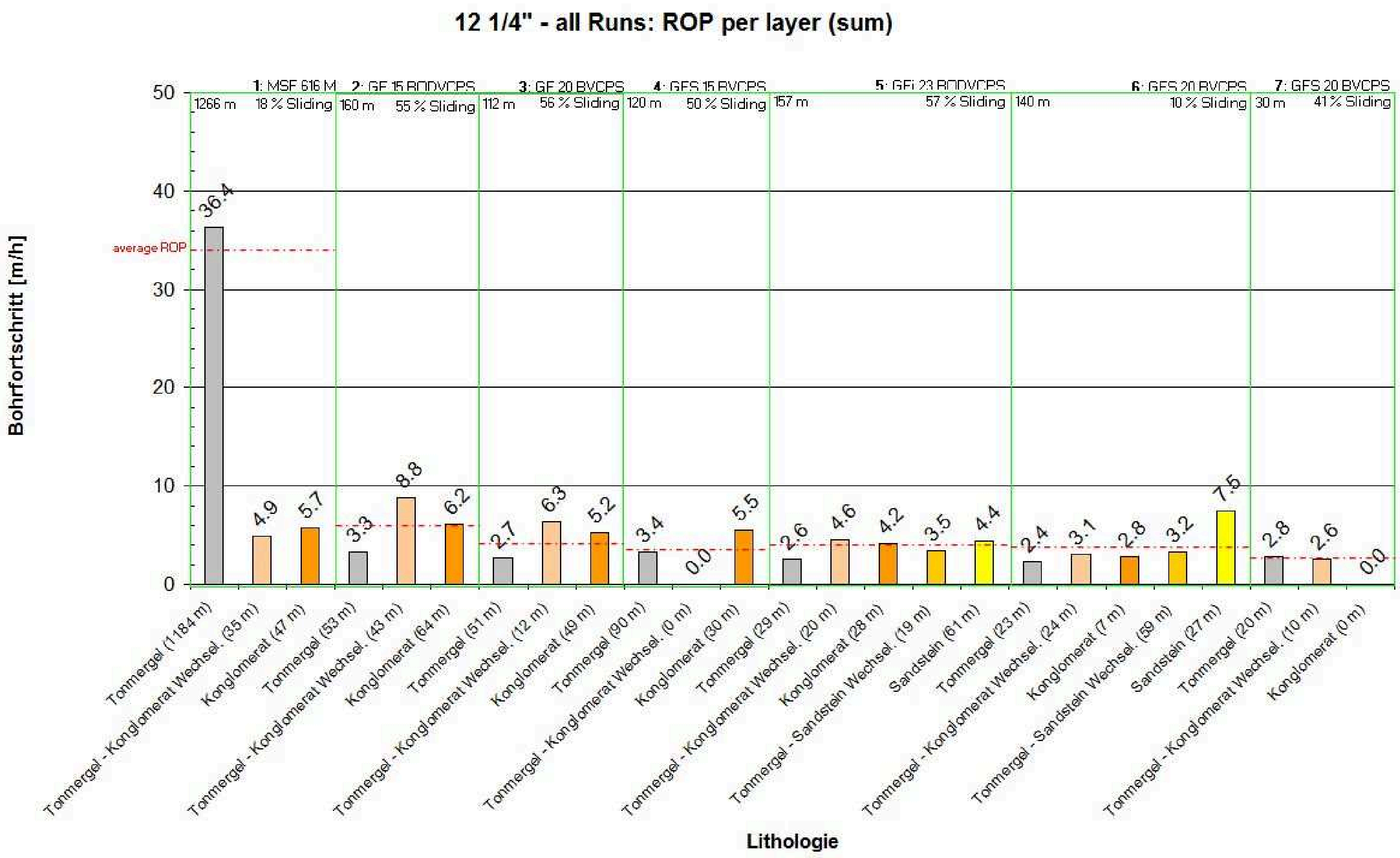
Run 13 in detail: FH 40 ODV

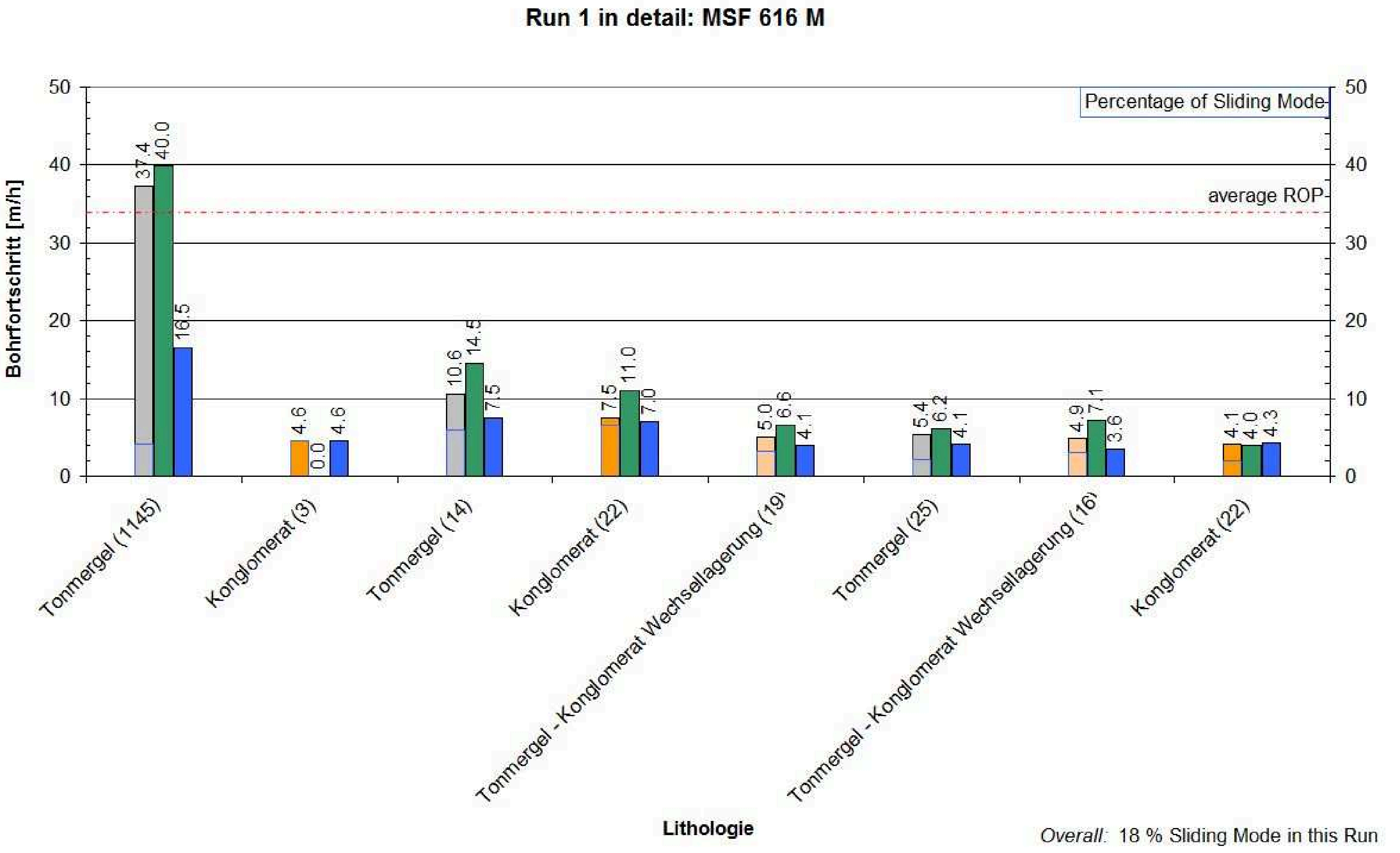


APPENDIX D - Excel sheet for OKSP-002



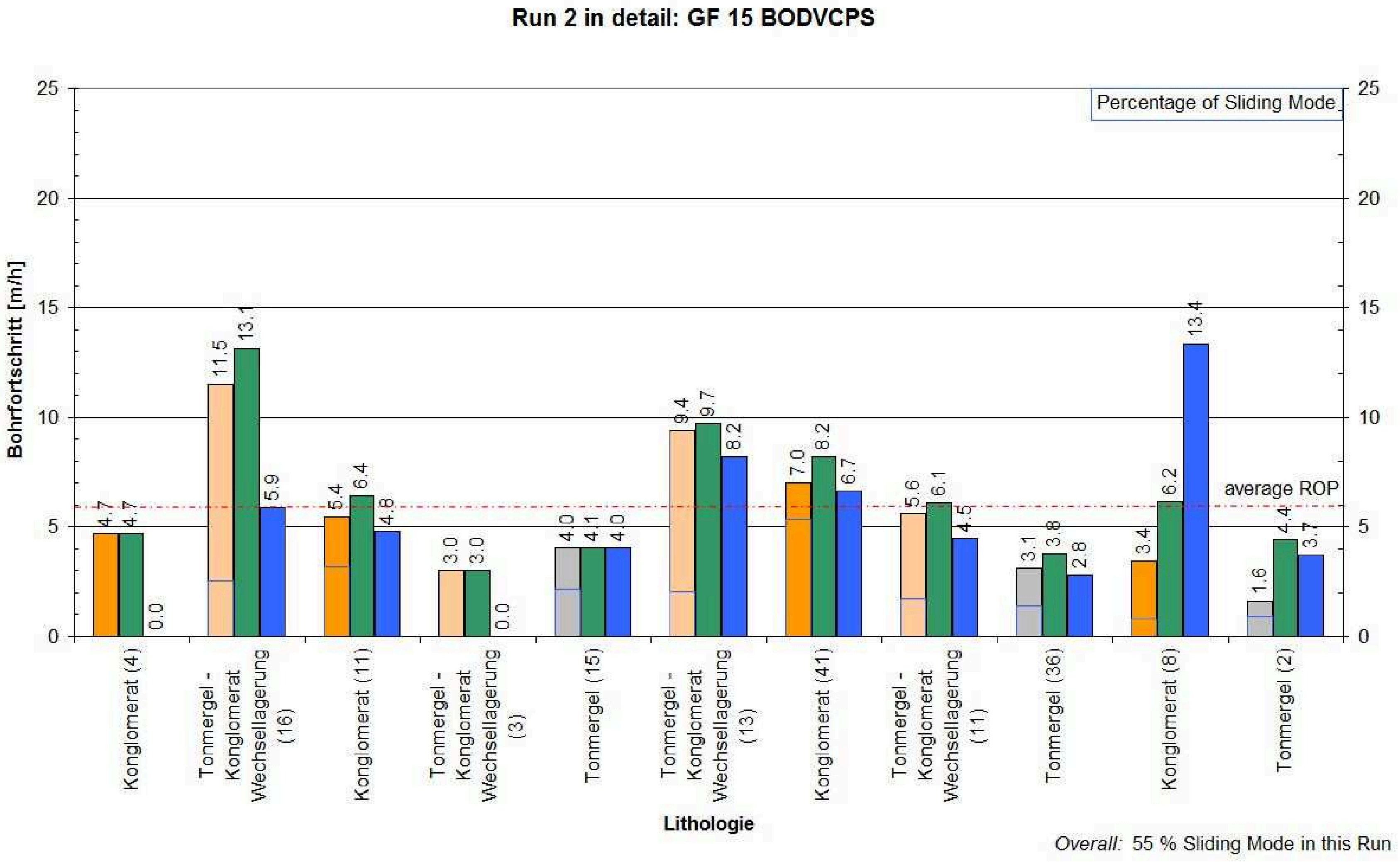
Run	Type	Art	Härte	Düsen [1/32 in]	von [m]	bis [m]	Meter gebohrt [m]	netto Bohrfortschritt per run [m/h]	Lithologie	von [m]	bis [m]	Mächtigkeit [m]	Bohrfortschritt [m/h]	für Diagram	Summe / Durchschnitt			Drilling Mode		
														Sliding (adapted for graph)	Lithologie	Mächtig-keit	Bohrfort-schritt	Sliding	Rotary	gesamt Sliding
1	MSF 616 M	PDC	6 Blades mit Domes	6 * 15	480	1746	1266	33.97	Tonmergel (1145)	480	1625	1145	37.4	4.11	Tonmergel (1184 m)	1184	36.4	11%	89%	
									Konglomerat (3)	1625	1628	3	4.6	4.64	Tonmergel - Konglomerat Wechsel. (35 m)	35	4.9	100%	0%	
									Tonmergel (14)	1628	1642	14	10.6	5.91	Konglomerat (47 m)	47	5.7	56%	44%	
									Konglomerat (22)	1642	1664	22	7.5	6.53	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	87%	13%	
									Tonmergel - Konglomerat Wechsellagerung (19)	1664	1683	19	5.0	3.15	Sandstein (0 m)	0	0.0	63%	37%	
									Tonmergel (25)	1683	1708	25	5.4	2.14				40%	60%	
									Tonmergel - Konglomerat Wechsellagerung (16)	1708	1724	16	4.9	3.11				64%	36%	
									Konglomerat (22)	1724	1746	22	4.1	1.94				47%	53%	18%
2	GF 15 BODVCPS	RC	15	16, 18, 2 * 20	1746	1906	160	5.89	Konglomerat (4)	1746	1750	4	4.7	0.00	Tonmergel (53 m)	53.00	3.3	0%	100%	
									Tonmergel - Konglomerat Wechsellagerung (16)	1750	1766	16	11.5	2.53	Tonmergel - Konglomerat Wechsel. (43 m)	43.00	8.8	22%	78%	
									Konglomerat (11)	1766	1777	11	5.4	3.21	Konglomerat (64 m)	64.00	6.2	59%	41%	
									Tonmergel - Konglomerat Wechsellagerung (3)	1777	1780	3	3.0	0.00	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	0%	100%	
									Tonmergel (15)	1780	1795	15	4.0	2.14	Sandstein (0 m)	0	0.0	53%	47%	
									Tonmergel - Konglomerat Wechsellagerung (13)	1795	1808	13	9.4	2.07				22%	78%	
									Konglomerat (41)	1808	1849	41	7.0	5.34				76%	24%	
									Tonmergel - Konglomerat Wechsellagerung (11)	1849	1860	11	5.6	1.74				31%	69%	
									Tonmergel (36)	1860	1896	36	3.1	1.42				46%	55%	
									Konglomerat (8)	1896	1904	8	3.4	0.83				24%	76%	
									Tonmergel (2)	1904	1906	2	1.6	0.94				59%	41%	55%
3	GF 20 BVCPS	RC	20	16, 18, 2 * 20	1906	2018	112	4.17	Konglomerat (30)	1906	1936	30	5.3	3.20	Tonmergel (51 m)	51	2.7	60%	40%	
									Tonmergel (16)	1936	1952	16	2.9	1.10	Tonmergel - Konglomerat Wechsel. (12 m)	12	6.3	38%	62%	
									Tonmergel - Konglomerat Wechsellagerung (12)	1952	1964	12	6.3	3.65	Konglomerat (49 m)	49	5.2	58%	42%	
									Tonmergel (11)	1964	1975	11	2.2	1.35	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	63%	37%	
									Konglomerat (8)	1975	1983	8	3.8	2.07	Sandstein (0 m)	0	0.0	55%	45%	
									Tonmergel (12)	1983	1995	12	3.0	2.30				76%	24%	
									Konglomerat (11)	1995	2006	11	6.0	0.54				9%	91%	
									Tonmergel (12)	2006	2018	12	2.7	2.08				78%	22%	56%
4	GFS 15 BVCPS	RC	15	16, 18, 2 * 20	2018	2138	120	3.88	Tonmergel (26)	2018	2044	26	3.2	1.79	Tonmergel (90 m)	90	3.4	56%	44%	
									Konglomerat (11)	2044	2055	11	5.7	4.38	Tonmergel - Konglomerat Wechsel. (0 m)	0	0.0	77%	23%	
									Tonmergel (32)	2055	2087	32	4.3	2.51	Konglomerat (30 m)	30	5.5	58%	42%	
									Konglomerat (19)	2087	2106	19	5.4	2.80	Tonmergel - Sandstein Wechsel. (0 m)	0	0.0	52%	48%	
									Tonmergel (32)	2106	2138	32	2.5	0.68	Sandstein (0 m)	0	0.0	27%	73%	50%
5	GFi 23 BODVCPS	RC	23	16, 18, 2 * 20	2138	2295	157	4.01	Tonmergel (4)	2138	2142	4	7.7	1.85	Tonmergel (29 m)	29	2.6	24%	76%	
									Sandstein (6)	2142	2148	6	3.5	3.19	Tonmergel - Konglomerat Wechsel. (20 m)	20	4.6	92%	8%	
									Konglomerat (9)	2148	2157	9	4.8	0.00	Konglomerat (28 m)	28	4.2	0%	100%	
									Sandstein (20)	2157	2177	20	4.7	1.80	Tonmergel - Sandstein Wechsel. (19 m)	19	3.5	38%	62%	
									Tonmergel (3)	2177	2180	3	2.2	2.16	Sandstein (61 m)	61	4.4	100%	0%	
									Sandstein (3)	2180	2183	3	1.8	1.84				100%	0%	
									Konglomerat (6)	2183	2189	6	4.4	1.18				27%	73%	
									Sandstein (32)	2189	2221	32	4.7	3.18				68%	32%	
									Tonmergel (22)	2221	2243	22	2.6	1.84				72%	28%	
									Tonmergel - Sandstein Wechsellagerung (19)	2243	2262	19	3.5	1.67				48%	52%	
									Konglomerat (13)	2262	2275	13	3.7	1.87				50%	50%	
									Tonmergel - Konglomerat Wechsellagerung (20)	2275	2295	20	4.6	3.23				71%	29%	57%
6	GFS 20 BVCPS	RC	20	4 * 18	2295	2435	140	3.95	Tonmergel - Konglomerat Wechsellagerung (19)	2295	2314	19	3.8	2.14	Tonmergel (23 m)	23	2.4	57%	43%	
									Sandstein (27)	2314	2341	27	7.5	0.98	Tonmergel - Konglomerat Wechsel. (24 m)	24	3.1	13%	87%	
									Konglomerat (7)	2341	2348	7	2.8	0.00	Konglomerat (7 m)	7	2.8	0%	100%	
									Tonmergel (3)	2348	2351	3	2.9	0.00	Tonmergel - Sandstein Wechsel. (59 m)	59	3.2	0%	100%	
									Tonmergel - Sandstein Wechsellagerung (45)	2351	2396	45	3.2	0.00	Sandstein (27 m)	27	7.5	0%	100%	
									Tonmergel - Konglomerat Wechsellagerung (5)	2396	2401	5	3.1	0.00				0%	100%	
									Tonmergel - Sandstein Wechsellagerung (14)	2401	2415	14	3.4	0.00				0%	100%	
									Tonmergel (20)	2415	2435	20	2.3	0.00				0%	100%	10%
7	GFS 20 BVCPS	RC	21	4 * 18	2435	2465	30	2.75	Tonmergel (4)	2435	2439	4	2.9	2.92	Tonmergel (20 m)	20	2.8	100%	0%	
									Tonmergel - Konglomerat Wechsellagerung (10)	2439	2449	10	2.6	1.16	Tonmergel - Konglomerat Wechsel. (10 m)	10	2.6	45%	55%	
									Tonmergel(16)	2449	2465	16	2.8	0.71	Konglomerat (0 m)	0	0.0	25%	75%	41%
															Tonmergel - Sandstein Wechsel. (0 m)	0	0.0			
															Sandstein (0 m)	0	0.0			


12 1/4" - all Runs: ROP per layer (sum)
Bohrfortschritt [m/h]
Lithologie
50
40
30
20
10
0
average ROP
1: MSF 616 M
1266 m
18 % Sliding
2: GF 15 BODVCPS
160 m
55 % Sliding
3: GF 20 BVCPS
112 m
56 % Sliding
4: GFS 15 BVCPS
120 m
50 % Sliding
5: GFi 23 BODVCPS
157 m
57 % Sliding
6: GFS 20 BVCPS
140 m
10 % Sliding
7: GFS 20 BVCPS
30 m
41 % Sliding
36.4
4.9
5.7
3.3
8.8
6.2
2.7
6.3
5.2
3.4
0.0
5.5
2.6
4.6
4.2
3.5
4.4
2.4
3.1
2.8
3.2
7.5
2.8
2.6
0.0
Tonmergel (1184 m)
Tonmergel - Konglomerat Wechsel. (35 m)
Konglomerat (47 m)
Tonmergel (53 m)
Tonmergel - Konglomerat Wechsel. (43 m)
Konglomerat (64 m)
Tonmergel (51 m)
Tonmergel - Konglomerat Wechsel. (12 m)
Konglomerat (49 m)
Tonmergel (90 m)
Tonmergel - Konglomerat Wechsel. (0 m)
Konglomerat (30 m)
Tonmergel (29 m)
Tonmergel - Konglomerat Wechsel. (20 m)
Konglomerat (28 m)
Tonmergel - Sandstein Wechsel. (19 m)
Sandstein (61 m)
Tonmergel (23 m)
Tonmergel - Konglomerat Wechsel. (24 m)
Konglomerat (7 m)
Tonmergel - Sandstein Wechsel. (59 m)
Sandstein (27 m)
Tonmergel (20 m)
Tonmergel - Konglomerat Wechsel. (10 m)
Konglomerat (0 m)

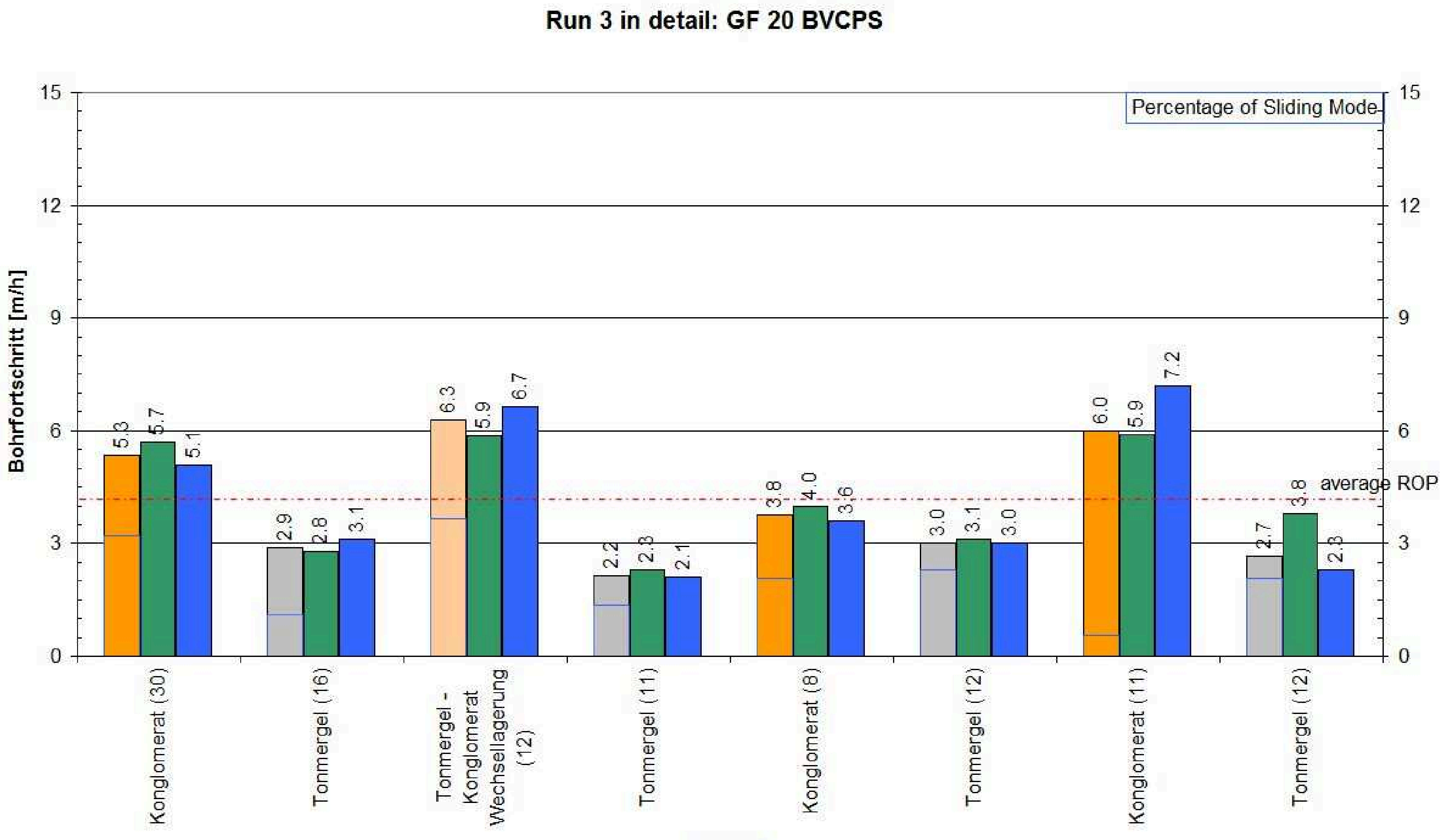


Run 1 in detail: MSF 616 M

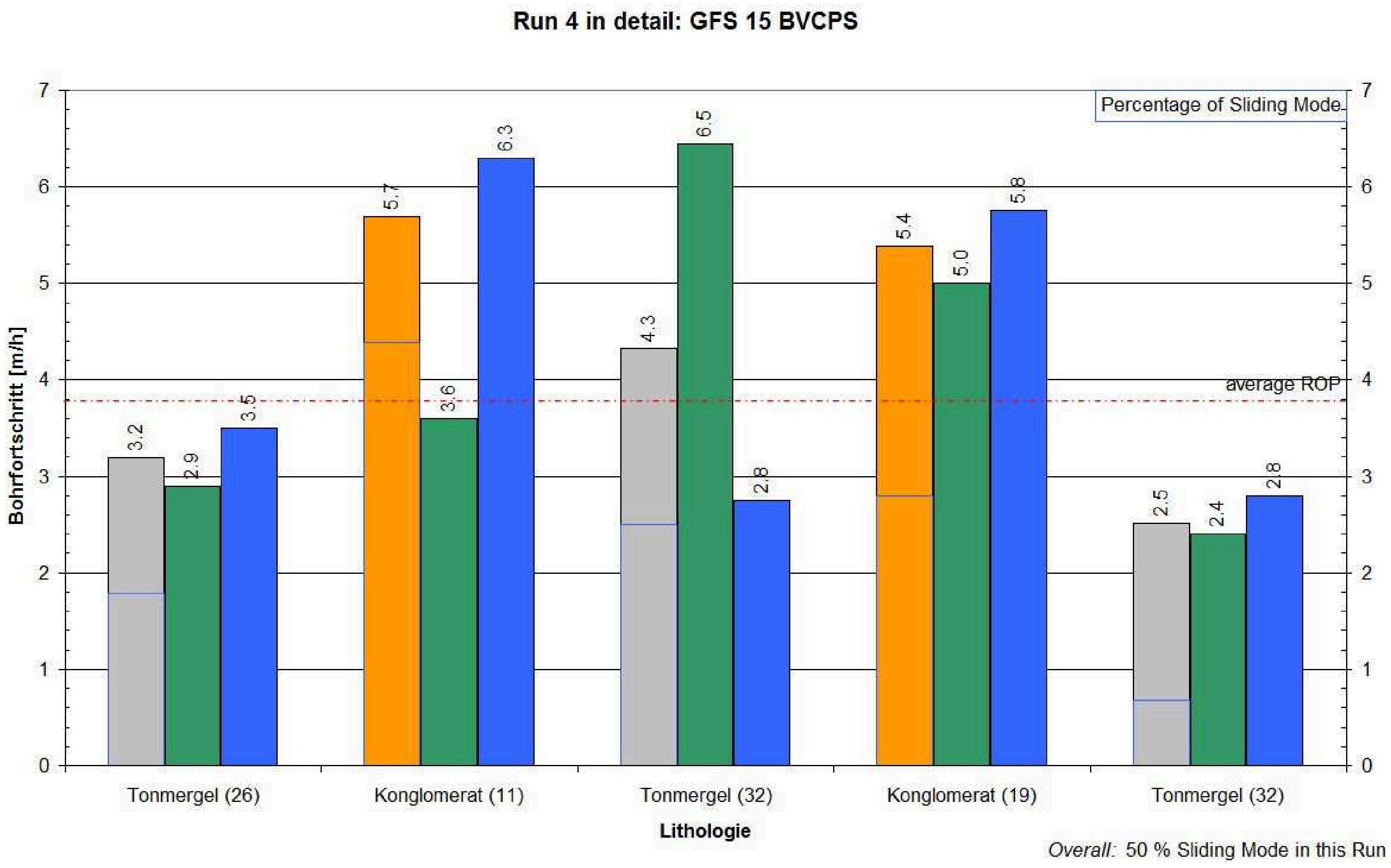
Overall: 18 % Sliding Mode in this Run

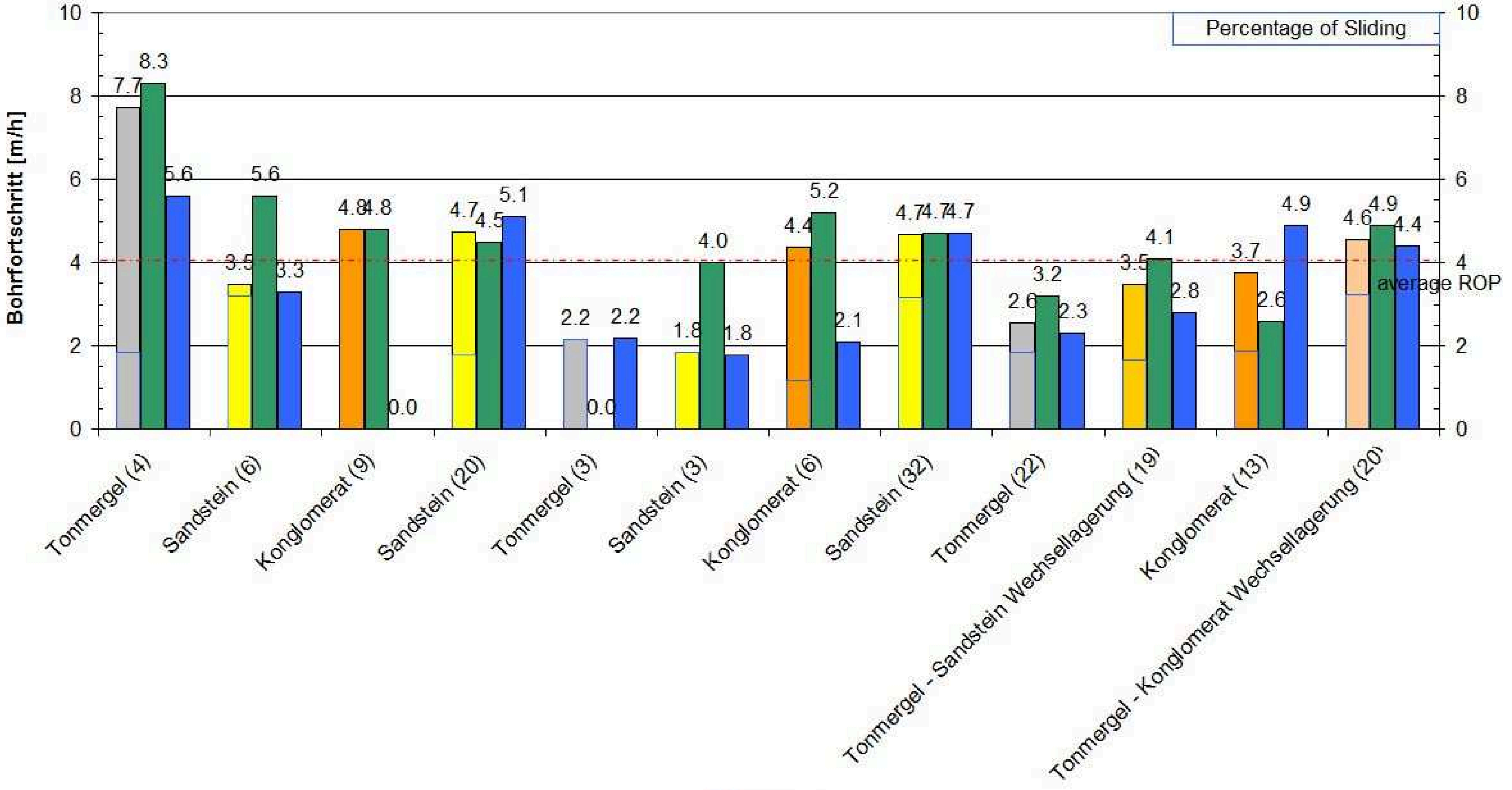


Run 2 in detail: GF 15 BODVCPS
Percentage of Sliding Mode
Bohrfortschritt [m/h]
25
20
15
10
5
0
average ROP
4.7
4.7
0.0
11.5
13.1
5.9
5.4
6.4
4.8
3.0
3.0
0.0
4.0
4.1
4.0
9.4
9.7
8.2
7.0
8.2
6.7
5.6
6.1
4.5
3.1
3.8
2.8
3.4
6.2
13.4
1.6
4.4
3.7
Konglomerat (4)
Tonmergel - Konglomerat Wechsellagerung (16)
Konglomerat (11)
Tonmergel - Konglomerat Wechsellagerung (3)
Tonmergel (15)
Tonmergel - Konglomerat Wechsellagerung (13)
Konglomerat (41)
Tonmergel - Konglomerat Wechsellagerung (11)
Tonmergel (36)
Konglomerat (8)
Tonmergel (2)
Lithologie
Overall: 55 % Sliding Mode in this Run



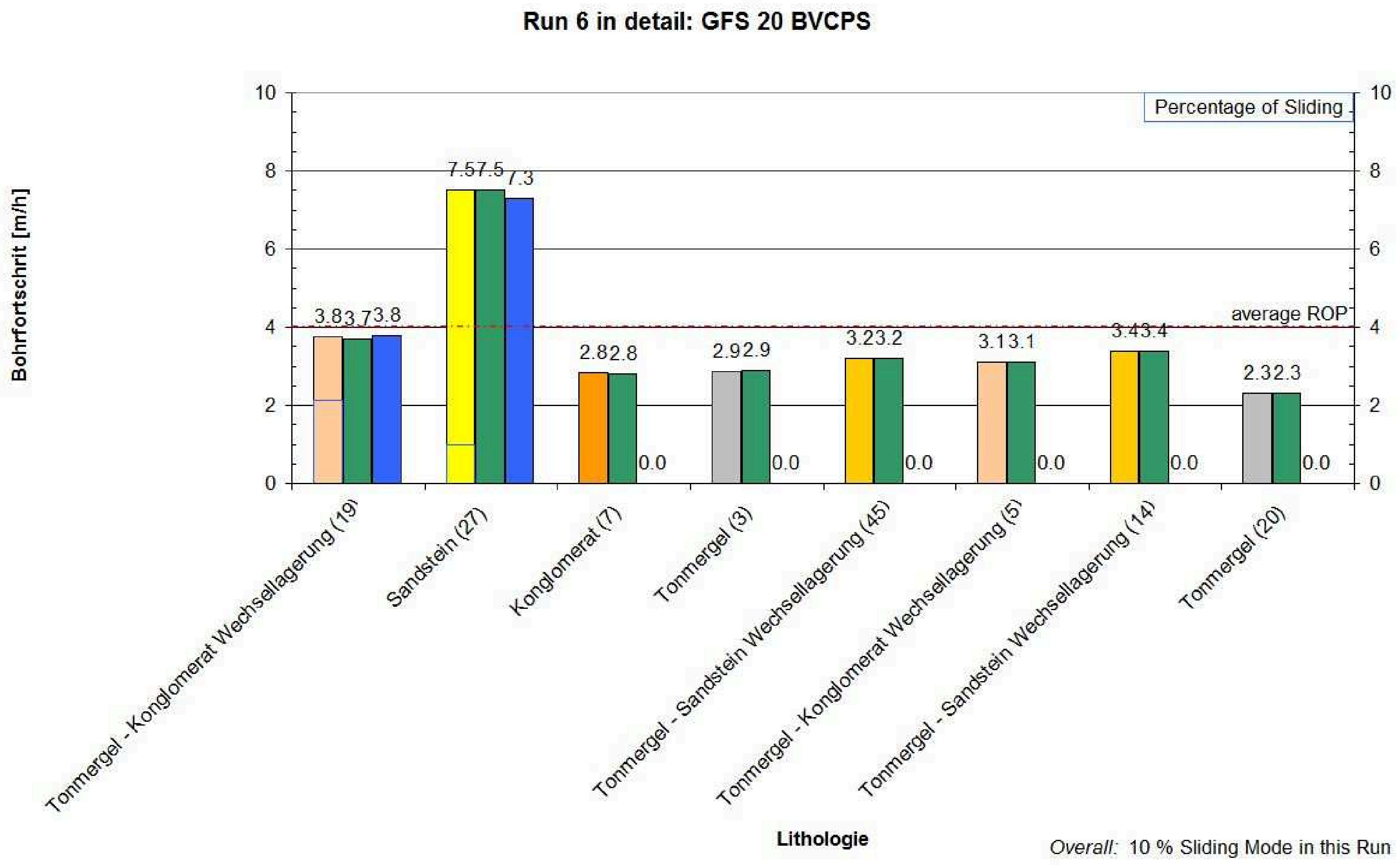
Overall: 56 % Sliding Mode in this Run

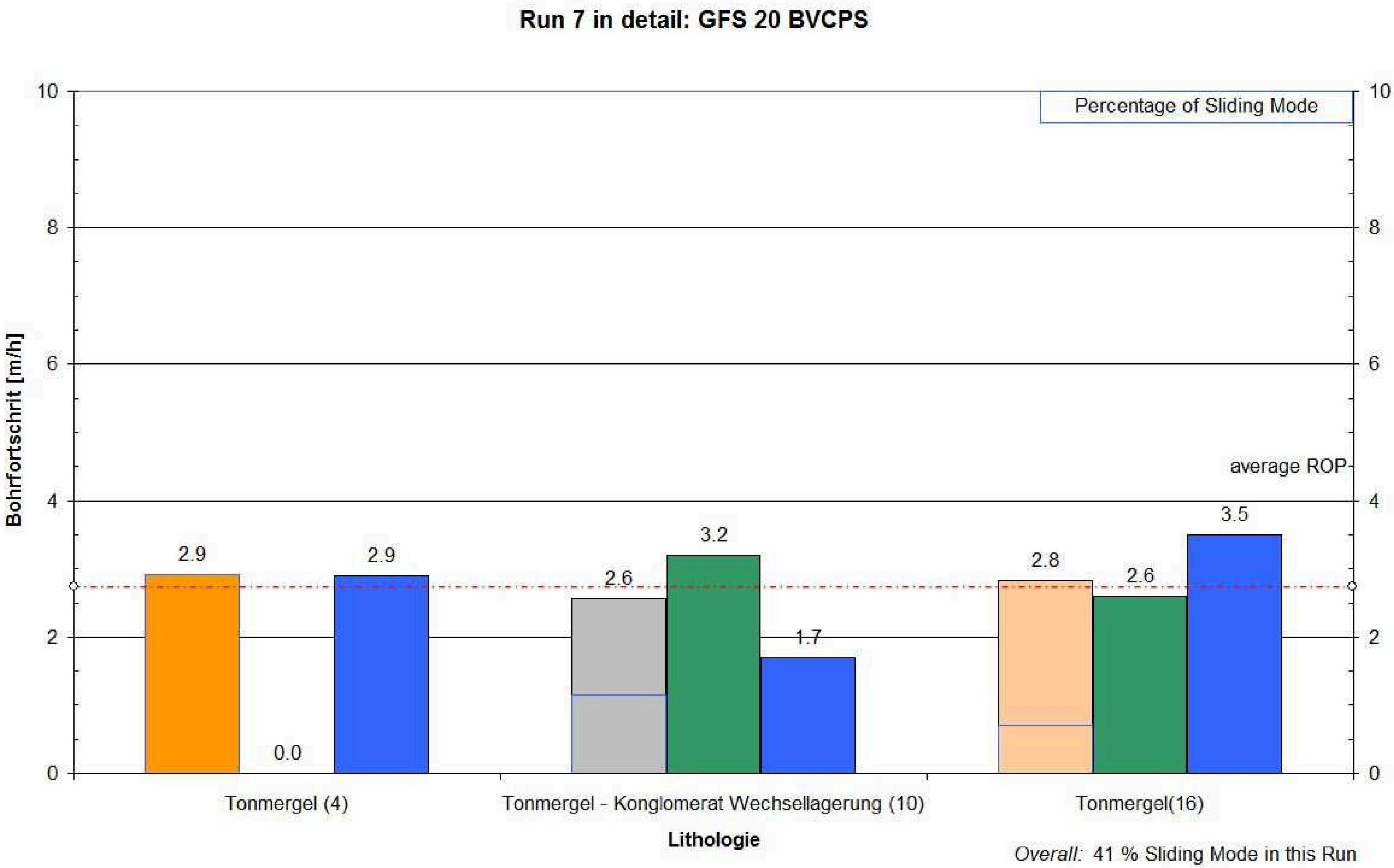

Run 4 in detail: GFS 15 BVCPS
Bohrfortschritt [m/h]
0
1
2
3
4
5
6
7
Percentage of Sliding Mode
average ROP
3.2
2.9
3.5
5.7
3.6
6.3
4.3
6.5
2.8
5.4
5.0
5.8
2.5
2.4
2.8
Tonmergel (26)
Konglomerat (11)
Tonmergel (32)
Konglomerat (19)
Tonmergel (32)
Lithologie
Overall: 50 % Sliding Mode in this Run

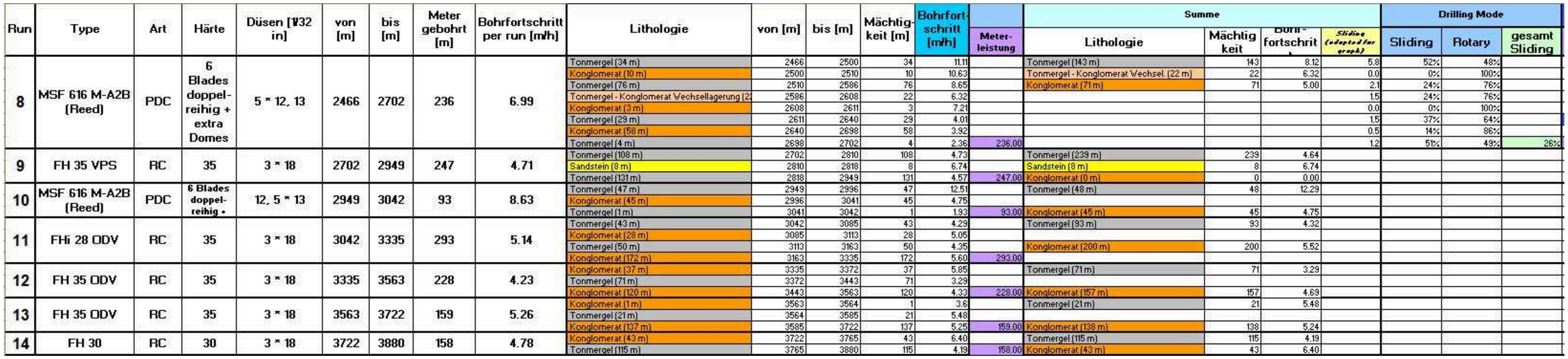


Run 5 in detail: GFi 23 BODVCPS

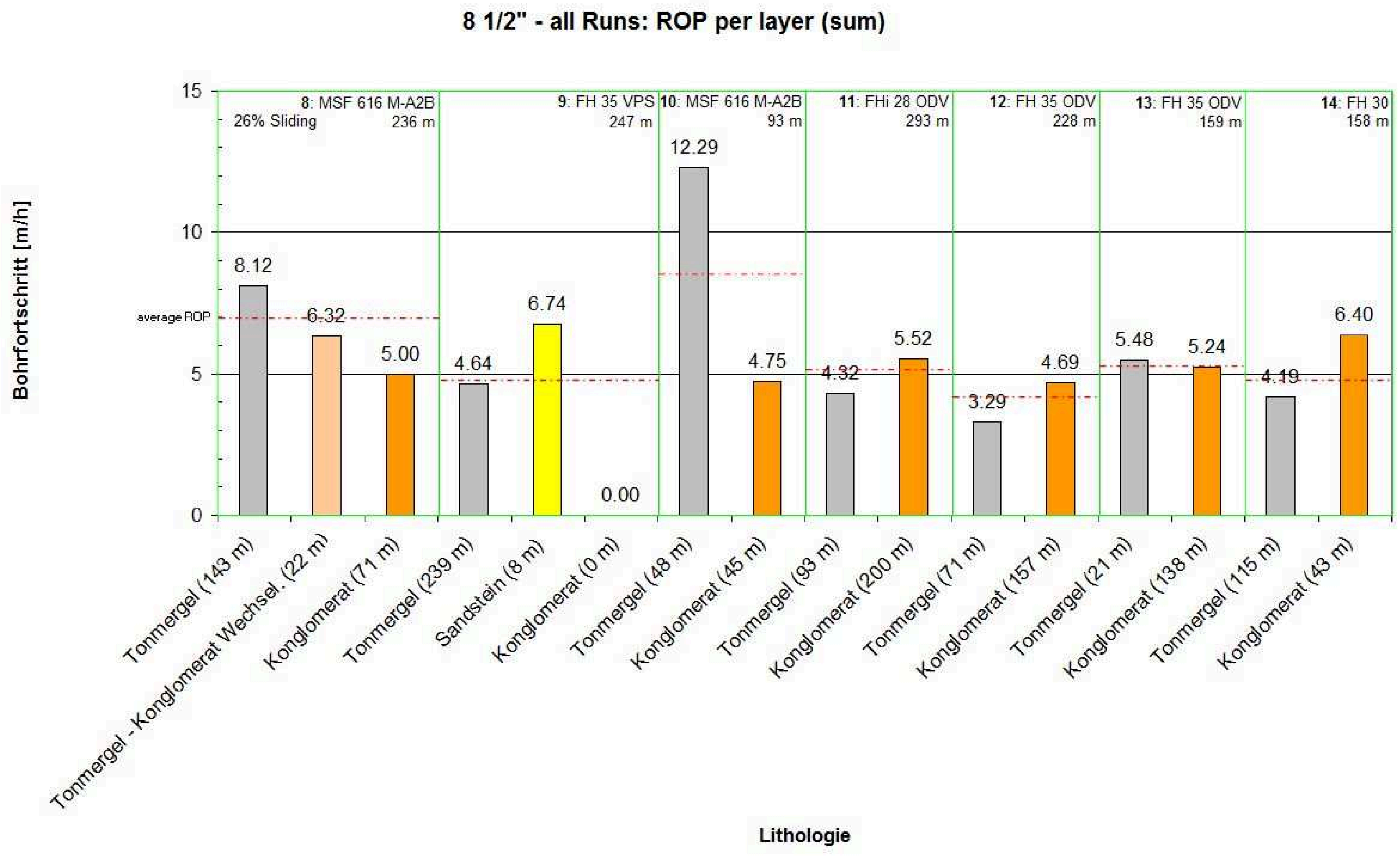
Overall: 57 % Sliding Mode in this Run

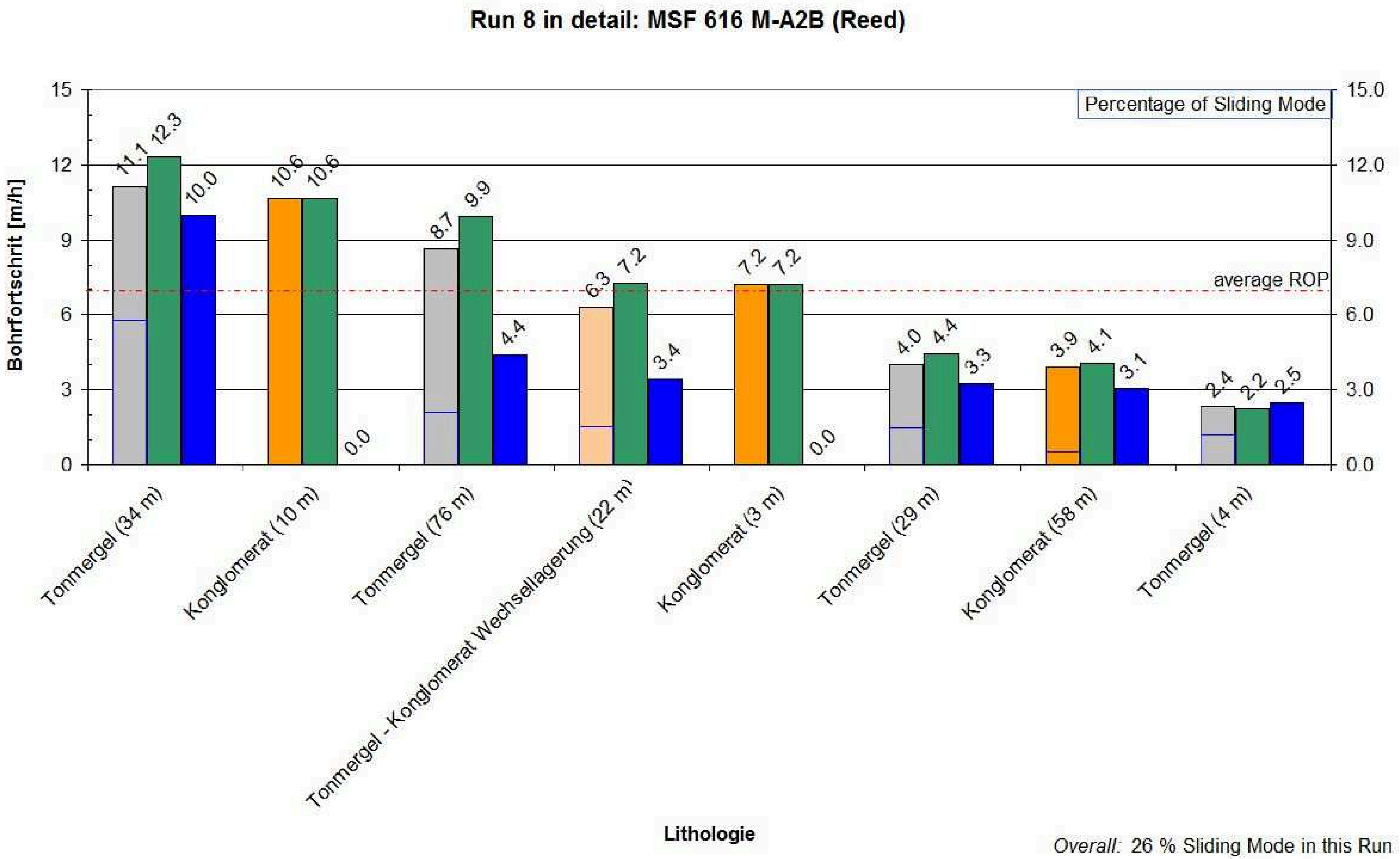

Run 6 in detail: GFS 20 BVCPS
Bohrfortschrit [m/h]
10
8
6
4
2
0
Percentage of Sliding
average ROP
3.8
3.7
3.8
7.5
7.5
7.3
2.8
2.8
0.0
2.9
2.9
0.0
3.2
3.2
0.0
3.1
3.1
0.0
3.4
3.4
0.0
2.3
2.3
0.0
Tonmergel - Konglomerat Wechsellagerung (19)
Sandstein (27)
Konglomerat (7)
Tonmergel (3)
Tonmergel - Sandstein Wechsellagerung (45)
Tonmergel - Konglomerat Wechsellagerung (5)
Tonmergel - Sandstein Wechsellagerung (14)
Tonmergel (20)
Lithologie
Overall: 10 % Sliding Mode in this Run


Run 7 in detail: GFS 20 BVCPS
Bohrfortschrit [m/h]
10
8
6
4
2
0
Percentage of Sliding Mode
average ROP
2.9
0.0
2.9
2.6
3.2
1.7
2.8
2.6
3.5
Tonmergel (4)
Tonmergel - Konglomerat Wechsellagerung (10)
Tonmergel(16)
Lithologie
Overall: 41 % Sliding Mode in this Run

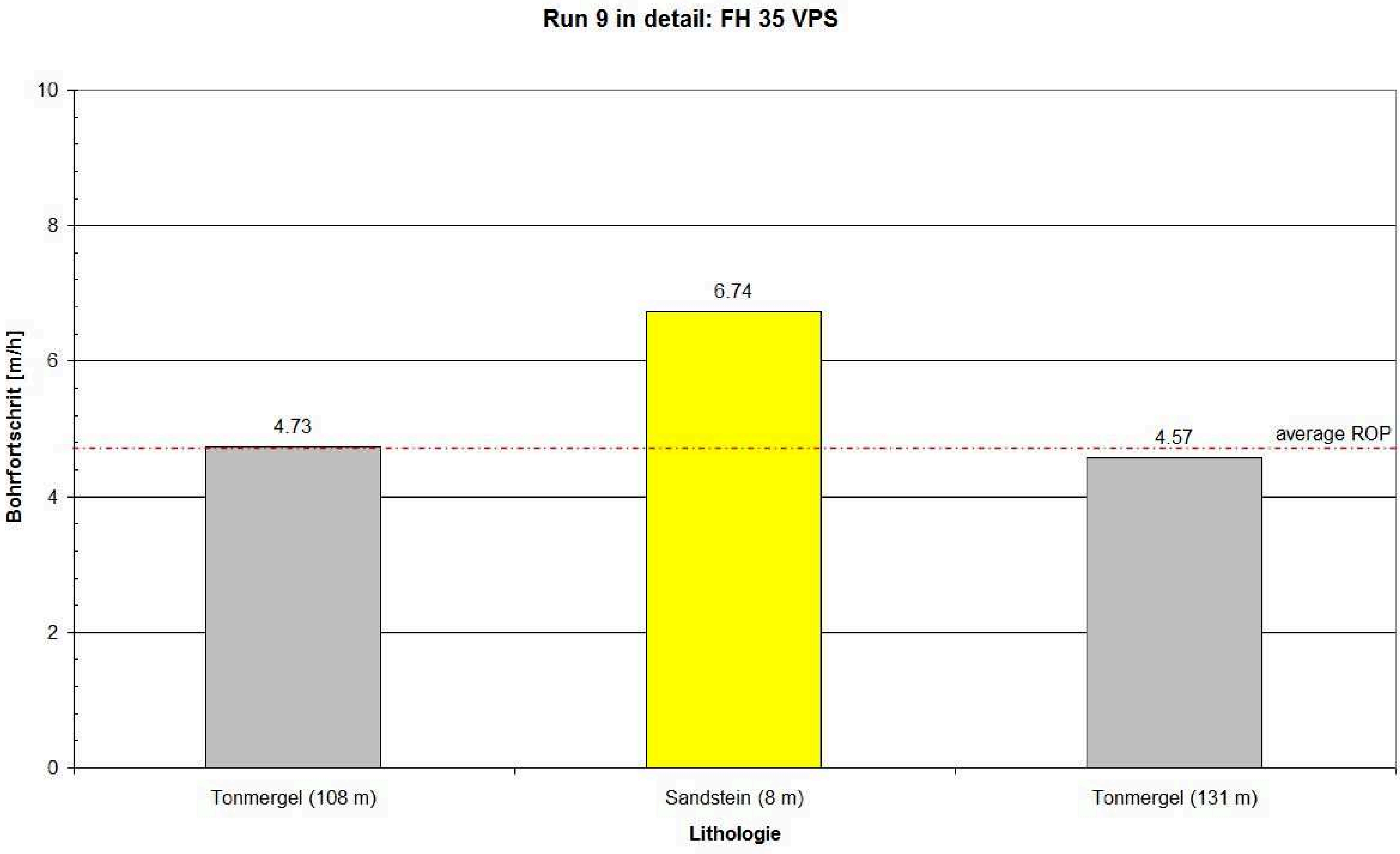


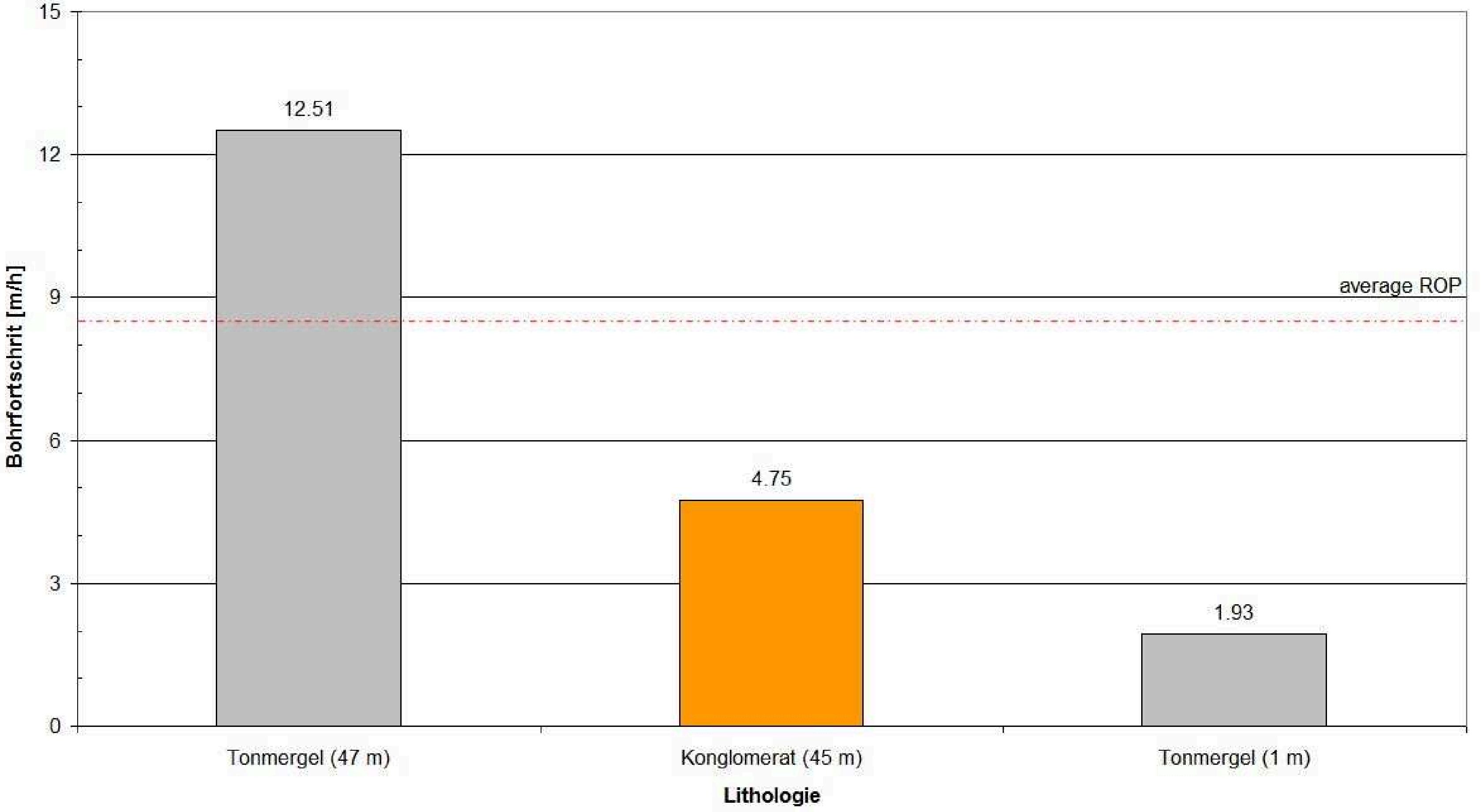
Run	Type	Art	Härte	Düsen [1/32 in]	von [m]	bis [m]	Meter gebohrt [m]	Bohrfortschritt per run [m/h]	Lithologie	von [m]	bis [m]	Mächtigkeit [m]	Bohrfortschritt [m/h]		Summe				Drilling Mode		
														Meterleistung	Lithologie	Mächtigkeit	Bohr-fortschrit	Sliding (adapted for graph)	Sliding	Rotary	gesamt Sliding
8	MSF 616 M-A2B (Reed)	PDC	6 Blades doppelreihig + extra Domes	5 * 12, 13	2466	2702	236	6.99	Tonmergel (34 m)	2466	2500	34	11.11		Tonmergel (143 m)	143	8.12	5.8	52%	48%	
									Konglomerat (10 m)	2500	2510	10	10.63		Tonmergel - Konglomerat Wechsel. (22 m)	22	6.32	0.0	0%	100%	
									Tonmergel (76 m)	2510	2586	76	8.65		Konglomerat (71 m)	71	5.00	2.1	24%	76%	
									Tonmergel - Konglomerat Wechsellagerung (2	2586	2608	22	6.32					1.5	24%	76%	
									Konglomerat (3 m)	2608	2611	3	7.21					0.0	0%	100%	
									Tonmergel (29 m)	2611	2640	29	4.01					1.5	37%	64%	
									Konglomerat (58 m)	2640	2698	58	3.92					0.5	14%	86%	
									Tonmergel (4 m)	2698	2702	4	2.36	236.00				1.2	51%	49%	26%
9	FH 35 VPS	RC	35	3 * 18	2702	2949	247	4.71	Tonmergel (108 m)	2702	2810	108	4.73		Tonmergel (239 m)	239	4.64				
									Sandstein (8 m)	2810	2818	8	6.74		Sandstein (8 m)	8	6.74				
									Tonmergel (131 m)	2818	2949	131	4.57	247.00	Konglomerat (0 m)	0	0.00				
10	MSF 616 M-A2B (Reed)	PDC	6 Blades doppelreihig +	12, 5 * 13	2949	3042	93	8.63	Tonmergel (47 m)	2949	2996	47	12.51		Tonmergel (48 m)	48	12.29				
									Konglomerat (45 m)	2996	3041	45	4.75								
									Tonmergel (1 m)	3041	3042	1	1.93	93.00	Konglomerat (45 m)	45	4.75				
11	FHi 28 ODV	RC	35	3 * 18	3042	3335	293	5.14	Tonmergel (43 m)	3042	3085	43	4.29		Tonmergel (93 m)	93	4.32				
									Konglomerat (28 m)	3085	3113	28	5.05								
									Tonmergel (50 m)	3113	3163	50	4.35		Konglomerat (200 m)	200	5.52				
									Konglomerat (172 m)	3163	3335	172	5.60	293.00							
12	FH 35 ODV	RC	35	3 * 18	3335	3563	228	4.23	Konglomerat (37 m)	3335	3372	37	5.85		Tonmergel (71 m)	71	3.29				
									Tonmergel (71 m)	3372	3443	71	3.29								
									Konglomerat (120 m)	3443	3563	120	4.33	228.00	Konglomerat (157 m)	157	4.69				
13	FH 35 ODV	RC	35	3 * 18	3563	3722	159	5.26	Konglomerat (1 m)	3563	3564	1	3.6		Tonmergel (21 m)	21	5.48				
									Tonmergel (21 m)	3564	3585	21	5.48								
									Konglomerat (137 m)	3585	3722	137	5.25	159.00	Konglomerat (138 m)	138	5.24				
14	FH 30	RC	30	3 * 18	3722	3880	158	4.78	Konglomerat (43 m)	3722	3765	43	6.40		Tonmergel (115 m)	115	4.19				
									Tonmergel (115 m)	3765	3880	115	4.19	158.00	Konglomerat (43 m)	43	6.40				


8 1/2" - all Runs: ROP per layer (sum)
Bohrfortschritt [m/h]
15
10
5
0
average ROP
8: MSF 616 M-A2B
26% Sliding
236 m
9: FH 35 VPS
247 m
10: MSF 616 M-A2B
93 m
11: FHi 28 ODV
293 m
12: FH 35 ODV
228 m
13: FH 35 ODV
159 m
14: FH 30
158 m
8.12
6.32
5.00
4.64
6.74
0.00
12.29
4.75
4.32
5.52
3.29
4.69
5.48
5.24
4.19
6.40
Tonmergel (143 m)
Tonmergel - Konglomerat Wechsel. (22 m)
Konglomerat (71 m)
Tonmergel (239 m)
Sandstein (8 m)
Konglomerat (0 m)
Tonmergel (48 m)
Konglomerat (45 m)
Tonmergel (93 m)
Konglomerat (200 m)
Tonmergel (71 m)
Konglomerat (157 m)
Tonmergel (21 m)
Konglomerat (138 m)
Tonmergel (115 m)
Konglomerat (43 m)
Lithologie

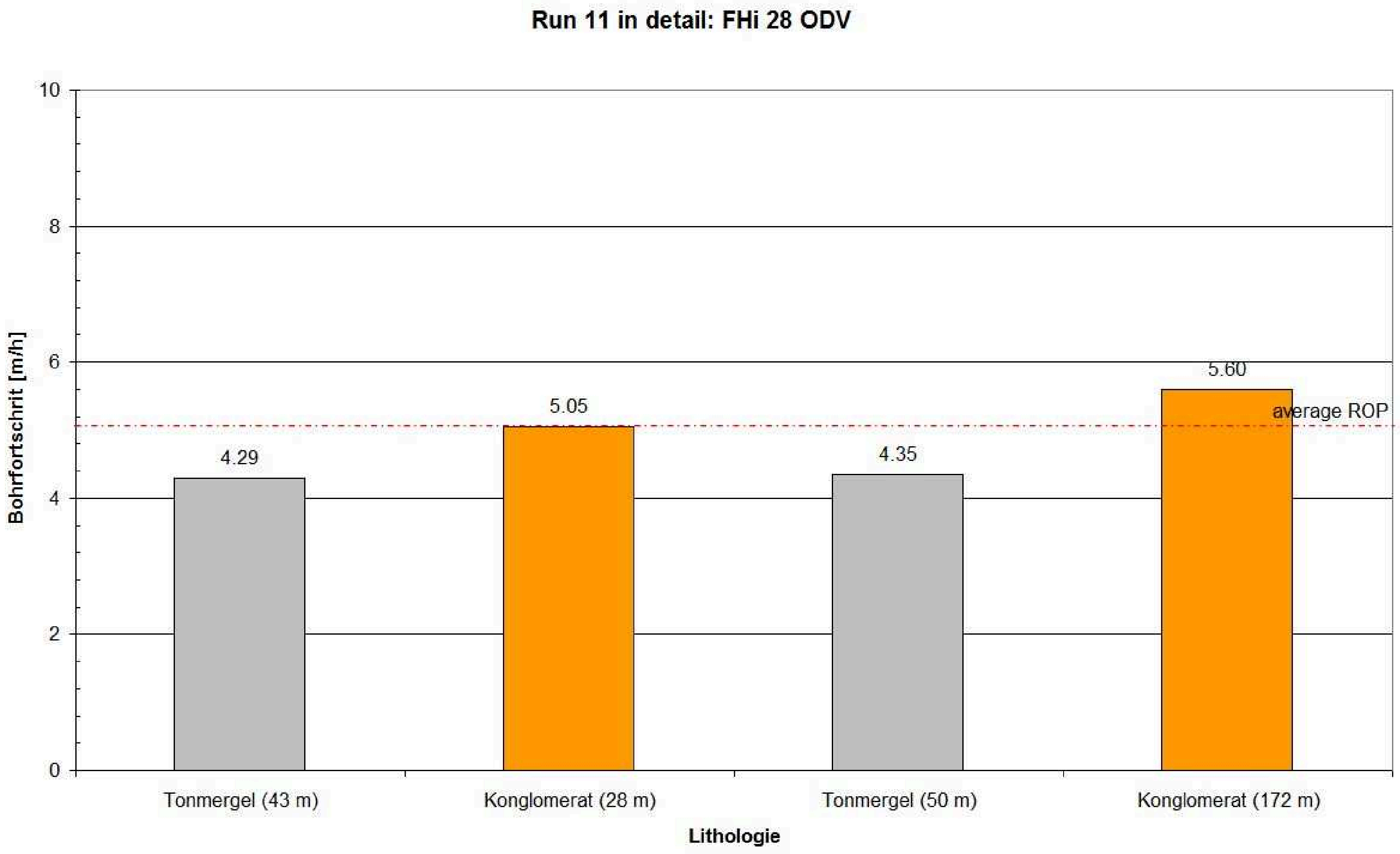


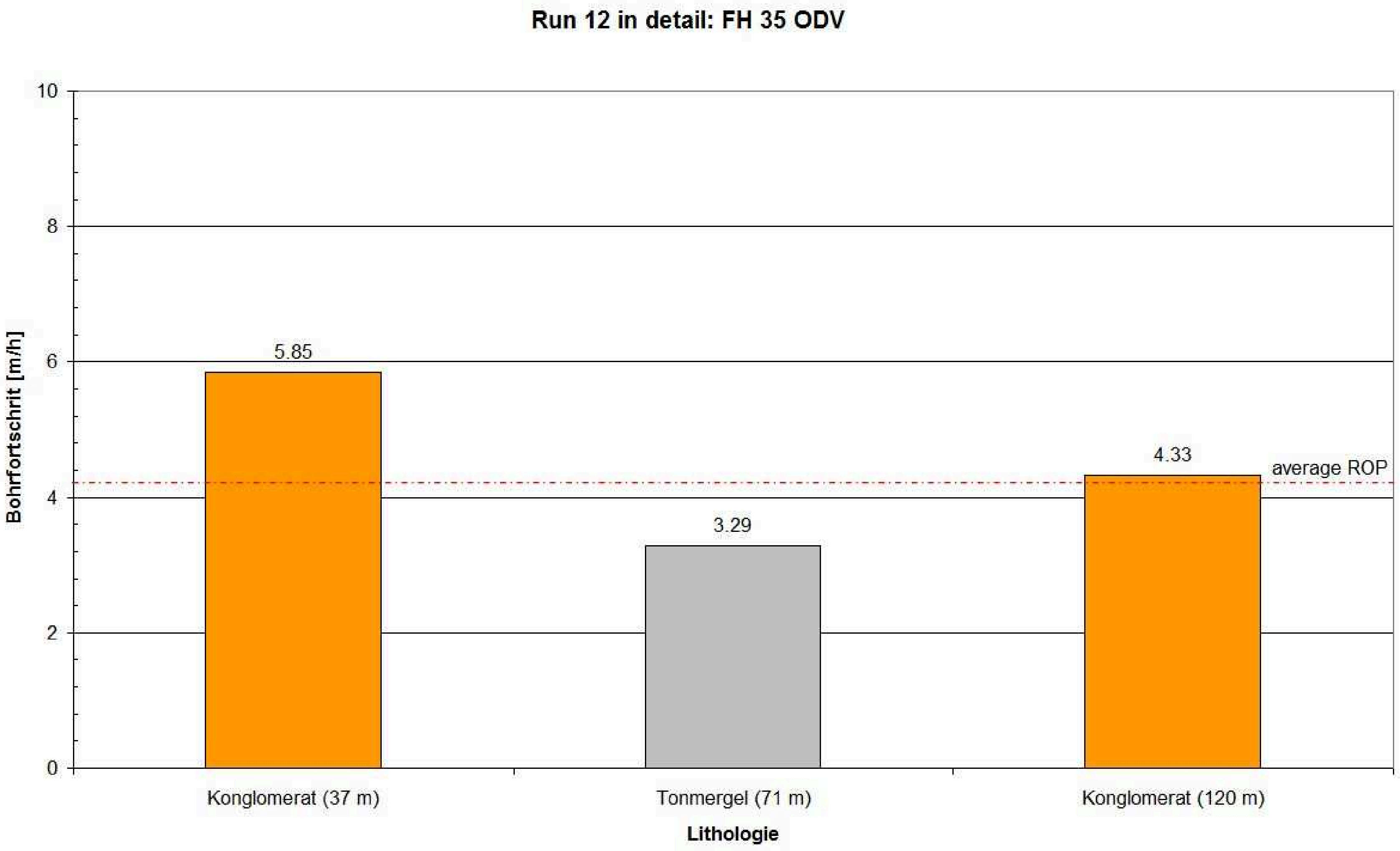
Overall: 26 % Sliding Mode in this Run

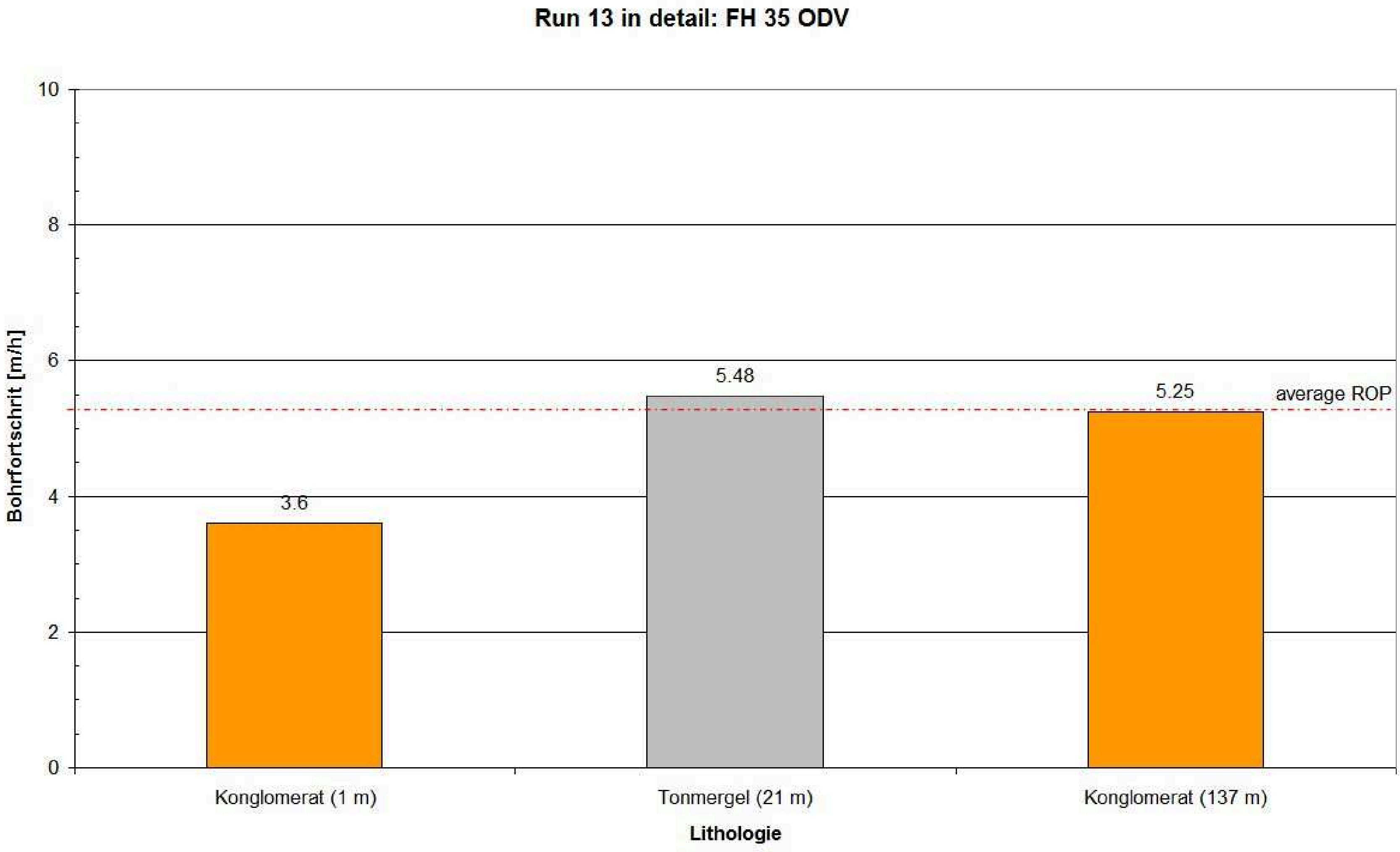

Run 9 in detail: FH 35 VPS
Bohrfortschrit [m/h]
10
8
6
4
2
0
4.73
6.74
4.57
average ROP
Tonmergel (108 m)
Sandstein (8 m)
Tonmergel (131 m)
Lithologie



Run 10 in detail: MSF 616 M-A2B (Reed)


Run 11 in detail: FHi 28 ODV
Bohrfortschrit [m/h]
10
8
6
4
2
0
4.29
5.05
4.35
5.60
average ROP
Tonmergel (43 m)
Konglomerat (28 m)
Tonmergel (50 m)
Konglomerat (172 m)
Lithologie


Run 12 in detail: FH 35 ODV
Bohrfortschrit [m/h]
10
8
6
4
2
0
5.85
3.29
4.33
average ROP
Konglomerat (37 m)
Tonmergel (71 m)
Konglomerat (120 m)
Lithologie


Run 13 in detail: FH 35 ODV
Bohrfortschrit [m/h]
10
8
6
4
2
0
3.6
5.48
5.25
average ROP
Konglomerat (1 m)
Tonmergel (21 m)
Konglomerat (137 m)
Lithologie

Run 14 in detail: FH 30