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Arbeitsbericht NAB 22-04

TBO Bachs-1-1: Data Report

Dossier I Drilling

August 2023

P. Hinterholzer-Reisegger

National Cooperative for the Disposal of Radioactive Waste

Hardstrasse 73
P.O. Box
5430 Wettingen
Switzerland
Tel. +41 56 437 11 11

nagra.ch

nagra

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BAC1-1, BAC1-1B, Nördlich Lägern, TBO, deep drilling campaign, end-of-well report, drilling, drill site, drilling technology, drilling tools, sections, casing, cementing, drilling fluid, mud system, mud losses, coring system, hole opening, potassium silicate, HSE, non-productive time

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Nagra Arbeitsberichte ("Working Reports") present the results of work in progress that have not necessarily been subject to a comprehensive review. They are intended to provide rapid dissemination of current information.

This NAB aims at reporting drilling results at an early stage. Additional borehole-specific data will be published elsewhere.

In the event of inconsistencies between dossiers of this NAB, the dossier addressing the specific topic takes priority. In the event of discrepancies between Nagra reports, the chronologically later report is generally considered to be correct. Data sets and interpretations laid out in this NAB may be revised in subsequent reports. The reasoning leading to these revisions will be detailed there.

This Dossier was prepared by a project team consisting of:
P. Hinterholzer-Reisegger (project management, writing)
F. Casanova (QC)

Editorial work: Geomecon, P. Blaser and M. Unger

The Dossier has greatly benefitted from technical discussions with, and reviews by, external and internal experts. Their input and work are very much appreciated.

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Abbreviations

API	American Petroleum Institute
APS	Accelerator porosity sonde
asl	Above sea level
ATEX	EU directives describing the minimum safety requirements of the workplace and equipment used in an explosive atmosphere (Appareils destinés à être utilisés en ATmosphères EXplosives)
bgl	Below ground level
BHA	Bottom hole assembly
BOP	Blowout preventer
BTC	Buttress thread connection
CBL	Cement bond log
CHH	Casing head housing
DDR	Daily drilling report
DETEC	Federal Department of the Environment, Transport, Energy and Communications
DMT	Deutsche Montan Technologie
EDTC	Enhanced digital telemetry cartridge
EMS	Electronic multishot system
EMW	Equivalent mud weight
ENSI	Swiss Federal Nuclear Safety Inspectorate (Eidgenössisches Nuklearsicherheitsinspektorat)
FIT	Formation integrity test
Fm.	Formation
FOEN	Federal Office for the Environment
FOPH	Federal Office of Public Health
GPIT	General purpose inclinometer tool
GR	Gamma ray
GTS	General Tubular Services GmbH
HLW	High-level waste
HSE	Health safety environment
HV	High viscosity
IADC	International Association of Drilling Contractors
KOP	Kickoff point
KSil	Potassium silicate (drilling fluid)
L/ILW	Low- and intermediate-level waste

LEH.QT	Logging equipment head with tension
LEL	Lower explosive level
LV95	National survey 95 (Landesvermessung 95)
Mb.	Member
MBT	Methylene blue test
MD	Measured depth
MDT	Modular formation dynamic tester
MHF	Micro-hydraulic fracturing
MSIP	Modular sonic imaging platform
MW	Mud weight
NL	Nördlich Lägern
NPT	Non-productive time
NSG	Application for exploration permits (Nagra Sondiergesuch)
OCMA	Oil Company Materials Association
OMM	Obere Meeresmolasse
PDC	Polycrystalline diamond compact
POOH	Pulling out of hole
PPC	Powered positioning caliper
PPE	Personal protective equipment
PV	Plastic viscosity
RIH	Run in hole
ROP	Rate of penetration
RPM	Revolutions per minute
RSS	Rotary steerable system
SG	Specific gravity
SGT	Sectoral Plan for Deep Geological Repositories
SHO	Staged hole opener
SLB	Schlumberger N. V.
SPM	Strokes per minute
SPP	Standpipe pressure
SR	Sulfate resistant
TBO	Tiefbohrungen
TCI	Tungsten carbide insert
TD	Target depth of section or hole / total depth
TOC	Top of cement

TSD	Thermally stable diamond
TVD	True vertical depth
UBI	Ultrasonic borehole imager
USIT	Ultrasonic imager tool
USM	Untere Süsswassermolasse
VSP	Vertical seismic profile
WEP	Well Engineering Partners BV
WOB	Weight on bit
WOC	Waiting on cement
WP	Work programme
YP	Yield point

1 Introduction

1.1 Context

To provide input for site selection and the safety case for deep geological repositories for radioactive waste, Nagra has drilled a series of deep boreholes ("Tiefbohrungen", TBO) in Northern Switzerland. The aim of the drilling campaign is to characterise the deep underground of the three remaining siting regions located at the edge of the Northern Alpine Molasse Basin (Fig. 1-1).

In this report, we present the results from the Bachs-1-1 borehole.

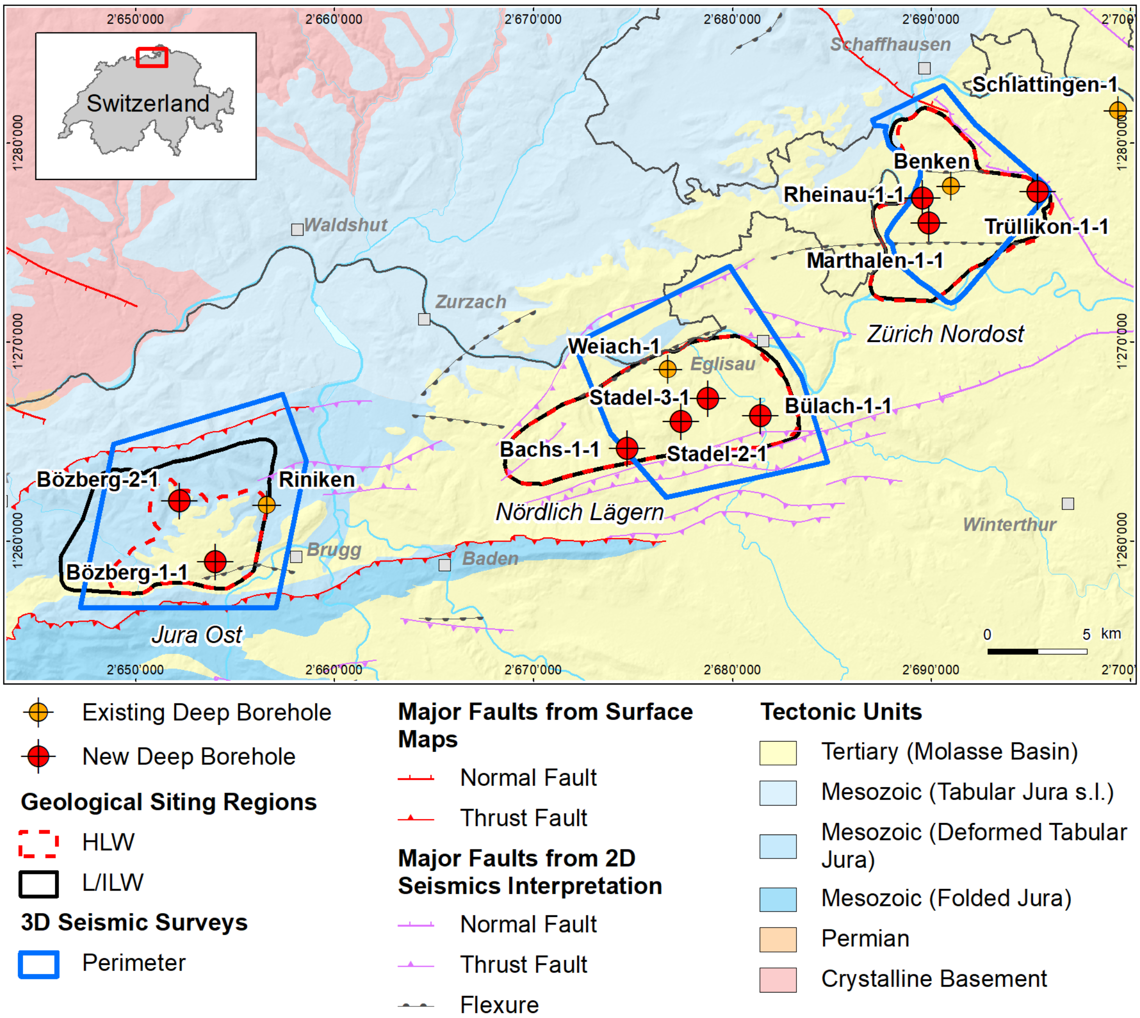

Fig. 1-1: Tectonic overview map with the three siting regions under investigation

1.2 Location and specifications of the borehole

The Bachs-1-1 (BAC1-1) exploratory borehole is the ninth (and last) borehole drilled within the framework of the TBO project. The drill site is located in the western part of the Nördlich Lägern siting region (Fig. 1-2). The vertical borehole reached a final depth of 1'306.26 m (MD)[1]. The borehole specifications are provided in Tab. 1-1.

Due to a loss of a measurement tool (dilatometer), the borehole was cemented up to 500 m MD and a sidetrack was initiated with a kickoff point (KOP) at about 600 m MD. This sidetrack was labelled Bachs-1-1B (BAC1-1B). BAC1-1B reached a final depth of 952 m MD but was abandoned during borehole reaming operations due to entering the original borehole BAC1-1. Therefore, the vertical borehole BAC1-1 was used again for the remaining investigations. For easier communication and labelling, the name BAC1-1 is generally used for this borehole, including the sidetrack, unless stated otherwise. A detailed description of all technical details about the drilling process can be found in Chapter 2.

Tab. 1-1: General information about the BAC1-1 borehole

Siting region	Nördlich Lägern
Municipality	Bachs (Canton Zürich / ZH), Switzerland
Drill site	Bachs-1 (BAC1)
Borehole	Bachs-1-1 (BAC1-1) including sidetrack Bachs-1-1B (BAC1-1B)
Coordinates	LV95: 2'674'769.089 / 1'264'600.698
Elevation	Ground level = top of rig cellar: 450.35 m above sea level (asl)
Borehole depth	1'306.26 m measured depth (MD) below ground level (bgl)
Drilling period	10th September 2021 – 23rd April 2022 (spud date to end of rig release)
Drilling company	Daldrup & Söhne AG
Drilling rig	Wirth B 152t
Drilling fluid	Water-based mud with various amounts of different components such as[2]: 0 – 700 m: Bentonite & polymers 700 – 1'057 m: Potassium silicate & polymers[3] 1'057 – 1'129 m: Water & polymers 1'129 – 1'306.26 m: Sodium chloride brine & polymers

The lithostratigraphic profile and the casing scheme are shown in Fig. 1-3. The comparison of the core versus log depth[4] of the main lithostratigraphic boundaries in the BAC1-1 borehole is shown in Tab. 1-2.

[1] Measured depth (MD) refers to the position along the borehole trajectory, starting at ground level, which for this borehole is the top of the rig cellar. For a perfectly vertical borehole, MD below ground level (bgl) and true vertical depth (TVD) are the same. In all Dossiers depth refers to MD unless stated otherwise.

[2] For detailed information see Chapter 3.

[3] Including sidetrack.

[4] Core depth refers to the depth marked on the drill cores. Log depth results from the depth observed during geophysical wireline logging. Note that the petrophysical logs have not been shifted to core depth, hence log depth differs from core depth.

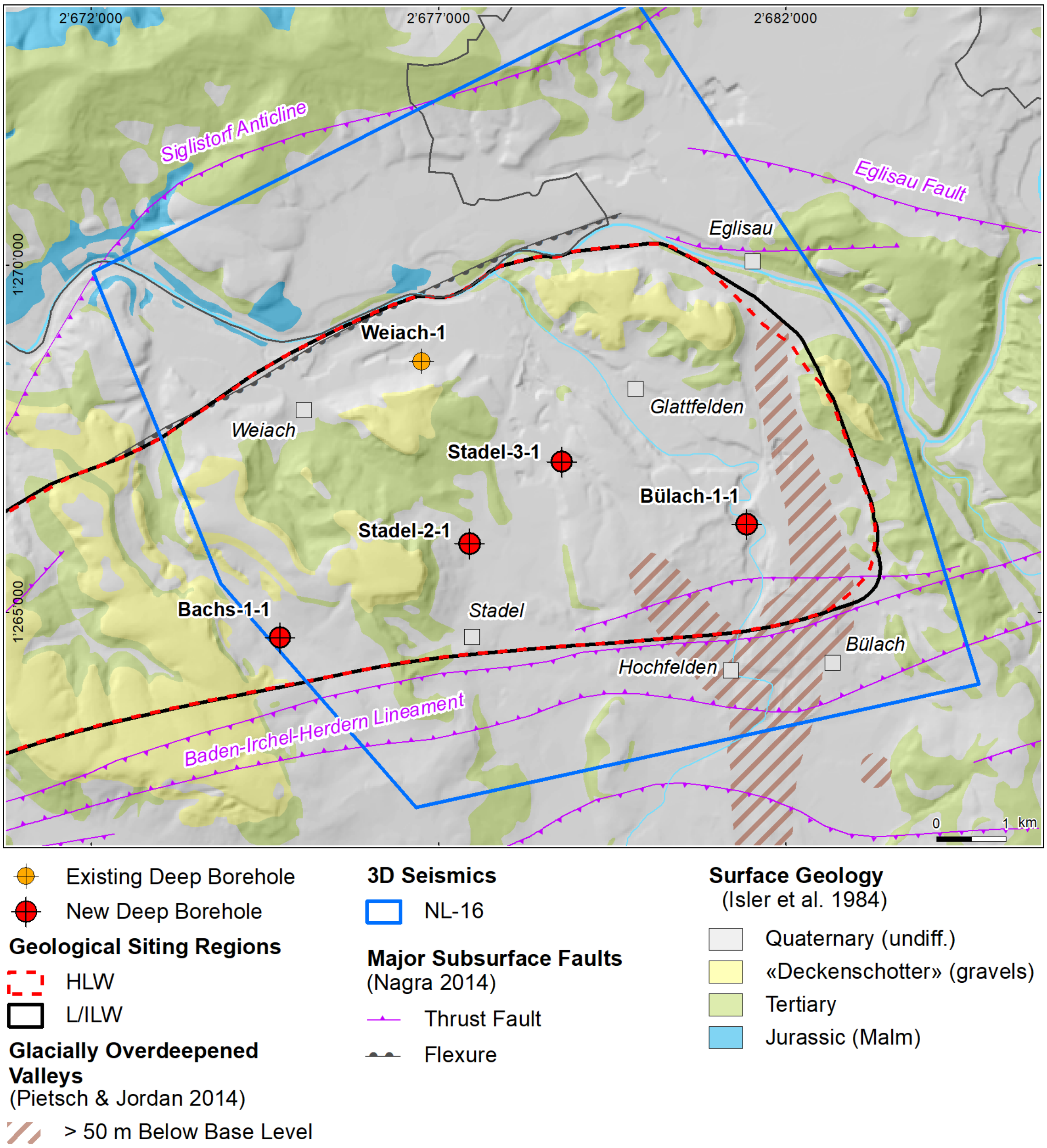

Fig. 1-2: Overview map of the investigation area in the Nördlich Lägern siting region with the location of the BAC1-1 borehole in relation to the boreholes Weiach-1, BUL1-1, STA3-1 and STA2-1

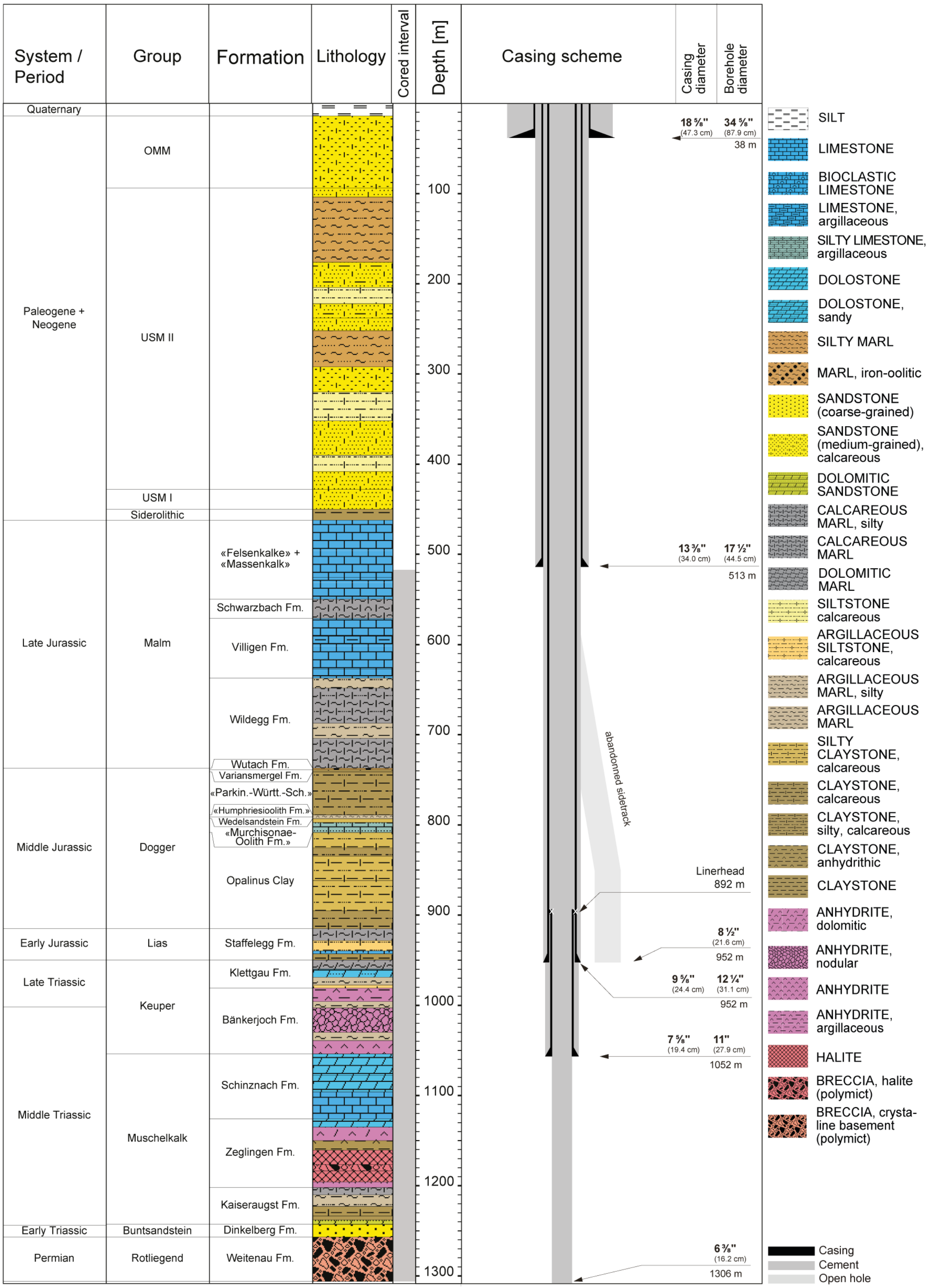

Fig. 1-3: Lithostratigraphic profile and casing scheme for the BAC1-1 borehole[5]

[5] For detailed information see Chapter 3 and Dossier III.

Tab. 1-2: Core and log depth for the main lithostratigraphic boundaries in the BAC1-1 borehole[6]

System / Period	**Group**	**Formation**	**Core** top depth in m (MD)	**Log** top depth in m (MD)
Quaternary				
Paleogene + Neogene	OMM		**14**	
	USM		94	
	Siderolithic		450	
Jurassic	Malm	«Felsenkalke» + «Massenkalk»	**462**	
		Schwarzbach Formation	549.69	550.03
		Villigen Formation	570.98	571.29
		Wildegg Formation	637.31	637.55
	Dogger	Wutach Formation	737.05	737.32
		Variansmergel Formation	738.81	739.08
		«Parkinsoni-Württembergica-Schichten»	741.22	741.47
		«Humphriesioolith Formation»	788.92	789.12
		Wedelsandstein Formation	791.05	791.25
		«Murchisonae-Oolith Formation»	793.11	793.31
		Opalinus Clay	808.34	808.57
	Lias	Staffelegg Formation	914.91	915.30
Triassic	Keuper	Klettgau Formation	**949.73**	**950.07**
		Bänkerjoch Formation	980.93	981.27
	Muschelkalk	Schinznach Formation	1053.90	1054.30
		Zeglingen Formation	1125.75	1126.20
		Kaiseraugst Formation	1202.03	1202.43
	Buntsandstein	Dinkelberg Formation	1242.82	1243.12
Permian	Rotliegend	Weitenau Formation	**1256.86**	**1257.26**
		final depth	1306.26	1306.77

[6] For details regarding lithostratigraphic boundaries see Dossier III and IV; for details about depth shifts (core goniometry) see Dossier V.

1.3 Documentation structure for the BAC1-1 borehole

NAB 22-04 documents the majority of the investigations carried out in the BAC1-1 borehole, including laboratory investigations on core material. The NAB comprises a series of stand-alone dossiers addressing individual topics and a final dossier with a summary composite plot (Tab. 1-3).

This documentation aims at early publication of the data collected in the BAC1-1 borehole. It includes most of the data available approximately one year after completion of the borehole. Some analyses are still ongoing (e.g. diffusion experiments, analysis of veins, hydrochemical interpretation of water samples) and results will be published in separate reports.

The current borehole report will provide an important basis for the integration of datasets from different boreholes. The integration and interpretation of the results in the wider geological context will be documented later in separate geoscientific reports.

Tab. 1-3: List of dossiers included in NAB 22-04

Black indicates the dossier at hand.

Dossier	Title	Authors
I	TBO Bachs-1-1: Drilling	P. Hinterholzer-Reisegger
II	TBO Bachs-1-1: Core Photography	D. Kaehr, M. Stockhecke & Hp. Weber
III	TBO Bachs-1-1: Lithostratigraphy	P. Jordan, P. Schürch, M. Schwarz, R. Felber, H. Naef, T. Ibele & F. Casanova
IV	TBO Bachs-1-1: Microfacies, Bio- and Chemostratigraphic Analyses	S. Wohlwend, H.R. Bläsi, S. Feist-Burkhardt, B. Hostettler, U. Menkveld-Gfeller, V. Dietze & G. Deplazes
V	TBO Bachs-1-1: Structural Geology	A. Ebert, E. Hägerstedt, S. Cioldi, L. Gregorczyk & F. Casanova
VI	TBO Bachs-1-1: Wireline Logging, Micro-hydraulic Fracturing and Pressure-meter Testing	J. Gonus, E. Bailey, J. Desroches & R. Garrard
VII	TBO Bachs-1-1: Hydraulic Packer Testing	R. Schwarz, R. Beauheim, L. Schlickenrieder, E. Manukyan & A. Pechstein
VIII	TBO Bachs-1-1: Rock Properties, Porewater Characterisation and Natural Tracer Profiles	E. Gaucher, L. Aschwanden, T. Gimmi, A. Jenni, M. Kiczka, M. Mazurek, P. Wersin, C. Zwahlen, U. Mäder & D. Traber
IX	*The geomechanical campaign in BAC-1-1 was limited to two oedometric tests. Hence, no dedicated Dossier IX was produced for NAB 22-04. The hydraulic conductivity values derived from the oedometric tests are documented in the Summary Plot.*	
X	TBO Bachs-1-1: Petrophysical Log Analysis	S. Marnat & J.K. Becker
	TBO Bachs-1-1: Summary Plot	Nagra

1.4 Scope and objectives of this dossier

The dossier at hand provides a summary of the drilling operations, including rig site construction, casing tallies, cement bond quality, coring parameters and recovery.

The report is organised as follows:

- Chapter 1 presents the general overview of the drilling campaign and the vertical borehole BAC1-1 including the sidetrack BAC1-1B
- Chapter 2 is dedicated to the drilling technology
- Chapter 3 describes the construction phase, drilling operations and their chronology
- Chapter 4 discusses the health, safety and environmental topic
- Finally, this report includes a set of appendices, which present relevant general project information and further investigation details

1.5 Involved companies

The following companies were involved in the drilling activities of the BAC1-1 borehole:

- Nagra
  - Drilling manager: project management, coordination and organisation of the drilling of the borehole, definition of test aims, quality control, technical drilling supervision, coring, casing running, cementing, logging and testing operations performed in the borehole
  - Drilling engineer: technical drilling supervision, coring, casing running, cementing, logging and testing operations performed in the borehole
  - Health safety & environment (HSE) manager
- Daldrup & Söhne AG: drilling contractor
- GEO-data GmbH: mud logging and core handling
- AKROS Oilfield Services GmbH: mud engineering
- Fangmann Energy Services: cementing service and liner hanger systems
- GTS General Tubular Services GmbH: casing running / float equipment service
- Schlumberger (SLB) Ltd.: wireline logging and testing, directional drilling services and RSS + mud motor equipment
- Terratec geophysical services GmbH & Co. KG: wireline logging
- INTERA Inc.: hydraulic and gas testing
- Solexperts AG: gas testing
- Deutsche Montan Technologie (DMT) GmbH & Co KG and SLB: seismic service
- Well Engineering Partners BV (WEP): drilling supervisors
- MICON-Drilling GmbH: wireline coring string
- National Service Company S.R.L.: fishing services and milling equipment
- Titan Tools Services Ltd.: underreaming services and equipment

2 Drilling technology

2.1 Overview

The rig and all peripheral facilities were operated electrically. The rig itself was connected to a separate electro-hydraulic main drive unit, and the mud pumps were operated by a variable frequency drive unit.

The nominal pulling force of the system was 175 t. Technical data of the system and its associated components can be found in Appendix C.

The drilling rig of the contractor Daldrup & Söhne AG was a Wirth B 152t (152 t operational hook load with ten lines) semi-trailer with moveable mast. The draw works had a power of 300 kW. The top drive was a B 152 with 255 kW drive system power. Mud pumps were two triplex pumps IDECO T-1000 with a 750 kW power rating for each pump. Three Falcon shale shakers, one centrifuge and one flocculation unit were provided by the mud service company. An overview of the general drilling rig data can be found in Tab. 2-1 and a detailed description of the equipment in Appendix C.

Tab. 2-1: General drilling rig data

Drilling rig manufacturer	Wirth Maschinen- und Bohrgeräte GmbH, Erkelenz
Type of drilling rig	Universal rig
Construction	Semi-trailer with moveable mast
Type	B 152t
Original	B 12 SH 30000 / DS 05
Construction year	1980, modified 2007
Total height above ground level	21.3 m
Height of rotary table	2.83 m
Rig floor area	24 m^2
Rig floor load capacity	1'500 kg/m^2
Hook load dynamic (10 lines)	1'520 kN
Hook load static (10 lines)	1'750 kN
Crown block load	2'000 kN
Maximum torque	50 kNm
Continuous torque	12.5 kNm
Maximum rotational speed	390 RPM
Drill pipe handling	Single drill pipe handling
Drive	Electro-hydraulic
Drive power	2 × 174 kW
Lifting drive	Hydrostatic
Lifting – input power	300 kW

Tab. 2-1: continued

Rotary system	Top drive
Maximum allowable wind force (operation)	80 km/h
Total trailer weight	54'000 kg
Maximum shaft load	12'000 kg
Maximum width	2'750 mm
Trailer length	17.89 m
Transport height	3.45 m

The top drive had been in operation since 1981 and was purchased by the drilling contractor in 2003. Records showed that the unit had completed a total of 79'655 m of drilling up to 2016. The deepest borehole was drilled to a depth of 3'005 m MD.

The load of the entire semi-trailer was transferred to four supports. The maximum vertical load on each support at the rig cellar supporting the mast was 950 kN. At the shaft end of the trailer the load on each support was 150 kN.

All drilling activities were continuously recorded by the mud logging service using real-time monitoring. The following parameters were recorded:

- suction pit levels
- mixing pit levels
- trip tank level
- desilting pit level
- sand trap level
- top drive torque
- make-up torque
- revolutions per minute (RPM) of bit and string
- flowrate OUT
- strokes per minute (SPM) of the two mud pumps
- standpipe pressure (SPP)
- hook load
- annular pressure
- hook height
- mud weight (MW) IN/OUT
- mud temperature IN/OUT
- wind speed and direction – anemometer
- gas detection: total hydrocarbons (C1 to iC5), lower explosive limit (LEL), H_2S, CO_2

2.2 Drilling / coring tools

2.2.1 Drill string and wireline coring string

Two different drill strings were used for the BAC1-1 borehole, the same as for the BUL1-1, MAR1-1, BOZ2-1 and STA2-1 boreholes. A 5½" wireline coring string (SK 5½" B, N80) from the manufacturer MICON-Drilling GmbH (MICON-Drilling 2016) was mainly used for coring operations, and a 5" drill string (S135, #19.5) was mainly used for destructive drilling, hole opening and drilling out cement and float equipment.

Wireline core barrels are designed for reliable, complete recovery of the core without pulling out the drill string. This technique speeds up core retrieval, reduces time-consuming drill rod handling and helps to maximise coring efficiency. The catching assembly is attached to a wireline winch system and lowered into the wireline drill string. The overshot securely interlocks with the latching head. Subsequently, the core-filled inner tube system can be hoisted out through the wireline drill string.

The wireline coring system used for the BAC1-1 borehole consisted of a core bit, inner and outer core barrel, core catcher, drill pipes, stabilisers, as well as crossovers and other spare parts and consumables. The drilling diameter was 6⅜" (161.9 mm), resulting in a core diameter of 95 mm. All cores were drilled with plastic liners for protection and higher quality of the cores. These plastic liners allowed simplified handling of the cores, eliminating mechanical impacts such as hammering or pumping out the core from the inner core barrel. It enabled transport of the cores to the core handling table in one piece. The core was then removed from the plastic liner by pushing it out by hand or cuttings the liner along the longitudinal axis. Core lengths up to 6 m could be reached with the wireline coring system, but to decrease the exposure time of the core in the drilling fluid and during sampling, the core length was fixed to 3 m.

Compared to conventional drill pipes, the wireline coring pipes with an average length of 9 m have slick tool joints, which means that the outer diameter of the pipe body and the tool joint are identical. Tool joints have no shoulders and the diameter of 5½" is the same along the entire drill string. This prevents flow restrictions and improves hole cleaning during coring within the small annulus between the formation and the coring string.

For drilling operations other than coring, conventional 5" drill pipes were used as they have standard connections which make assembling the BHA much easier compared to the coring string, which has non-standard connections. The outer diameter of the tool joint is larger (168 mm) than the body of the 5" drill pipe to accommodate the threads. Furthermore, these shoulders provide stiffness to prevent bending and breaking. Due to the large diameter at the tool joint, the 5" drill pipes with an average length of 9.6 m did not fit into the 6⅜" borehole.

A hydrocarbon-free and metal-free pipe grease was used for all tool and pipe connections to prevent the drilling mud from contamination with traces of hydrocarbons, which was very important for hydrotesting and fluid sampling. The datasheet for the pipe grease can be found in Appendix J.

2.2.2 Core bits

Two different types of core bits (see Fig. 2-1) were used in the BAC1-1 borehole:

- Thermally stable diamond (TSD) core bit, also called 'synset' core bit:

  This type of core bit is designed for medium hard to hard and medium abrasive formations. TSD cutters consist of multiple layers of synthetic diamond fragments. This feature gives TSD cutters a self-sharpening behaviour.

  Synset core bits were mainly used in the clay-rich formations of BAC1-1, such as the Opalinus Clay.

- Diamond-impregnated matrix core bit:

  This type of core bit is designed for medium hard to extremely hard formations, but also for less abrasive to very abrasive rocks. Multiple layers of synthetic diamond fragments are sintered into a hard metal matrix. This compound behaves self-sharpening during progressive abrasion. Worn diamonds are released and replaced by new ones, until the matrix compound is completely eroded. This core bit is available with different types of matrix.

  For BAC1-1, impregnated core bits with a medium to soft matrix were chosen mainly for coring limestone, dolostone, anhydrite and sandstone. This type of matrix is designed for less abrasive but hard, fine-grained and homogeneous formations.

Fig. 2-1: Synset core bit (left) and impregnated core bit (right)

Four new impregnated and four new synset core bits were used for coring the borehole. Used core bits were usually run in hole to execute roundtrips and condition the mud. A bit summary including bit grading for BAC1-1 can be found in Appendix K. All bit grading given in this report refers to the IADC dull grading system.

Coring operations do not usually require a complex BHA design due to the small clearance between the formation and the drill string. The list of BHA components for coring is therefore limited to core bits and stabilisers.

2.2.3 Drilling and hole opening bits

Section I of the BAC1-1 borehole was drilled with a 17½" tungsten carbide insert (TCI) tricone bit which showed very good performance. Especially for this section, the drill bit selection, hydraulics and BHA design were key factors to stay vertical during drilling, to create sufficient rate of penetration (ROP) and to ensure good hole cleaning. Based on experiences from the MAR1-1 and STA2-1 boreholes, it was decided to use a 9⅝" mud motor for drilling Section I (see datasheet for the mud motor in Appendix L).

Drilling out cement and float equipment of the individual sections was mostly done with milled tooth tricone bits without any problems. These bits are a type of rolling cutter bit that has tooth cutters made up of steel which have been assembled as part of the bit cone.

The sidetrack BAC1-1B was drilled with an 8½" polycrystalline diamond compact (PDC) bit. This type of bit has a fixed head, rotating as one piece with no separately moving parts. PDC bits are usually long lasting and have a high ROP potential. For drilling the sidetrack with the RSS, the 8½" PDC bit showed very good performance reaching ROPs up to 12 m/h.

Staged hole openers (SHOs) were used to enlarge the existing borehole to the required diameter for casing running and cementing, mostly in steps from 6⅜" to 8½" and from 8½" to 12¼". These SHOs run with a bullnose or a pilot bit of the same size as the existing borehole at the bottom, which serves as guidance for the enlarged hole. The pilot section of the SHO itself (lower part of the SHO) consists of one or two rows of cuttings structures to recondition the pilot hole and remove any swelling clays or loose material. Gauge pads provide initial stabilisation as the SHO begins the staged reaming process to reduce stick/slip, whirling or off-centre tendencies. The lower cutters of the SHO are designed to minimise work rates on each cutter position for maximum durability. By relieving stress from the formation with this intermediate stage, larger-hole drilling can be done at a more aggressive ROP. This part of the SHO recentralises the SHO on the given vertical borehole trajectory. The main body of the SHO completes the final hole diameter. With the formation being already stress-relieved, the reaming section remains aggressive, even in more competent formations. Gauge trimmers and spiralled gauge pads ensure good hole quality.

Besides the drilling and hole opening bits, a good stock of various stabilisers, drill collars, heavy weight drill pipes and other BHA components was kept onsite to be able to arrange proper BHA setups for the planned work steps. Appropriate BHA designs are of great importance in drilling operations to effectively load and control the drill bit.

3 Drilling operations

3.1 Overview

Following a licensing procedure which lasted several years, accessing and construction of the drill site began in May 2021. During the construction phase, an 18⅝" (473 mm) conductor casing was installed and cemented down to a depth of 38 m MD (measured depth). This conductor was installed through the Quaternary and several metres into the Untere Süsswassermolasse (USM) to protect the groundwater. Construction of the drill site ended by the beginning of August 2021 and the site was handed over to the drilling contractor on 13.08.2021. Minor correction work on the drill site was carried out by the construction company up to 30.08.2021.

With the drilling permission granted by the Swiss Federal Nuclear Safety Inspectorate (ENSI 2017) on 10.09.2021, drilling operations started on the same day and, including the scientific investigations carried out in the borehole, continued until 23.04.2022 (225 days, 24 h operations, 81 days of which were for logging and testing activities and 16 days of Christmas break). At a final depth of 1'306 m MD, the borehole passed through 1'306 m of Cenozoic, Mesozoic and Paleozoic sediments. The Opalinus Clay was found from 808 m to 915 m MD (107 m thick).

The borehole was drilled with a tricone bit for the uppermost 515 m. The remaining sections were continuously cored using the wireline coring technique. The drilling rig used was a hydraulic rotary drilling rig, type Wirth B 152t.

The cored sections were drilled entirely with a wireline coring string using an inner core barrel and plastic liners for core protection. Core recovery was almost 100%. The main coring diameter and the final diameter of the borehole at 1'306 m MD was 6⅜" (161.9 mm). The cores had a diameter of 95 mm.

A total of five permanent casings were installed in the borehole and, with the exception of the 7⅝" liner hanger, cemented up to surface.

During the logging and testing sequence at 952 m MD, a dilatometer tool was lost in hole on 08.12.2021. After several fishing attempts, the tool could not be recovered. It was decided to cement the borehole back until 500 m MD and drill the whole section again with an 8½" sidetrack after the Christmas break. The borehole was then named BAC1-1B. After logging and testing the sidetrack, the borehole should have been opened up to 12¼" for running the casing. The hole opener could not enter the 8½" sidetrack and opened up the original and cemented BAC1-1 borehole instead. It was not possible to deviate from the original borehole nor to find the sidetrack again. Therefore, the dilatometer tool was milled out and the working programme could be continued as per plan. The sidetrack BAC1-1B was abandoned and the borehole was named BAC1-1 again on 05.02.2022 after running and cementing the 9⅝" casing.

The upper section of the borehole down to the bottom of the Malm limestones was drilled using a freshwater bentonite polymer drilling fluid. The Opalinus Clay and its neighbouring formations were drilled using a potassium silicate drilling fluid. This drilling mud showed excellent functioning in inhibiting swelling of clay formations sensitive to freshwater. Despite multiple time-intensive hydraulic borehole tests in the target formations, the borehole showed excellent stability with the potassium silicate fluid.

Besides these two types of drilling fluid (bentonite polymer and potassium silicate), the last section (Muschelkalk, Buntsandstein and Rotliegend) was drilled using a saturated salt mud to ensure good core quality in the expected salt layer.

Once the final depth of 1'306 m MD had been reached and the active borehole investigations were completed, the borehole was abandoned and backfilled with cement up to surface.

Work was completed within 225 working days (continuous 24 h operation) after spud. Rig down was performed over two weeks until the construction company started with the dismantling works of the drill site. The deep borehole (TBO) project was finalised by finishing the BAC1-1 borehole on 23.04.2022. The time used for scientific investigations in the BAC1-1 and BAC1-1B borehole amounted to around 36% and the drilling and coring activities to 64%, including casing and cementing operations. The total duration of the project was 64 days longer than the original work programme. The sidetrack BAC1-1B made up for 15% of the total time for completing the borehole. Non-productive time (NPT) added up to a total of 19.6 days; 14.4 days were related to drilling activities and 5.2 days NPT were related to logging and testing activities.

Continuous gas detection during the execution of the BAC1-1 and BAC1-1B borehole showed no significant occurrences of hydrocarbon gases, CO_2 or H_2S.

Regarding health, safety and environment (HSE), no first aid cases, no lost time incidents, no spills and no COVID-19 infections were reported from September 2021 to April 2022.

Unless mentioned otherwise, depth values indicated in this report should be understood as driller's depth.

3.2 Drill site construction and conductor

Start of execution

Before the start of construction, a technical investigation as well as soil investigations were carried out for the drill site, including extensive profile recordings. In accordance with the specifications of the authorities, the building permission was divided into:

- Stage 1: earthworks (permission given on 28.04.2021)
- Stage 2: in situ concrete construction of the rig cellar (permission given on 02.06.2021)

Work preparation

The layout of the drill site was planned and prepared by Nagra with the assistance of the contracted civil engineering company Gähler und Partner AG. After the permitting procedure, a tight time schedule was followed and respected.

Construction engineering of the drill site and conductor

The construction of the drill site (Fig. 3-1) started on 17.05.2021 (LANDOLT + Co. AG construction company, Kleinandelfingen). A subcontractor (Birchmeier Spezialtiefbau AG) was hired to drill and install the conductor.

Fig. 3-1: Drill site before (top) and after (bottom) construction

Soil removal was kept to a minimum and most of the drill site was backfilled with gravel, which was placed directly onto the turf. After the upper soil layers had been removed and deposited along the access route of the drill site, the foundation work began. The soil was kept beside the drill site for later renaturation because the land was to be farmed on a regular basis afterwards. After soil removal, the conductor casing was drilled and installed and the connection lines for electricity, water and drainage were installed. A CO_2 neutralising system with three collection tanks was installed at the north-west side of the drill site according to the drainage concept. These tanks were mainly installed to collect the water from the asphalted area of the drill site after passing through a scum collector and an oil separator installed below ground level.

The drill site consisted primarily of a rig cellar, including the conductor, a surrounding area with an asphalted pavement and other gravel areas that were used to accommodate the testing and office containers.

The conductor drilling rig was directly placed onto the gravel foundation. An 880 mm diameter hole was drilled dry through 38 m of Quaternary sediments and several metres of solid formation of the Untere Süsswassermolasse. The 18⅝" (473 mm) conductor pipe was welded and equipped with centralisers on the surface and then installed in one piece down to a depth of 38 m MD. The conductor was adjusted for verticality with several spirit levels while the cementation was performed through the annulus between the formation and the steel pipe. Logging showed a vertical deviation below 0.3° and homogeneous cementation to all sides.

The following significant adjustments were implemented on the drill site during construction:

- strengthening of the bridge on the access route
- adjusting and construction of access road to the drill site
- enlargement of the gravel areas of the rig site for parking, truck manoeuvring and accommodation
- soil deposit areas beside the drill site
- noise protection wall around the mud pumps and hydraulic unit of the drilling rig
- concrete foundations for the rig and peripheral facilities
- washing trough for cleaning the cores
- parking lots outside the fenced area
- levelling and building an access path for the visitor containers
- installation of connections with all additional media required
- various area entrances and emergency exits in the fence and noise wall
- amphibian protection fence around the drill site

The water collected on the drill site was channelled across a pitched roof to the edges of the asphalt where it was drained through the scum collector and oil separator and on to the collection tanks.

The site was fenced off. The main access gate was guarded 24/7 by a security company as soon as construction of the drill site was completed. No incidents, vandalism or other external perturbations occurred during the construction and drilling phase.

A construction plan, including plant management and arrangement of the drilling rig and its peripheral facilities, can be found in Appendix E. Fig. 3-2 shows the fully assembled drill site directly after construction.

Fig. 3-2: Drill site after installation of the drilling rig and peripheral facilities

3.3 Chronology of the BAC1-1 and BAC1-1B borehole

Below is a chronology of all working steps of the BAC1-1 borehole. Details can be found in the daily drilling reports (DDR) in Appendix H.

17.05.2021	Start of drill site construction
08.07.2021 – 16.08.2021	Rig down STA2-1 and waiting for drill site construction to be finished in BAC1-1
16.08.2021	Start moving to BAC1-1
16.08.2021 – 10.09.2021	Rig up and installation of drilling rig, diverter and all peripheral facilities, prepare bentonite polymer mud
10.09.2021	RIH (run in hole) 17½" drill string, start of drilling operations
10.09.2021 – 20.09.2021	Drilling 17½" from 40 m to 515 m MD with downhole motor, POOH (pull out of hole) 17½" drill string
20.09.2021 – 22.09.2021	Caliper log, RIH 13⅜" surface casing until 513 m MD, cementation with stinger to surface, WOC (waiting on cement)

22.09.2021 – 25.09.2021	WOC, rig down diverter, rig up BOP (blow-out preventer) + testing, RIH 12¼" drill string, drilling out shoe track + 3 m new formation, perform FIT (formation integrity test), POOH 12¼" drill string
25.09.2021 – 03.10.2021	RIH 7⅝" auxiliary casing, magnet run, RIH coring string, coring 6⅜" from 518 m to 700 m MD, POOH coring string
03.10.2021 – 07.10.2021	POOH 7⅝" auxiliary casing, mud exchange from bentonite polymer mud to tap water, fluid logging, technical logging, mud exchange from tap water to potassium silicate polymer mud
07.10.2021 – 26.10.2021	RIH 7⅝" auxiliary casing, RIH coring string, coring 6⅜" from 700 m to 952 m MD (three core bit changes and several round trips due to jammed cores)
26.10.2021 – 28.10.2021	POOH coring string, POOH 7⅝" auxiliary casing, check trip
28.10.2021 – 14.11.2021	Petrophysical logging, BOP test, four hydraulic tests (Lias, Opalinus Clay)
14.11.2021	Check trip, mud conditioning
14.11.2021 – 26.11.2021	Four hydraulic tests («Brauner Dogger», Opalinus Clay, Malm)
26.11.2021 – 27.11.2021	BOP test, check trip, mud conditioning
27.11.2021 – 04.12.2021	Hydraulic test (Opalinus Clay) with fluid exchange
04.12.2021 – 07.12.2021	RIH 8½" hole opener, hole opening from 515 m to 952 m MD, POOH 8½" hole opener
07.12.2021 – 15.12.2021	Petrophysical logging, dilatometer (lost tool), fishing operations (unsuccessful), technical logging, MHF, logging after MHF
15.12.2021 – 21.12.2021	Mud exchange from potassium silicate polymer to water polymer mud, back-cementation in three steps from TD until 500 m MD, WOC, mud exchange from water polymer to potassium silicate polymer mud, securing the borehole for Christmas break
21.12.2021 – 03.01.2022	Christmas break
03.01.2022 – 04.01.2022	Borehole named BAC1-1B for drilling the sidetrack Mud conditioning, BOP test, RIH 12¼" drill string, drilling 12¼" from 500 m to 518 m MD, POOH 12¼" drill string

04.01.2022 – 05.01.2022	RIH 8½" drill string, drilling 8½" pilot hole for sidetrack from 518 m to 520.5 m MD, POOH 8½" drill string
05.01.2022 – 12.01.2022	Drilling 8½" sidetrack from 520.5 m to 952 m MD (951 m TVD)
12.01.2022 – 23.01.2022	Logging prior to MHF, MHF, check trip, caliper log, MHF, logging after MHF, hydraulic test, logging after hydraulic test
23.01.2022 – 26.01.2022	RIH 12¼" hole opener, hole opening from 518 m to 611 m MD, POOH 12¼" hole opener, change pilot bit, hole opening from 611 m to 651 m MD, POOH 12¼" hole opener
26.01.2022	RIH coring string, coring 6⅜" from 651 m to 654 m MD (100% cement core, lost sidetrack and landed in original borehole BAC1-1), POOH coring string
26.01.2022 – 02.02.2022	RIH 12¼" hole opener, hole opening from 651 m to 903 m MD, POOH 12¼" hole opener, change from hole opener to normal tricone bit, drilling 12¼" from 903 m to 947.5 m MD (top of dilatometer tool), POOH 12¼" drill string, RIH 12¼" milling BHA, milling dilatometer from 947.5 m to 952 m MD, POOH 12¼" milling BHA
02.02.2022 – 04.02.2022	Technical logging, RIH 9⅝" intermediate casing until 951 m MD, plug cementation, WOC
	Borehole named BAC1-1 again
05.02.2022 – 06.02.2022	BOP test, RIH 8½" drill string, drilling out cement, shoe track + 2 m new formation, perform FIT, POOH 8½" drill string, magnet run, RIH coring string
06.02.2022 – 08.02.2022	Coring 6⅜" from 954 m to 979 m MD, POOH coring string
08.02.2022 – 17.02.2022	Two hydraulic tests (Klettgau Formation)
17.02.2022 – 22.02.2022	Magnet run, RIH coring string, coring 6⅜" from 979 m to 1'057 m MD, POOH coring string
22.02.2022 – 24.02.2022	Petrophysical logging
24.02.2022 – 26.02.2022	BOP test, RIH 8½" hole opener, hole opening from 954 m to 1'055 m MD, POOH 8½" hole opener
26.02.2022 – 03.03.2022	Logging prior to MHF, check trip, logging, MHF, logging after MHF

03.03.2022 – 08.03.2022	RIH 9⅞" – 11" underreamer, underreaming from 952 m to 1'055 m MD, POOH 9⅞" – 11" underreamer, magnet run, caliper log, RIH 11" underreamer, underreaming from 952 m to 1'055 m MD, POOH 11" underreamer, 9⅝" scraper run
08.03.2022 – 12.03.2022	RIH 7⅝" liner hanger until 1'052 m MD (liner head at 892 m MD), plug cementation, POOH setting tool, WOC, BOP test, cleaning tank system
12.03.2022 – 13.03.2022	RIH 6½" drill string, drilling out cement, shoe track + 2 m new formation, mud exchange from potassium silicate to water polymer mud, perform FIT, POOH 6½" drill string
13.03.2022 – 15.03.2022	RIH coring string, coring 6⅜" from 1'059 m to 1'088 m MD
15.03.2022 – 26.03.2022	Top drive gearbox failure (> 10 days standby)
26.03.2022 – 28.03.2022	Coring 6⅜" from 1'088 m to 1'129 m MD, POOH coring string
28.03.2022 – 01.04.2022	Hydraulic test in Muschelkalk
01.04.2022 – 13.04.2022	Magnet run, RIH coring string, salt up mud to full saturation, coring 6⅜" from 1'129 m to 1'150 m MD, waiting for salt-water delivery, coring 6⅜" from 1'150 m to 1'306 m MD, POOH coring string
13.04.2022 – 18.04.2022	Start petrophysical logging, VSP, continue petrophysical logging, MHF, logging after MHF
18.04.2022 – 22.04.2022	Back-cementation from 1'306 m to surface in five steps
22.04.2022 – 23.04.2022	Deinstallation of BOP, rig release – start of rig down

3.4 Time analysis

The BAC1-1 borehole was completed within 212 working days (continuous 24 h operation, except the Christmas break from 21.12.2021 to 03.01.2022) after spud on 10.09.2021. Rig down was performed within two weeks until the construction company started with deconstruction work of the drill site.

The time analysis in Appendix I shows that the total time for completing the borehole adds up to around 36% for scientific investigations and 64% for drilling and coring activities, including casing and cementing operations. The sidetrack BAC1-1B makes up for 15% of the total time for completing the borehole.

NPT added up to a total of 19.6 days:

- 1.6 days of waiting time:
  - 0.2 days of waiting on logging or testing
  - 1.4 days of waiting on equipment or salt-water
- 12.0 days of repair time (mainly related to top drive repair)
- 6.0 days due to problems with equipment:
  - 0.4 days during logging and testing activities
  - 4.6 days fishing of the dilatometer tool
  - 1.0 days during drilling activities

3.5 Drilling process

The drilling operations combined wireline coring and rotary drilling techniques.

Because the USM and the upper part of the Malm were not required to be cored, they were drilled destructively. Section I was drilled with a mud motor to increase the rate of penetration (ROP). Because there was no directional control of the drill bit, a good balance between drilling speed and verticality had to be achieved and the bottomhole assembly (BHA) had to be designed in such a way as to keep the drill bit straight (see Appendix N, BHA Report 17½"). The lithostratigraphy of the intersected formations was determined by analysing the drilled rock fragments (cuttings) (*cf.* Dossier III).

The wireline coring process was driven by the top drive from the surface with specific drilling parameters. The main advantage of the wireline coring technique is that the coring string can be left in the borehole while retrieving the core, meaning that the string does not have to be pulled for every core. The inner core barrel, which contains the core, is pulled to the surface with a special core catcher on a wireline. Wireline coring is faster and involves fewer tripping operations. Therefore, less deterioration of the borehole occurs compared to conventional coring. Additionally, it also results in a shorter exposure time of the cores to the drilling fluid. In the BAC1-1 borehole, the core length was mostly kept at 3 m for better handling at the surface and to obtain good core quality. In total, 60% (788 m) of the entire borehole length was cored. Core recovery was over 99%: 784.9 m were recovered out of 788 m targeted.

After borehole stability problems in the BUL1-1 borehole mainly in the clay-rich sections such as the Opalinus Clay, where a conventional water-based drilling fluid (combination of polysaccharides and polymers) proved to be unsuccessful, potassium silicate mud was successfully used in TRU1-1, MAR1-1, BOZ1-1, BOZ2-1, STA2-1 and STA3-1 and was also used for the BAC1-1 borehole. This mud system showed excellent performance in terms of borehole stability, core quality and coring advance rate and the full investigation programme could be executed without any major issues.

An overview of the main drilling parameters of the BAC1-1 borehole including the sidetrack BAC1-1B can be found in the drilling engineering plots in Appendix D a and b.

3.5.1 18⅝"conductor to 38 m MD

Starting on 14.06.2021, the conductor was drilled by a subcontractor (Birchmeier Spezialtiefbau AG) with the Liebherr LRB 355 XL drilling rig using kelly drilling during the construction phase. Temporary double-walled casings were used while drilling in segments of 1.0 m to 5.0 m with a diameter of 880 mm. These temporary casings are used to stabilise boreholes in unstable soil formations. They are designed specifically for the transmission of high torques and crowd forces generated during the drilling process. A double-wall construction of the temporary casing gives additional rigidity and strength and provides a continuously flushed drill string (preventing jamming of drilling tools during insertion and extraction). No drilling fluids were used, which means that drilling was performed dry. Verticality was continuously checked using spirit levels.

The double-walled temporary casings were screwed into the ground at the same time as the drilling operations until a final depth of 38 m MD was reached. Afterwards, the borehole was reamed, cleaned and prepared for running the 18⅝" (473 mm) permanent conductor casing in hole with a wall thickness of 11.0 mm.

The conductor pipe segments had a length of around 12 m and were welded together at the surface before installation. Four centralisers (flat steel, 2 cm wide and 5 mm thick) spaced at angles of 90° were welded onto the outer surface of the casing every several meters to centre the conductor within the borehole. Additionally, 1" (25.4 mm) steel pipes were mounted along the conductor for cementation.

Before running in hole and orienting the conductor casing, cement was pumped into the bottom of the borehole to seal off the conductor casing shoe. Verticality was measured with two electrical spirit levels and the conductor was fixed against the temporary casings using wooden wedges.

The main cementation was performed through the 1" steel pipes into the annulus. The cement was pre-mixed and pumped from cement trucks until it reached the surface. The temporary casings were pulled directly after pumping the cement by oscillating movement. Some additional cement was pumped for metal displacement. The cement type used was CEM III B 42.5 L-LH/SR with a density of 1.8 SG.

The borehole deviation logs performed after the cement job showed that the maximum deviation from vertical is below 0.3 m in all directions, resulting in an inclination of less than 0.1°.

Conductor installation was completed on 21.06.2021.

3.5.2 Section I: 38 m to 515 m MD

The main drilling operations started on 10.09.2021.

17½" destructive drilling

Section I was drilled destructively with a 17½" (444.5 mm) tricone bit and a 9⅝" mud motor (see Fig. 3-3). A bit trip was performed at 350 m MD to change the tricone bit. BHA #1 and #2 used for this section can be found in Appendix N. Cement was first drilled from 36.5 m to 38 m MD. Afterwards, the USM and the Siderolithic were drilled down to 462 m MD and finally the upper part of the Malm down to 515 m MD. Single shot measurements were taken every 50 m to check the verticality of the borehole. All measurements were below 1° inclination.

Average drilling parameters were as follows:

- ROP: 2.7 m/h
- WOB (weight on bit): 7.5 t
- string revolutions: 21 RPM
- torque: 722 daNm
- flowrate: 2'895 l/min
- SPP: 53.4 bar

The mud system used was a freshwater bentonite polymer drilling fluid with an increasing MW from 1.03 SG in the beginning to 1.09 SG at TD. Details can be found in section 3.6.

As soon as section TD was reached, the borehole was circulated until "shakers clean" (i.e. until no more cuttings were seen on the shaker screens). Schlumberger performed a caliper log for volume calculations for the upcoming cementing job.

No pressure and circulation problems nor slack-offs and overpulls during tripping and drilling operations were observed in this section.

Fig. 3-3: 17½" tricone bit and 9⅝" mud motor after POOH at 350 m MD

13⅜" casing and cementing

The 13⅜" casing was installed with bow-spring centralisers to a depth of 513 m MD without any major problems. The casing tally can be found in Appendix M. The cementation of the 13⅜" casing was performed with a stinger until surface. A volume of 18.0 m^3 cement / mixing zone came to surface and had to be disposed of. In total, 52.8 m^3 of cement were pumped.

Specifications regarding the cement and casing can be found in sections 3.8 and 3.9. The cementing programme, service report and laboratory measurements can be found in Appendix O.

Section I was completed on 21.09.2021. For well control, a 20¾" diverter unit was installed for drilling operations in this section.

Non-productive time (NPT) and remarks

- The bit trip at 350 m MD could have been avoided by using a new tricone bit instead of two used tricone bits.

3.5.3 Section II: 515 m to 952 m MD – original borehole BAC1-1

After completing Section I, the 13⅝" 3K casing head housing (CHH) was installed on the 13⅜" casing and a BOP was mounted on top for borehole control. The 13⅝" BOP stack consisted of a 13⅝" 10K double ram preventer (blind rams and 4½" – 7" fixed rams) and a 13⅝" 5K annular preventer. The BOP was tested successfully according to the BOP testing protocol (low: 500 psi and high: 3'000 psi).

The cement and float equipment of the 13⅜" casing were drilled out with a 12¼" tricone bit from 499 m to 515 m MD (see BHA #4 in Appendix N). After drilling new formation until 518 m MD, the hole was circulated clean and the mud was conditioned. A FIT was performed at 518 m MD according to protocol with an equivalent mud weight (EMW) of 1.65 SG. For a MW of 1.08 SG, a surface pressure of 28 bar was applied. The FIT was successful without any significant pressure drop.

6⅜" coring operations

Before starting drilling operations of Section II, a 7⅝" auxiliary casing was installed to a depth of 515 m MD (see casing tally in Appendix M). The auxiliary casing was used for centralising the drill string and enabling a better flow regime within the annulus while drilling and coring. Using no auxiliary casing, the volume transition between the 6⅜" hole and the 13⅜" casing would lead to hole cleaning problems triggered by an instantaneous decrease in annular velocity at the diameter transition zone. The auxiliary casing was set into the CHH with a tubing hanger. Connections between the pipes were welded to protect the casing from unscrewing.

Coring operations started on 26.09.2021 using an impregnated core bit with an outer diameter of 6⅜" (see BHA #5 in Appendix N). Plastic liners within the inner core barrel were used for core protection. Core length was fixed to 3 m.

After successfully coring through the Malm limestones to a depth of 700 m MD, the coring string was POOH to perform the upcoming logging and testing programme. The core bit showed significant wear with several broken teeth (see Fig. 3-4).

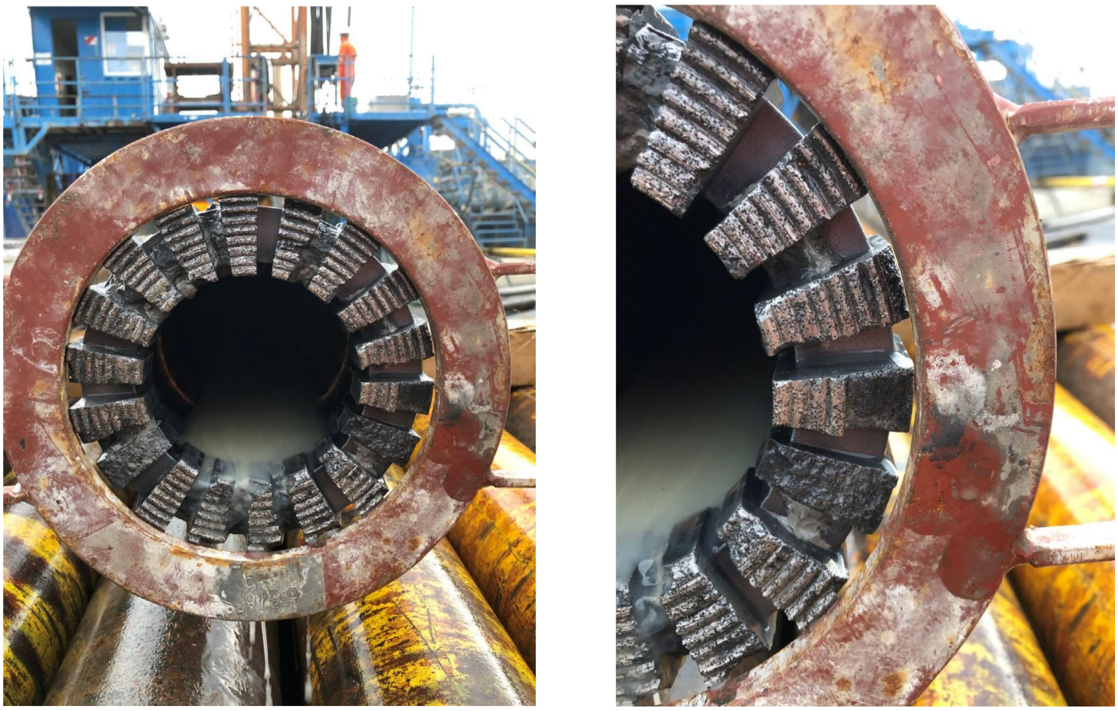

Fig. 3-4: Impregnated core bit after POOH from a depth of 700 m MD

The 7⅝" auxiliary casing was POOH without any problems. The bentonite polymer mud was exchanged with freshwater (MW: 1.00 SG) for fluid logging operations, which were performed by the company Terratec. Terratec also performed a calliper log directly after fluid logging. The freshwater was then replaced by a potassium silicate mud (MW: 1.18 SG) using the coring string. Details about the drilling fluid can be found in section 3.6.

The 7⅝" auxiliary casing could not be installed as before as the tally was slightly changed (see casing tally in Appendix M). After removing one casing joint, the auxiliary casing could be hung off at 507 m MD and coring operations continued with the same impregnated core bit used before (see BHA #8 in Appendix N).

While coring down to 709 m MD the ROP continuously dropped until it was decided to POOH. Because the clay content in the bottom part of the Malm seemed to significantly increase, it was decided to change the core bit to a new thermally stable diamond core bit, i.e. synset (see BHA #9 in Appendix N). The synset core bit type had already been used successfully in the BUL1-1, the MAR1-1, BOZ2-1 and the STA2-1 boreholes to core the clayey formations.

With the new synset core bit, coring continued without any problems. At 763 m MD no core was found in the inner core barrel and the coring string had to be POOH. A 9 cm core piece was recovered from the outer core barrel and the coring string was RIH again with the same coring bit. It was possible to catch the lost core and coring could continue. At 769 m MD, exactly the same problem occurred, and an 8 cm core piece was stuck in the outer core barrel. After removing and cleaning the coring assembly the string was RIH again and coring continued without any further issues.

At around 807 m MD slight drilling fluid losses of 800 l/h could be observed. In total, 15 m^3 of mud losses occurred while coring and then stopped.

With increasing depth standpipe pressure started to increase until it was decided to POOH at 832 m MD to change the core bit. The synset core bit showed several broken cutters but normal wear after drilling 123 m (see Fig. 3-5).

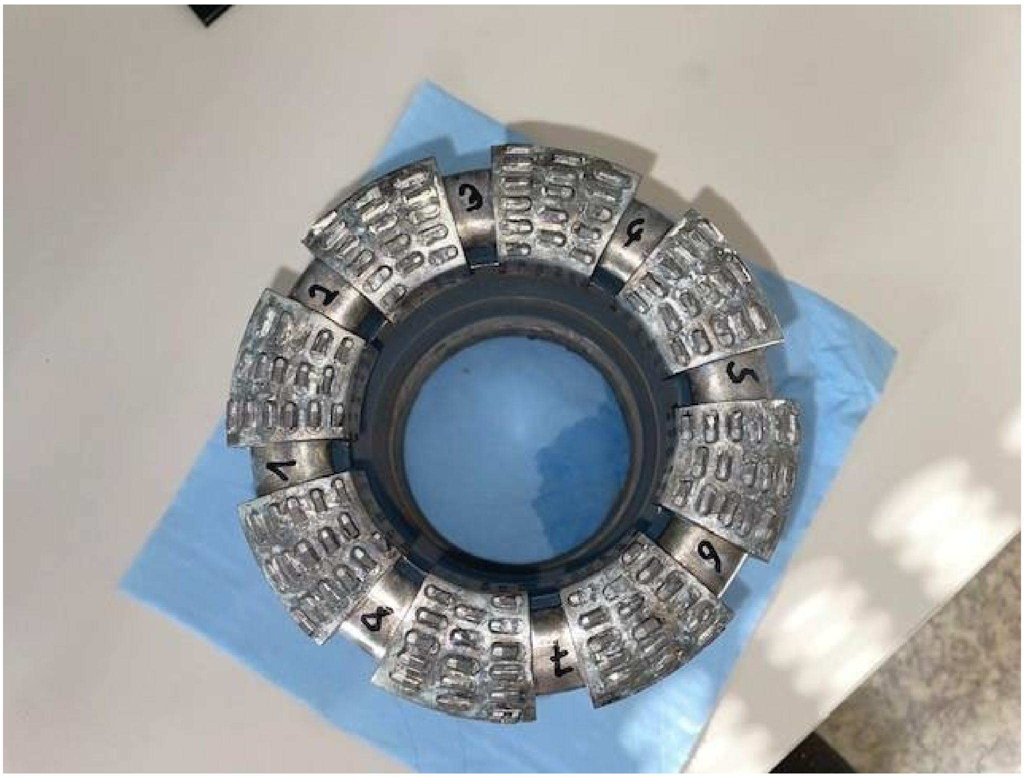

Fig. 3-5: Synset core bit after POOH from a depth of 832 m MD

A new synset core bit was RIH (see BHA #12 in Appendix N) to continue coring but the coring string had to be POOH multiple times at 853 m, 877 m and 880 m MD due to problems with jammed cores that could only be removed at surface. As the problems with jammed cores continuously occurred, it was decided to add freshly mixed potassium silicate mud (MW: 1.19 SG) to improve the clay inhibition of the drilling fluid. Additionally, all parts of the coring assembly were inspected and some of them exchanged. Despite this, jammed cores happened once more at 887 m and 901 m MD, and the coring string had to be POOH to recover the core pieces.

At 901 m MD the used synset core bit showed significant wear (see Fig. 3-6) and was changed to a new synset core bit (see BHA #17 in Appendix N).

Fig. 3-6: Synset core bit after POOH from a depth of 901 m MD

The new synset core bit only cored down to 905 m MD until it had to be POOH again because of a jammed core. The 8 cm core piece that was stuck in the outer core barrel was recovered and the coring string RIH with the same core bit. Further coring could continue until 922 m MD without POOH. The jammed core pieces at 908 m MD and 917 m MD could be recovered with the inner core barrel.

At 922 m MD the coring string had to be POOH again because of a jammed core piece. Additionally, the breaking point of the wireline broke and had to be changed as soon as the coring BHA was at surface.

The same core bit was used to RIH and continue coring (see BHA #19 in Appendix N). Between 945 m and 946 m MD torque and ROP values dropped to zero. Therefore, the inner core barrel was POOH on wireline. The plastic liner was found stuck in the outer core barrel and had to be removed before coring could continue.

As the cores were heavily jammed due to a fault it was decided to stop at 952 m MD and end the section for the upcoming logging and testing program. The synset core bit showed normal wear after drilling 51 m (see Fig. 3-7).

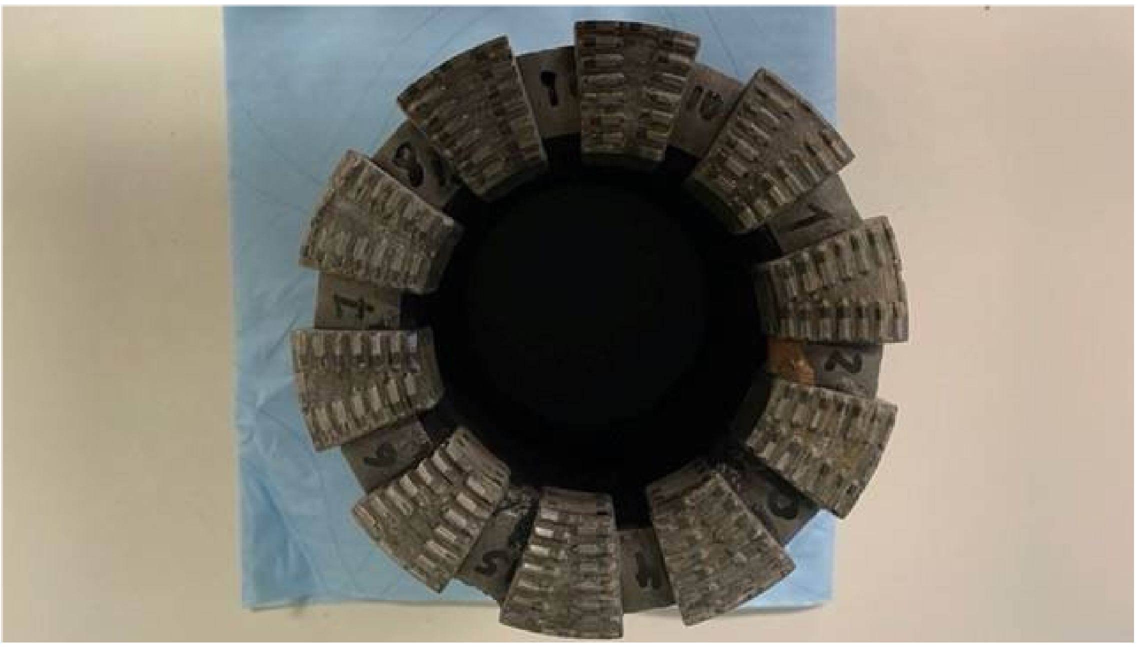

Fig. 3-7: Synset core bit after POOH from a depth of 952 m MD

In Section II, 151 cores were retrieved, number #1 to #151. Detailed parameters for each core can be found in Appendix P. Single shot measurements were carried out every 50 m. All inclination measurements were below 0.5°.

Average drilling parameters for coring operations were as follows:

- ROP: 1.58 m/h
- WOB: 3.5 t
- string revolutions: 189 RPM
- torque: 333 daNm
- flowrate: 328 l/min
- SPP: 25.4 bar

Coring operations were followed by retrieving the 7⅝" auxiliary casing and performing a check trip down to section TD at 952 m MD. The restriction zones at 937 m, 946 m and 950 m MD were reamed and circulated clean before POOH. The zone between 946 m and 937 m MD showed overpulls between 3 – 4 t and the coring string was POOH with pumping and circulating. The check trip was then followed by the extended logging and hydraulic testing programme of the Opalinus Clay and its confining units. The borehole was found to be in an excellent shape without any breakouts or restrictions (see Appendix F). After finishing wireline operations, the BOP was pressure tested.

A series of four hydrotests was carried out in Lias and Opalinus Clay using a single packer assembly for the first test in Lias and a double packer assembly for the following tests with an interval length of approximately 13 m, run on 2⅞" tubing. After keeping the borehole open for almost 17 days without any circulation, a check trip was performed using the coring string (see BHA #25 in Appendix N) to check the hole condition and to recondition the mud. During this check trip, one restriction zone was observed at around 938 m MD, with a stand-up of 4 – 5 t. The zone was washed and reamed before POOH. The potassium silicate mud was still in an acceptable condition without significant depletion.

After the first check trip, four additional hydrotests were performed in Brauner Dogger, Opalinus Clay and Malm using a double packer assembly with an interval length of approximately 22 m, run on 2⅞" tubing. The second check trip and the regular BOP pressure test (minimum every 21 days) were carried out after another 12 days of open hole. The same restriction zone as during the first check trip was observed at around 938 m MD but the rest of the borehole and also the drilling fluid were found to be in very good condition.

Due to the good borehole stability with the potassium silicate mud in the hole, it was decided to run another hydrotest with fluid exchange in the «Brauner Dogger» using a double packer assembly with an interval length of approximatey 47 m, run on 2⅞" tubing. This additional test added another 6.5 days of open hole time.

In total, the interval of Section II with a length of 439 m had an open hole time of more than 38 days without any borehole stability problems after retrieving the last core.

8½" hole opening

The 6⅜" borehole was opened up to 8½" with an SHO bit (see BHA #32 in Appendix N) starting on 04.12.2021. This SHO bit used a bullnose on bottom as guidance within the already cored borehole.

Average drilling parameters for 8½" hole opening were as follows:

- ROP: 7 m/h to 11 m/h
- WOB: 1.3 t to 4.6 t
- string revolutions: 61 RPM
- torque: 1'053 daNm to 1'601 daNm
- flowrate: 1'267 l/min to 1'685 l/min
- SPP: 26 bar to 47 bar

After 8½" hole opening and wireline logging, a dilatometer run was carried out. The dilatometer test was successful but after trying to free the tool, it got stuck at around 793 m MD. All attempts to free the tool, also by pulling with the maximum allowed pulling force of 20 t, failed. Communication to the tool was fully lost and ultimately the wireline broke entirely at the breaking point directly above the tool. The only connection to surface was the control line within the coil. But all attempts to free the tool by pulling it with the control line also failed until the control line also broke.

Special fishing tools were ordered for fishing the dilatometer tool but only had limited success. The gamma ray tool and parts of the dilatometer safety joint could be retrieved but the remaining 4 m of the dilatometer tool were still stuck within the borehole.

Finally, it was decided to push down the dilatometer tool as deep as possible and to cement back the borehole for drilling a sidetrack.

The dilatometer tool could be pushed down successfully to 945 m MD (see BHA #35 in Appendix N). Afterwards, a caliper run was performed down to 938 m MD for the upcoming MHF tests. As soon as the MHF tests and the logging after MHF were performed, the borehole was prepared for the back-cementation by exchanging the drilling mud from potassium silicate to water polymer. The potassium silicate mud was stored in the empty silos directly at the drill site.

The back-cementation was executed in 3 steps, each cementation between 4 m^3 and 6 m^3, with 2⅞" tubing. Specifications regarding cement can be found in section 3.8. The cementing programme, service report and laboratory measurements can be found in Appendix O. After finishing the back-cementation, the top of cement (TOC) was found to be at 500 m MD and the water polymer fluid was changed back to potassium silicate mud.

The rig was prepared for the Christmas break which lasted from 21.12.2021 to 03.01.2022.

3.5.4 Section II: 515 m to 952 m MD – sidetrack BAC1-1B

After the Christmas break and organising upcoming working steps, rig operations started on 03.01.2022 by conducting a BOP test according to the protocol. Afterwards, a pilot hole was drilled for the sidetrack by using a 12¼" milled tooth tricone bit (see BHA #37 in Appendix N) from 500 m until 518 m MD and an 8½" TCI bit (see BHA #38 in Appendix N) from 518 m until 520.5 m MD.

The RSS was prepared according to plan and RIH with an 8½" PDC bit (see BHA #39 in Appendix N). The first attempts to kick off from the original borehole with different drilling parameters were not successful and at 577 m MD the decision was made to POOH to switch to a motor BHA with an 8½" TCI bit. After POOH, the RSS and the PDC bit were found to be in good shape (see Fig. 3-8).

The motor with bent housing was set to an angle of 1.4° and drilled in time drilling mode until 594 m MD with different drilling parameters, where formation cuttings increased to 25% (75% cement). The BHA was POOH to change the drilling bit back to the 8½" PDC bit and to increase the angle of the bend to 1.85°. With this setting, formation cuttings increased continuously until reaching 75% at 602 m MD. Upon reaching 80% formation cuttings at 605 m MD, it was decided to switch from sliding mode to rotary mode to confirm the sidetrack. Next formation cuttings reading from rotary mode showed 90% formation cuttings. Therefore, kicking off from vertical was proven to be successful and drilling the borehole could be continued with the RSS.

Finally, the RSS was RIH as per original plan (see BHA #42 in Appendix N) and drilled the S-shaped sidetrack down to 952 m MD (951 m TVD). The kickoff point (KOP) of the sidetrack was at around 600 m MD. The step-out (horizontal distance) between the end point of the sidetrack and the original borehole BAC1-1 was 21.95 m.

Average drilling parameters for 8½" drilling of the sidetrack were as follows:

- ROP: 11 m/h
- WOB: 4.2 t
- string revolutions: 59 RPM
- torque: 1'564 daNm
- flowrate: 1'951 l/min
- SPP: 66 bar

After finishing the drilling operations of the sidetrack, logging and MHF testing were performed. A check trip with the 8½" SHO bit had to be conducted after the first MHF station to clean and ream the borehole for further measurements.

Additionally, one hydrotest in the «Brauner Dogger» was performed by using a double packer assembly with an interval length of approximately 15 m, run on 2⅞" tubing.

Fig. 3-8: RSS system and PDC bit after POOH from a depth of 577 m MD

Hole opening for casing running was started with a 12¼" SHO bit and an 8½" PDC pilot bit (see BHA #46 in Appendix N). The borehole was opened up from 520 m to 611 m MD, but the cuttings continuously showed cement and with increasing depth more drilling fluid than usually was necessary. It was decided to POOH and change the pilot bit to an 8½" mill tooth bit. The drill string was RIH again and hole opening continued down to 652 m MD, but the same issues persisted. The drill cuttings were still contaminated with cement and increasingly more drilling fluid than calculated was needed.

It was assumed that the hole opening BHA was too stiff and could not enter the sidetrack, but instead followed the original, cemented BAC1-1 borehole. To confirm these assumptions, it was decided to core 3 m with the coring BHA. The pulled core consisted of 100% cement (see Fig. 3-9) and proved that the original BAC1--1 borehole was drilled.

Fig. 3-9: 100% cement core from 651 m till 654 m MD

After intensive discussions about further possible working steps, the sidetrack was given up and the decision was made to continue drilling in the original BAC1-1 borehole with the 12¼" SHO bit. In the meanwhile, a new 12¼" mill tooth bit and 12¼" milling equipment were ordered.

The 12¼" SHO BHA drilled down to 903 m MD without deviating from the original borehole. Therefore, the BHA setup was changed and the new 12¼" mill tooth bit was RIH (see BHA #50 in Appendix N). This BHA setup did not deviate from the original borehole either and the bit tagged the lost dilatometer tool at around 947 m MD. Aluminium parts from the dilatometer tool were observed on the shale shakers. At 947.5 m MD the drill string was POOH. The 12¼" mill tooth bit was found heavily damaged (see Fig. 3-10).

A 12¼" junk mill assembly with junk basket was RIH (see Fig. 3-11 and BHA #51 in Appendix N) and successfully milled the entire dilatometer tool in one go until 952 m MD. A great quantity of rubber, aluminium, and steel parts were washed over the shale shakers. The milling equipment functioned flawlessly (see Fig. 3-12).

Fig. 3-10: 12¼" mill tooth bit after POOH from 947.5 m MD

After milling, the borehole was circulated clean, the drill string was POOH and a caliper log was performed by Schlumberger.

Average drilling parameters for 12¼" drilling in the original borehole were as follows:

- ROP: 7 m/h to 12 m/h
- WOB: 1.2 t to 4.8 t
- string revolutions: 62 rpm
- torque: 1'113 daNm to 1'584 daNm
- flowrate: 1'241 l/min to 1'705 l/min
- SPP: 24 bar to 51 bar

Fig. 3-11: 12¼" junk mill assembly before (left) and after (right) milling the dilatometer tool

Fig. 3-12: Rubber, aluminium and steel parts from the milled dilatometer tool

9⅝" casing and cementing

The 9⅝" casing was installed with bow-spring centralisers to a depth of 951 m MD without any problems. The casing tally can be found in Appendix M.

The cement job of the 9⅝" casing was planned as a two-plug cementation. Operations started by pumping 10 m^3 of wash pill and 10 m^3 of spacer fluid, followed by the first (bottom) plug. Afterwards, a volume of 34.7 m^3 of lead (density: 1.35 SG) and 3.1 m^3 of tail cement (density: 1.65 SG) were pumped, followed by the second (top) plug. To complete the cement job, 5 m^3 of water and 31.4 m^3 of mud were pumped behind the second plug, and the plug successfully bumped after 36.35 m^3. A casing pressure test with 55 bar for 15 min confirmed the tightness of the casing shoe and rig down of the cementing service could start.

Specifications regarding the cement and casing can be found in sections 3.8 and 3.9. The cementing programme, service report and laboratory measurements can be found in Appendix O.

NPT and remarks

- The potassium silicate mud from the STA2-1 drill site was recycled and used for BAC1-1 and BAC1-1B. Due to several problems with jammed cores, some of the mud was disposed of and fresh potassium silicate mud was circulated into the active system. Additionally, multiple parts of the coring assembly were changed out. All those measures could not fully eliminate the core jamming problems.
- The dilatometer tool got stuck because its diameter was too large to pass the small restriction zone in the borehole. The maximum pulling force would have been much higher and the whole string could have been worked up and down in case of any problems if the tool had been run on tubing instead of wireline plus control line.
- The clearance between the dilatometer tool and the 8½" borehole wall was too small. Therefore, fishing operations were not successful either.
- A Christmas break from 21.12.2021 to 03.01.2022 was necessary to prepare and organise the sidetrack.
- The formation was too hard to kick off with the RSS. The usage of a motor with bent housing was mandatory to kick off from the original borehole.
- To complete the planned logging and testing programme of the BAC1-1 borehole, especially of Section II containing all the target formations, it was necessary to conduct a sidetrack.
- The hole opening BHA for opening up the sidetrack from 8½" to 12¼" was too stiff. Furthermore, the 8½" PDC bit was too aggressive as a pilot bit.

Section II was completed on 04.02.2022. Due to the lost sidetrack and completing Section II within the original borehole, the borehole was named BAC1-1 again from 05.02.2022 on.

3.5.5 Section III: 952 m to 1'057 m MD

After completing Section II, the BOP was tested successfully according to the BOP testing protocol (low: 500 psi and high: 3'000 psi).

The cement and float equipment of the 9⅝" casing were drilled out with an 8½" tricone bit from 913 m to 952 m MD (see BHA #52 in Appendix N). After drilling new formation until 954 m MD the hole was circulated clean. The potassium silicate mud from Section II was kept at a MW of 1.18 SG. A FIT was performed at 954 m MD according to protocol with an EMW of 1.65 SG. For a MW of 1.18 SG a surface pressure of 44 bar was applied. The FIT was successful without any significant pressure drop. A magnet run did not recover any significant amounts of steel parts.

6⅜" coring operations

Coring operations of Section III started on 06.02.2022 using a new impregnated core bit (see BHA #53 in Appendix N). This core bit drilled 25 m of new formation from 954 m to 979 m MD, approximately 3 m into the Bänkerjoch Formation, to perform two hydrotests in the Keuper aquifer of the Klettgau Formation. Several junk parts from the dilatometer tool were recovered while coring the first 10 m. The core bit showed broken teeth after POOH (see Fig. 3-13).

Fig. 3-13: Impregnated core bit after POOH from a depth of 979 m MD

The first hydrotest was carried out using a single packer assembly with an interval length of 22 m and the second hydrotest was carried out using a double packer assembly with an interval length of 11 m. Both tests were run on 2⅞" tubing.

Coring resumed with a new impregnated core bit (see BHA #56 in Appendix N) until section TD at 1'057 m MD. Some overpulls with 3 t were observed between 982 m and 985 m MD. The core bit showed normal wear after POOH (see Fig. 3-14).

Petrophysical logging and a BOP test were performed after coring according to plan.

In Section III, 34 cores were retrieved: number #152 to #186. Detailed parameters for each core can be found in Appendix P. Single shot measurements were carried out every 50 m. All inclination measurements were below 0.5°.

Average drilling parameters for coring operations were as follows:

- ROP: 1.2 m/h
- WOB: 4.0 t
- string revolutions: 193 rpm
- torque: 405 daNm
- flowrate: 326 l/min
- SPP: 13.5 bar

The MW of the potassium silicate polymer mud was kept at 1.18 SG over the entire duration of Section III.

Fig. 3-14: Impregnated core bit after POOH from a depth of 1'057 m MD

8½" hole opening and 11" underreaming

The 6⅜" borehole was opened up to 8½" with an SHO bit (see BHA #57 in Appendix N) starting on 24.02.2022. This SHO bit used a bullnose at the bottom as guidance within the already cored borehole.

Average drilling parameters for 8½" hole opening were as follows:

- ROP: 3.5 m/h
- WOB: 3.0 t
- string revolutions: 63 rpm
- torque: 1'581 daNm
- flowrate: 1'520 l/min
- SPP: 39 bar

After 8½" hole opening, wireline logging and MHF stress tests were carried out. After the first logging run, a check trip was performed to ream the zone between 980 m and 950 m MD.

Finally, an 11" underreamer with 13 mm PDC cutters (see BHA #59 in Appendix N) was RIH (see Fig. 3-15). After drilling down to 1'046 m MD, the underreamer was POOH and found to have heavily worn and broken cutters. Therefore, the back-up tool (also with 13 mm cutters) was prepared and RIH for a second underreamer run. The underreamer BHA could be RIH without any problems until 1'046 m MD and drilled until 1'049 m MD by using different drilling parameters. After POOH, a magnet run was performed without any significant observations. A caliper run showed that the underreaming operations in the lower part of the borehole were not fully successful. Therefore, the underreamer was RIH again with different settings and the borehole reamed until TD at 1'057 m MD without any problems.

Fig. 3-15: 11" underreamer before RIH

Average drilling parameters for 11" underreaming from 951 m to 1'057 m MD were as follows:

- ROP: 2.1 m/h
- WOB: 1.3 t
- string revolutions: 60 rpm
- torque: 1'440 daNm
- flowrate: 1'929 l/min
- SPP: 121 bar

7⅝" liner hanger and cementation

A 9⅝" scraper run was performed to clean the inner surface of the 9⅝" casing to properly set the liner hanger head.

The 7⅝" liner hanger was run down to 480 m MD. Then, a circulation check was performed but was unsuccessful. Circulating pressure went up to 100 bar and made it impossible to circulate. As the problem could not be solved, the entire liner hanger had to be POOH again to perform a visual inspection of the float equipment. Once the float shoe was back at surface, the float collar valve was found to be broken. The broken valve had landed on the float shoe and had therefore blocked the entire circulation. New float equipment had to be ordered short-term.

With the new float equipment on-site, the liner could be RIH on 09.03.2022 with a 5" drill pipe. The liner hanger head was located at 892 m MD, resulting in an overlap of approximately 59 m with the previous casing. The last several joints were run with circulation and the liner hanger was then set with one right turn. The casing tally of the 7⅝" liner hanger can be found in Appendix M.

The plug cementation of the 7⅝" liner hanger was performed without any problems. Before pumping the first plug, 10 m^3 of wash-pill and 10 m^3 of spacer were pumped. In total, 9.3 m^3 of cement were pumped. To complete the cement job, 4.5 m^3 of water and 6.3 m^3 of mud were pumped behind the second plug, and the plug successfully bumped after 11 m^3. A casing pressure test with 80 bar for 10 min confirmed the tightness of the casing shoe. The liner hanger was set with 8 t. Afterwards 6 m^3 of cement / water mixing zone and 19 m^3 of spacer / wash-pill mixing zone were circulated out.

Specifications regarding the cement and casing can be found in sections 3.8 and 3.9. The cementing programme, service report and laboratory measurements can be found in Appendix O.

NPT and remarks

- Although the hot shot delivery of the float equipment was very fast and did not lead to a lot of overtime, it would have been more practical to have a back-up float equipment directly onsite.

Section III was completed on 10.03.2022.

3.5.6 Section IV: 1'057 m to 1'306 m MD

After executing the regular BOP test while WOC, the cement and float equipment of the 7⅝" liner hanger were drilled out with a 6½" tricone bit from 1'010 m to 1'059 m MD (see BHA #63 in Appendix N). The potassium silicate polymer mud was then changed to a water polymer mud for Section IV because the focus was on hydraulic testing in the upper part of the section, particularly water sampling from the Muschelkalk aquifer. The potassium silicate polymer mud was transported away to the waste treatment facility.

A FIT was performed on 13.03.2022 at 1'059 m MD. The applied surface pressure of 40 bar could not be held. Therefore, the pressure was reduced in steps until reaching a value that could be held. At a surface pressure of 15 bar, the FIT was stable. This results in an EMW of 1.15 SG at an original MW of 1.02 SG of the water polymer drilling fluid. It was decided to continue with Section IV as per plan.

6⅜" coring operations

Coring of Section IV started on 13.03.2022 using an impregnated core bit (see BHA #64 in Appendix N). Core length was fixed to 3 m as in the previous sections. At a depth of 1'062 m MD, the coring string had to be POOH due to a jammed core piece. Afterwards, the same core bit was RIH and coring resumed until 1'088 m MD where a major malfunction of the top drive gear happened. The top drive had to be demounted and transported away into a workshop to fix the problem. Repair work took almost 11 days. In the meanwhile, the coring string was pulled back into the last casing shoe and the borehole was secured and observed over the trip tank. Once a day, the borehole was circulated to keep the drilling mud within specifications.

As soon as the top drive repair was finished, coring could continue without any problems. At a depth of 1'105 m MD dynamic and static drilling fluid losses occurred. Details about the mud losses can be found in section 3.6.4.

The hydrotest in the Muschelkalk was carried out at a depth of 1'129 m MD using a single packer assembly with an interval length of 48 m, run on 2⅞" tubing.

After finishing the hydrotest, a new impregnated core bit was RIH (see BHA #67 in Appendix N) and a lost circulation material (LCM) pill was pumped to reduce the increasing mud losses. The water polymer mud was then salted up with NaCl to full saturation with a density of 1.21 SG and coring resumed.

As the mud losses worsened, the active tank system had to be filled up with water and polymers on a regular basis to keep the borehole full while coring. This resulted in a steadily decreasing mud weight and salt content. At the same time, salt brine was ordered from a nearby salt plant to have a fully saturated drilling fluid ready as soon as the salt layer in the Zeglingen Formation was encountered. While waiting on the salt brine deliveries, another LCM pill was pumped.

The salt brine deliveries started on 05.04.2022 at a depth of 1'150 m MD. With the increased mud weight of 1.21 SG, mud losses significantly increased again, and two more LCM pills had to be pumped at 1'156 m and 1'165 m MD during coring.

With increasing depth and regular salt brine deliveries, mud losses were under control and coring could continue without any further interruptions until TD of Section IV at 1'306 m MD.

Mud losses added up to 763 m^3 while coring plus 83 m^3 before back-cementation. Four LCM pills were pumped in Section IV. Details about mud losses and LCM pills can be found in section 3.6.5.

Average drilling parameters for coring operations were as follows:

- ROP: 1.9 m/h
- WOB: 3.0 t
- string revolutions: 180 rpm
- torque: 597 daNm
- flowrate: 308 l/min
- SPP: 11.3 bar

In Section IV, 84 cores were retrieved: number #187 to #269. Detailed parameters for each core can be found in Appendix P. Single shot measurements were carried out every 50 m. All inclination measurements were below 0.5°.

Petrophysical logging, VSP and MHF stress tests were performed directly after coring.

6⅜" back-cementation

The borehole was backfilled with cement through a 2⅞" cement stinger (see BHA #68 to #70 in Appendix N) in six steps from 18.04.2022 to 22.04.2022:

- Step 1 from 1'306 m to 1'056 m MD with 6.8 m³ of cement (1.65 SG)
- Step 2 from 1'056 m to 862 m MD with 5.4 m³ of cement (1.65 SG)
- Step 3 from 862 m to 646 m MD with 7.9 m³ of cement (1.65 SG)
- Step 4 from 646 m to 406 m MD with 9.3 m³ of cement (1.67 SG)
- Step 5 from 406 m to 160 m MD with 9.5 m³ of cement (1.67 SG)
- Step 6 from 160 m MD to surface with 7.1 m³ of cement (1.67 SG)

A flow check was performed between each step to check on losses. No losses occurred during the entire back-cementation. Cement samples were collected and kept in the oven at downhole temperature to investigate the time required for cement hardening.

Specifications regarding the cement can be found in section 3.9. The cementing programme, service report and laboratory measurements can be found in Appendix O.

To finalise drilling operations on the BAC1-1 borehole, the BOP stack was demounted and the casings extensions were cut (see Fig. 3-16).

The rig was released on 23.04.2022, initiating rig down.

Fig. 3-16: Borehole BAC1-1 completely backfilled and casing extensions cut

NPT and remarks

- Petrophysical logging and VSP were interrupted several times due to heavy rainfalls.

3.6 Drilling fluids

The drilling fluid engineering service was contracted by the drilling contractor and was permanently on-site during the entire drilling phase.

In total, three different types of drilling fluid were used in the BAC1-1 and BAC1-1B borehole. A bentonite polymer mud was used for the Quaternary and most of the Malm , a potassium silicate polymer mud was used for the most relevant Dogger, Lias and Keuper, and a sodium chloride polymer mud was used for the Muschelkalk until final depth within the upper part of the Rotliegend.

Tab. 3-1: Drilling fluids data

From (m MD)	**To** (m MD)	**Section**	**Type / specification**	**Density**
0	38	0	Dry	-
0	515	I	Bentonite + polymer	1.08 SG
0	700	II	Bentonite + polymer	1.08 SG
0	952	II	Potassium silicate (KSil) + polymer	1.20 SG
BAC1-1B sidetrack				
0	952	II	Potassium silicate (KSil) + polymer	1.18 SG
BAC1-1 original borehole				
0	1'057	III	Potassium silicate (KSil) + polymer	1.18 SG
0	1'129	IV	Water + polymer	1.02 SG
0	1'306	IV	NaCl + polymer	1.21 SG

3.6.1 Section I: Bentonite polymer drilling fluid

Before starting drilling operations, 135 m³ of bentonite polymer mud with a MW of 1.03 SG were mixed and treated with bactericide to protect the mud system from contamination by bacteria. Section I was drilled without any problems with the bentonite polymer mud until 515 m MD. MW slightly increased from 1.03 SG to 1.09 SG while drilling with the centrifuge and flocculation unit permanently operating. While drilling, new mud was mixed and added to the active system. Polymers were added occasionally to reduce the API (American Petroleum Institute) fluid loss and to regulate the viscosity. After reaching TD at 515 m MD, a high viscosity pill was pumped to clean the borehole for the upcoming cementing and casing job.

Section I was drilled without any problems with the bentonite polymer mud.

The drilling fluid parameters of Section I are given in Tab. 3-2, and the drilling fluid materials are listed in Tab. 3-3.

Tab. 3-2: Drilling fluid parameters – Section I

Parameter	**Unit**	**Min.**	**Max.**	**Planned**
Flowline temperature	°C	19	45	-
Density	SG	1.03	1.09	1.01 – 1.10
Plastic viscosity	cP	12	16	as low as possible
Yield point	lb/100 ft²	15	22	20 – 30
Gel strength	10 s	2	5	-
Gel strength	10 min	3	6	-
pH	-	8.1	10.0	9 – 10
Sand content	vol.-%	0.0	0.3	< 1.0%
Methylene blue test (MBT)	kg/m³	28	50	< 36

Tab. 3-3: Drilling fluid materials – Section I

Product	**Unit size**	**Quantity**
Bentonite OCMA	25 kg	28
Bentonite AMC	25 kg	164
Defoamex	200 l	2
Biozid Grotan OX	10 l	2
Biozid Grotan WS	10 l	15
Drispac Superlo	25 kg	20
Drispac Regular	25 kg	17
Floc cationic	25 kg	25
Sodium carbonate	25 kg	7
PAC LV Premium	25 kg	62
Xanthan gum	25 kg	16

Three Falcon shale shakers were installed for mud cleaning. Shakers 1 and 2 were equipped with API 100-140 screens and shaker 3 with API 80 – 140 screens. The centrifuge with flocculation ran permanently during the drilling phase. The sand content could thus be kept below 1.0 vol.-%.

3.6.2 Section II – original borehole BAC1-1: Bentonite polymer and potassium silicate (KSil) drilling fluids

For Section II, the bentonite polymer mud from Section I was used to core until 700 m MD. After drilling out the shoe track of the 13⅜" casing and 3 m of new formation, the mud was treated with citric acid and sodium bicarbonate to regulate the pH value. Additionally, the mud was treated with Drispac Superlo and PAC LV to regulate the API fluid loss and the viscosity. Sodium bicarbonate was used to decrease the pH value. While coring, the mud had to be treated with only low quantities of Drispac and PAC LV.

At a depth of 700 m MD the borehole was circulated clean, and part of the surface tank system was cleaned to prepare for the exchange to freshwater. The auxiliary casing was POOH to RIH the coring string for the fluid exchange. The exchange was performed with 5 m^3 of high viscosity (HV) spacer and 52 m^3 of traced freshwater. During this time, most of the bentonite polymer mud was already disposed of. The rest of the bentonite polymer mud was disposed of after completing the exchange to freshwater. While fluid logging, 110 m^3 of potassium silicate mud with a density of 1.18 SG were prepared and mixed according to the programme. The potassium silicate mud from the STA2-1 borehole could be successfully reused for mixing. The freshwater was replaced by the potassium silicate mud after fluid logging with 4 m^3 of HV spacer and the water was disposed of. The product and technical datasheet for the potassium silicate fluid used for mixing the drilling fluid can be found in Appendix Q.

The KSil polymer mud was treated with polymers, xanthan gum and fresh silicate on a regular basis to adjust mud properties.

The drilling fluid parameters of Section II are given in Tabs. 3-4 and 3-5, and the drilling fluid materials are listed in Tab. 3-6.

Tab. 3-4: Drilling fluid parameters of the bentonite polymer mud – Section II – original borehole BAC1-1

Parameter	Unit	Min.	Max.	Planned
Flowline temperature	[°C]	23	30	-
Density	[SG]	1.07	1.09	1.01 – 1.10
Plastic viscosity	[cP]	13	19	as low as possible
Yield point	[lb/100 ft^2]	11	17	20 – 30
API fluid loss	[ml/30 min]	6.0	7.8	-
Gel strength (10 s)	[lb/100 ft^2]	2	5	-
Gel strength (10 min)	[lb/100 ft^2]	4	8	-
pH	-	9.1	10.0	9 – 10
Sand content	[vol.-%]	0.1	0.2	< 1.0
Methylene blue test (MBT)	[kg/m^3]	28	29	< 36

At the beginning of coring, the centrifuge was permanently running to reduce the solid content of the drilling fluid. With increasing depth, the solid content was under control. At around 807 m MD, 15 m^3 of potassium silicate mud were slowly lost into the formation while coring.

Tab. 3-5: Drilling fluid parameters of the potassium silicate mud – Section II – original borehole BAC1-1

Parameter	**Unit**	**Min.**	**Max.**	**Planned**
Flowline temperature	[°C]	16	30	-
Density	[SG]	1.18	1.20	1.20 – 1.25
Plastic viscosity	[cP]	14	23	as low as possible
Yield point	[lb/100 ft^2]	8	17	5 – 20
API fluid loss	[ml/30 min]	4.8	6.7	4 – 8
pH	–	12.5	13.3	12 – 14
Chlorides	[mg/l]	1'802	4'456	-
Silicate content	[vol.-%]	30.67	44.94	-

Tab. 3-6: Drilling fluid materials – Section II – original borehole BAC1-1

Product	**Unit size**	**Quantity**
Calcium carbonate fine	20 kg	372
Citric acid	25 kg	19
Defoamex	200 l	1
Drispac Superlo	25 kg	28
Drispac Regular	25 kg	4
PAC LV	25 kg	67
Soda ash	25 kg	7
DuoVis	25 kg	5
K + silicate	1'000 l	34.7
Xanthan gum	25 kg	6

Due to problems with jammed cores, the coring string had to be POOH several times. Adjustments of the coring BHA and exchanging several parts of the coring equipment turned out to be unsuccessful and it was decided to exchange half of the potassium silicate mud in the active mud system by freshly mixed drilling fluid (MW: 1.19 SG). The idea was to improve the clay inhibition and therefore avoid core jammers. A total of 20 m^3 of pure potassium silicate and 26 m^3 of fresh water were mixed and treated with 4 kg/m^3 Drispac Superlo, 4 kg/m^3 PAC LV and 2 kg/m^3 Duovis before adding it to half of the active mud system. The other half of the removed potassium silicate mud was stored in silos as a reserve quantity.

By adding fresh drilling fluid, the silicate content increased to 42% and the solid content decreased to 4% which was very satisfying. However, the problems with core jammers did not improve. Another 5.5 m^3 of pure potassium silicate were added to the system to increase the MW from 1.19 SG to 1.20 SG. The API fluid loss reduced to 3 ml/30 min, the silicate content went up to 44% and the solid content decreased to 3%. Nevertheless, while coring down to TD of the section, there were still problems with jammed cores.

After reaching TD of Section II at 952 m MD, the borehole was without any circulation for around 17 days due to logging and testing. A caliper log showed no significant impacts of the jammed cores from coring operations on the borehole stability. While logging and testing, the mud in the surface tanks was properly maintained and conditioned to remain within the planned specifications. The first check trip was performed to check the borehole condition. No problems were observed during the check trip until 938 m MD. With a stand-up of 4 t to 5 t it was not possible to pass the restriction zone at 938 m MD. As the testing programme did not require to go deeper, it was decided to end the check trip and POOH to start the next testing sequence.

A second check trip was performed after a further series of two hydrotests and another 12 days without circulation. The second check trip was carried out without any problems until 938 m MD before the ninth and last hydrotest was performed.

After finishing the hydrotests in Section II, the borehole was opened up from 6⅜" to 8½" without any problems, also at the restriction zone at 938 m MD. The potassium silicate mud was treated with PAC LV and Xanthan gum to regulate the API fluid loss and the viscosity. Additionally, the MW was decreased from 1.20 SG to 1.18 SG. The lower MW was considered to be sufficient for the following MHF stress tests and 12¼" hole opening operations.

While testing operations within the 8½" borehole, a dilatometer tool got stuck around 790 m MD. All fishing attempts were unsuccessful. Therefore, the fish was pushed down to TD of the section and the borehole was backfilled with cement until 500 m MD in three steps. Before backfilling with cement, the potassium silicate mud was exchanged to water polymer fluid. The potassium silicate mud was stored in silos during the Christmas break from 21.12.2021 to 03.01.2022.

Shale shakers 1 and 2 were equipped with API 200 screens and shaker 3 was equipped with API 140 screens for coring. The centrifuge was only partially in use during the drilling and hole opening phase but was permanently in use while coring.

3.6.3 Section II – sidetrack BAC1-1B: Potassium silicate (KSil) drilling fluids

For drilling the sidetrack BAC1-1B, the water polymer fluid was exchanged to potassium silicate mud (from the storage silos) after the Christmas break on 04.01.2022. The MW was brought back within specifications from 1.16 SG to 1.18 SG. Additionally, the viscosity was slightly increased to ensure an appropriate hole cleaning while drilling.

After drilling the pilot hole 12¼" from 500 m to 518 m MD and 8½" from 518 m to 520.5 m MD, the RSS tried to kick off the sidetrack until 577 m MD but did not manage to. Therefore, a motor with bent housing was RIH instead of the RSS BHA. A bend of 1.41° did not manage to kick off but as soon as the bend was increased to 1.85° the motor managed to kick off at around 600 m MD. After kicking off from vertical for several metres, the motor with bent housing was exchanged to the RSS system and the sidetrack was drilled as planned down to 952 m MD (951 m TVD).

The quality of the drilling mud was properly investigated after the first logging and testing runs as the tools got stuck several times during POOH. After performing a check trip, the logging and testing programme could be executed without any problems and the drilling mud was held within specifications over the whole time.

Because the 8½" sidetrack was lost during 12¼" hole opening operations and the original BAC1-1 borehole was reopened, the stuck dilatometer tool had to be milled out. The drilling fluid properties were held constant by proper hole and mud cleaning and by adding polymers and fresh potassium silicate from time to time.

Finally, the 9⅝" casing and cementing job could be finished successfully within the original BAC1-1 borehole.

The KSil polymer mud was treated with polymers, xanthan gum and fresh silicate on a regular basis to adjust mud properties.

The drilling fluid parameters of Section II are given in Tab. 3-7, and the drilling fluid materials are listed in Tab. 3-8.

Tab. 3-7: Drilling fluid parameters of the potassium silicate mud – Section II – sidetrack BAC1-1B

Parameter	**Unit**	**Min.**	**Max.**	**Planned**
Flowline temperature	[°C]	18.5	38	-
Density	[SG]	1.16	1.18	1.20 – 1.25
Plastic viscosity	[cP]	16	27	as low as possible
Yield point	[lb/100 ft^2]	11	21	5 – 20
API fluid loss	[ml/30 min]	3.9	5.3	4 – 8
pH	–	12.9	13.5	12 – 14
Chlorides	[mg/l]	4'125	4'367	-
Silicate content	[vol.-%]	33.24	39.75	-

Tab. 3-8: Drilling fluid materials – Section II – sidetrack BAC1-1B

Product	**Unit size**	**Quantity**
Calcium carbonate fine	20 kg	110
Calcium carbonate fine	1'000 kg	2
Defoamex	200 l	1
Drispac Superlo	25 kg	8
Drispac Regular	25 kg	15
PAC LV	25 kg	44
K + silicate	1'000 l	34.1
Xanthan gum	25 kg	2

Shale shakers 1 and 2 were equipped with API 200 screens and shaker 3 was equipped with API 140 screens for drilling the sidetrack. The centrifuge was partially in use during the drilling, hole opening and milling phase.

3.6.4 Section III: Potassium silicate (KSil) drilling fluid

For Section III the potassium silicate polymer mud from Section II was used by holding the MW constant at 1.18 SG. While coring, hole opening and underreaming the mud was treated with polymers on a regular basis to adjust the API fluid loss and the viscosity.

The drilling fluid parameters of Section III are given in Tab. 3-9, and the drilling fluid materials are listed in Tab. 3-10.

Tab. 3-9: Drilling fluid parameters of the potassium silicate mud – Section III

Parameter	**Unit**	**Min.**	**Max.**	**Planned**
Flowline temperature	[°C]	20.5	49	-
Density	[SG]	1.18	1.18	1.20 – 1.25
Plastic viscosity	[cP]	17	25	as low as possible
Yield point	[lb/100 ft^2]	12	19	5 – 20
API fluid loss	[ml/30 min]	4.8	6.1	4 – 8
pH	–	12.8	13.2	12 – 14
Chlorides	[mg/l]	3'713	4'378	-
Silicate content	[vol.-%]	31.87	35.21	-

Tab. 3-10: Drilling fluid materials – Section III

Product	**Unit size**	**Quantity**
Calcium carbonate fine	20 kg	238
Drispac Regular	25 kg	1
Xanthan Gum	25 kg	1
PAC LV Premium	25 kg	12
DuoVis	25 kg	2

Shale shakers 1 and 2 were equipped with API 200 screens and shaker 3 was equipped with API 140 screens. The centrifuge was partially in use during the coring and hole opening phase.

3.6.5 Section IV: Water polymer and sodium chloride drilling fluids

For Section IV the potassium silicate polymer mud was used to drill out the shoe track of the 7⅝" liner hanger and 2 m of new formation. At the same time some of the surface tanks were cleaned for the mud exchange and transport of the potassium silicate polymer mud away to the waste treatment facility was begun. In total, 100 m^3 of freshwater polymer mud with a MW of 1.02 SG were prepared. Furthermore, the drilling fluid was treated with uranine tracer fluid and analysed for tracer concentration on a regular basis.

The potassium silicate polymer mud was replaced by water polymer mud by pumping 6.0 m^3 of HV spacer followed by fresh drilling fluid. After the mud exchange the drilling mud had to be circulated to shear the polymers.

After coring down to 1'088 m MD the rig was on standby for about 10 days due to a top drive repair. During the repair time the borehole was circulated once a day. During that time minor losses of around 100 l to 200 l per day could be observed over four days in a row. After those four days losses stopped.

As soon as coring could be continued, dynamic mud losses occurred between 1'105 m and 1'114 m MD with 500 l/h. From 1'114 m to 1'129 m MD dynamic mud losses stopped but static losses started to occur before hydrotesting. After finishing the hydrotest, mud losses started to increase directly and after salting up the drilling fluid with 46 t of NaCl to full saturation, resulting in a MW of 1.21 SG. Mud losses significantly increased to 10 m^3/h to 12 m^3/h while coring. A maximum of 15 m^3/h of mud losses were observed. It was decided to continue coring by filling up the borehole with water and polymers.

The MW decreased to 1.07 SG while dynamic and static mud losses also decreased to between 6 m^3/h and 8 m^3/h. Coring continued under reduced losses down to 1'150 m MD. An LCM pill was pumped while waiting on the salt brine deliveries. As soon as the pre-mixed salt brine deliveries arrived onsite, they were added into the active mud system and treated with polymers. MW increased from 1.06 SG to 1.21 SG and mud losses increased to 12 m^3/h.

After coring 6 m down to 1'156 m MD, another 6 m^3 LCM pill was pumped and static losses were significantly reduced. Dynamic losses were fluctuating between 4 m^3/h and 8 m^3/h. Another 3 m^3 LCM pill was pumped at 1'165 m MD, whereas dynamic losses reduced further to between 2.5 m^3/h and 3.5 m^3/h. The salt mud was treated with PAC LV, soda and xanthan gum to improve hole cleaning.

While coring down to 1'306 m MD, i.e. TD of the borehole, static and dynamic mud losses were reduced constantly with depth until reaching between 0.5 m^3/h and 1.1 m^3/h, resulting in 15 m^3 mud losses per day on average. Final logging operations could be performed without any problems under static losses of 1.5 m^3/h.

Mud losses in Section IV added up to 763 m^3 until the end of logging and testing operations, plus 83 m^3 before back-cementation.

During back-cementation of the entire borehole in six steps, the sodium chloride polymer mud was entirely disposed of.

The drilling fluid parameters of Section IV are given in Tab. 3-11, and the drilling fluid materials are listed in Tab. 3-12.

Tab. 3-11: Drilling fluid parameters of the sodium chloride mud – Section IV

Parameter	**Unit**	**Min.**	**Max.**	**Planned**
Flowline temperature	[°C]	13.9	26	-
Density	[SG]	1.02	1.21	1.20 – 1.25
Plastic viscosity	[cP]	5	26	as low as possible
Yield point	[lb/100 ft^2]	4	22	15 – 25
API fluid loss	[ml/30 min]	4.5	11.2	< 6
Gel strength (10 s)	[lb/100 ft^2]	1	4	-
Gel strength (10 min)	[lb/100 ft^2]	1	6	-
pH	-	8.0	10.5	8 – 10

Tab. 3-12: Drilling fluid materials – Section IV

Product	**Unit size**	**Quantity**
Barite	25 kg	66
Calcium carbonate fine	20 kg	576
Defoamex	200 l	1
Floc cationic	25 kg	1
Soda ash	25 kg	15
Xanthan Gum	25 kg	29
Floc anionic	25 kg	1
Pac LV Premium	25 kg	206
Pure Bore ULV	25 kg	14
DuoVis	25 kg	8
Grotan WS	10 l	5
Mica medium	25 kg	18
NOV Carb 0.35-0.7/0.5-1.5	25 kg	20
Nutshells fine	25 kg	18
Calcium carbonate «Perlkalk»	25 kg	12
Calcium carbonate «Textkreide»	25 kg	18

Shale shakers 1 and 2 were equipped with API 200 screens and shaker 3 was equipped with API 140 screens. The centrifuge was not in use due to the losses.

3.7 Borehole measurements

Borehole measurements planned as per work programme (WP) are described in Appendix B.

Technical logging operations were carried out in all sections (Tab. 3-13).

A series of caliper logging runs was performed in the 6⅜" open hole of Section II between the logging and testing sequences. A comparison of the borehole conditions and the very small changes in borehole conditions between the runs can be found in Appendix F.

Petrophysical logging operations and vertical seismic profiling (VSP) were carried out in Sections II, III and IV by Schlumberger with the assistance of the drilling contractor. Details on petrophysical logging and VSP can be found in Dossier VI.

In situ stress testing (micro-hydraulic fracturing MHF) with the modular formation dynamic tester (MDT) was carried out in Sections II, III and IV by Schlumberger with the assistance of the drilling contractor. Details on MHF can be found in Dossier VI.

Hydraulic packer tests were carried out in Sections II, III and IV by Solexperts with the assistance of the drilling contractor. Details on hydraulic testing can be found in Dossier VII.

Tab. 3-13: Overview of technical logging

Date	From [m MD]	To [m MD]	Company	Measurement	Run
20.09.2021	503	14	Schlumberger	EMS caliper log: PPC-MSIP-PPC-GPIT-EMS-EDTC-LEH.QT	1.1.1
05.10.2021	690	500	Terratec	Caliper log: CAL-GR	2.1.1
29.10.2021	520	0	Schlumberger	Cement bond log: PPC-MSIP-PPC-GPIT-EDTC-LEH.QT	2.2.3
30.10.2021	950	490	Schlumberger	EMS caliper log: SPE-EMS.B-HRLA-EDTC.B-LEH.QT	2.2.8
31.10.2021	514	1	Schlumberger	USIT composite log: USIT-EDTC-LEH.QT	2.2.9
13.12.2021	939	500	Schlumberger	EMS caliper log: EMS-EDTC-LEH.QT	2.4.1
BAC1-1B sidetrack					
13.01.2022	948	490	Schlumberger	Caliper log: FBST.E-EMS-EDTC-LEH.QT	2.5.1
14.01.2022	950	490	Schlumberger	EMS caliper log: PPC-EMS-EDTC-LEH.QT	2.6.1
16.01.2022	951	490	Schlumberger	Caliper log: FBST.E-PPC-EMS-EDTC-LEH.QT	2.6.4
23.01.2022	820	500	Schlumberger	Caliper log: FBST.E-PPC-EMS-EDTC-LEH.QT	2.7.1

Tab. 3-13: continued

Date	**From** [m MD]	**To** [m MD]	**Company**	**Measurement**	**Run**
BAC1-1 original borehole					
02.02.2022	951	490	Schlumberger	EMS caliper log: EMS-EDTC-LEH.QT	2.8.1
22.02.2022	975	7	Schlumberger	Cement bond log: PPC-MSIP-PPC-GPIT-EDTC-LEH.QT	3.1.2
23.02.2022	1'057	920	Schlumberger	EMS caliper log: SP-EMS-HRLA-EDTC-LEH.QT	3.1.7
23.02.2022	949	2	Schlumberger	Ultrasonic log: USIT.D-EDTC-LEH.QT	3.1.8
26.02.2022	1'055	938	Schlumberger	EMS caliper log: EMS-EDTC-LEH.QT	3.2.1
27.02.2022	1'055	940	Schlumberger	EMS caliper log: EMS-EDTC-LEH.QT	3.3.1
27.02.2022	1'044	939	Schlumberger	EMS caliper log: UBI-GPIT-EMS-EDTC-LEH.QT	3.3.2
07.03.2022	1'050	940	Schlumberger	EMS caliper log: EMS-EDTC-LEH.QT	3.4.1
13.04.2022	1'306	1'010	Schlumberger	EMS caliper log: FBST.E-EMS-EDTC-LEH.QT	4.2.1
14.04.2022	1'080	884	Schlumberger	Cement bond log: PPC-MSIP-PPC-GPIT-EDTC-LEH.QT	4.2.2
15.04.2022	1'306	1'035	Schlumberger	EMS caliper log: BNS-ILE-APS-EMS-EDTC-LEH.QT	4.2.5
15.04.2022	1'306	1'155	Schlumberger	EMS caliper log: HNGS-ILE-EMS-EDTC-LEH.QT	4.2.7
16.04.2022	1'052	885	Schlumberger	Ultrasonic log: USIT-EDTC-LEH.QT	4.2.9
16.04.2022	1'306	1'040	Schlumberger	EMS caliper log: SPE-EMS-HRLA-EDTC-LEH.QT	4.2.10

3.8 Borehole diameters and casing

Borehole diameter

The borehole diameters are given in Tab. 3-14.

Tab. 3-14: Borehole diameters

From [m MD]	To [m MD]	Diameter	Drilling method	Comment
0	38	34⅝"	Destructive drilling	For 18⅝" conductor
36.5	515	17½"	Destructive drilling	Section I
499	518	12¼"	Destructive drilling	Drilling out cement, shoe track + 3 m new formation
518	952	6⅜"	Coring	Section II
518	952	8½"	Hole opening	For MHF
BAC1-1B sidetrack				
500	518	12¼"	Destructive drilling	Drilling cement for sidetrack
518	520.5	8½"	Destructive drilling	Drilling pilot hole for sidetrack
520.5	952	8½"	Destructive drilling	Drilling sidetrack with mud motor and RSS (rotary steerable system)
518	651	12¼"	Hole opening	For 9⅝" casing
651	654	6⅜"	Coring	100% cement; sidetrack lost; landed in original hole BAC1-1
651	947.5	12¼"	Destructive drilling	Drilling original hole BAC1-1
947.5	952	12¼"	Milling	Milling out the dilatometer tool
BAC1-1 original borehole				
913	954	8½"	Destructive drilling	Drilling out cement, shoe track + 2 m new formation
954	1'057	6⅜"	Coring	Section III
954	1'055	8½"	Hole opening	For 7⅝" liner hanger
952	1'055	9⅞" to 11"	Underreaming	For 7⅝" liner hanger
1'015	1'059	6½"	Destructive drilling	Drilling out cement, shoe track + 2 m new formation
1'053	1'306	6⅜"	Coring	Section IV

Casing

The casing data are given in Tab. 3-15.

Tab. 3-15: Casing data

From [m MD]	**To** [m MD]	**Diameter**	**Section**	**Specification**
0	38	18⅝"	0 – Conductor	K55, 87.5, buttress thread connection (BTC)
0	513	13⅜"	I – Surface casing	K55, #68.0, BTC
0	951	9⅝"	II – Intermediate casing	J55, #40.0, BTC
892	1'052	7⅝"	III – Liner hanger	J55, #29.7, BTC

3.9 Cementation

Cementing data are shown in Tab. 3-16.

Tab. 3-16: Cementing data

From [m MD]	**To** [m MD]	**Casing**	**Amount** [m³]	**Density**	**Type / Specification**
0	38	18⅝"	n/a	1.8 SG	CEM III B 42.5 L-LH/SR
0	515	13⅜"	52.8	1.63 SG	CEM III B 32.5 N-LH/HS/NA
952	500	open hole in 3 steps	5.6 5.9 4.7	1.66 SG 1.65 SG 1.68 SG	CEM III B 32.5 N-LH/HS/NA CEM III B 32.5 N-LH/HS/NA CEM III B 32.5 N-LH/HS/NA
0	952	9⅝"	34.7 3.1	1.35 SG 1.65 SG	Lead: HOZlite Tail: CEM III B 32.5 N-LH/HS/NA
892	1'057	7⅝"	9.3	1.37 SG	HOZlite
1'306	0	Back-cementation in 6 steps	6.8 5.4 7.9 9.3 9.5 7.1	1.65 SG 1.65 SG 1.65 SG 1.67 SG 1.67 SG 1.67 SG	CEM III B 32.5 N-LH/HS/NA CEM III B 32.5 N-LH/HS/NA CEM III B 32.5 N-LH/HS/NA CEM III B 32.5 N-LH/HS/NA CEM III B 32.5 N-LH/HS/NA CEM III B 32.5 N-LH/HS/NA

For evaluation of the cement jobs in the BAC1-1 borehole, cement bond logs (CBL) and more detailed measurements with an ultrasonic imager tool (USIT) were performed. These measurements are listed in Tab. 3-13 of section 3.7.

In Section I the 13⅜" casing was successfully cemented to surface. The cement job shows a rather poor quality above 30 m MD but improves progressively down to the 18⅝" conductor shoe. From 38 m to 120 m MD, the CBL amplitude shows high values with strong casing arrivals on the variable density log (VDL) in some intervals, indicating medium bonding until 111 m MD but good bonding until 120 m MD. From 120 m to 513 m MD the CBL mostly shows weak casing arrivals and strong formation arrivals, which indicates good to excellent bonding between casing and cement as well as between cement and formation. The USIT mostly shows high acoustic impedance and good cement coverage. Zonal isolation is achieved from the 13⅜" casing shoe upwards to at least 30 m MD.

The CBL and USIT logging runs of the 9⅝" casing cement job show medium to good bonding from surface to 470 m MD. Channelling is observed in several sections, but those channels are arrested with zones of good cement indicating that zonal isolation is achieved. From 470 m MD the cement bond is much improved showing good isolation around the previous 13⅜" casing shoe. The cement is excellent in claystone units down to TD of Section II. The logs show strong formation arrivals with high acoustic impedance and the cement map indicates a strong cement.

The cement job of the 7⅝" liner hanger has good to excellent bonding and zonal isolation across the full length, including the liner lap. No channelling is observed in this wellbore section.

A graphical overview of the quality of the cement jobs as evaluated by logging can be found in Appendix G. This overview shows that zonal isolation of the different aquifers in BAC1-1 could be achieved. The host rock and its surrounding formations are well isolated and show a good cement bond to the casing as well as to the formation. Furthermore, aquifers are isolated from each other.

The BAC1-1B sidetrack could not be cemented as it was impossible to find it again. It was decided to abandon the sidetrack (filled with potassium silicate) and continue with the original borehole BAC1-1.

3.10 Borehole deviation

The inclination and azimuth of the vertical BAC1-1 borehole were measured by Schlumberger by performing survey runs during wireline logging. The survey data were filtered at 10 m intervals from 0 m to 1'306 m MD. Figs. 3-17 and 3-18 show the borehole survey. Maximum dog-leg severity is 1.16°/30 m at 520 m MD. Step-out at TD is 0.75 m south and 1.17 m east. The borehole can be considered vertical with a maximum inclination of 0.65° at 530 m MD. MD values mostly correspond to TVD (true vertical depth) values.

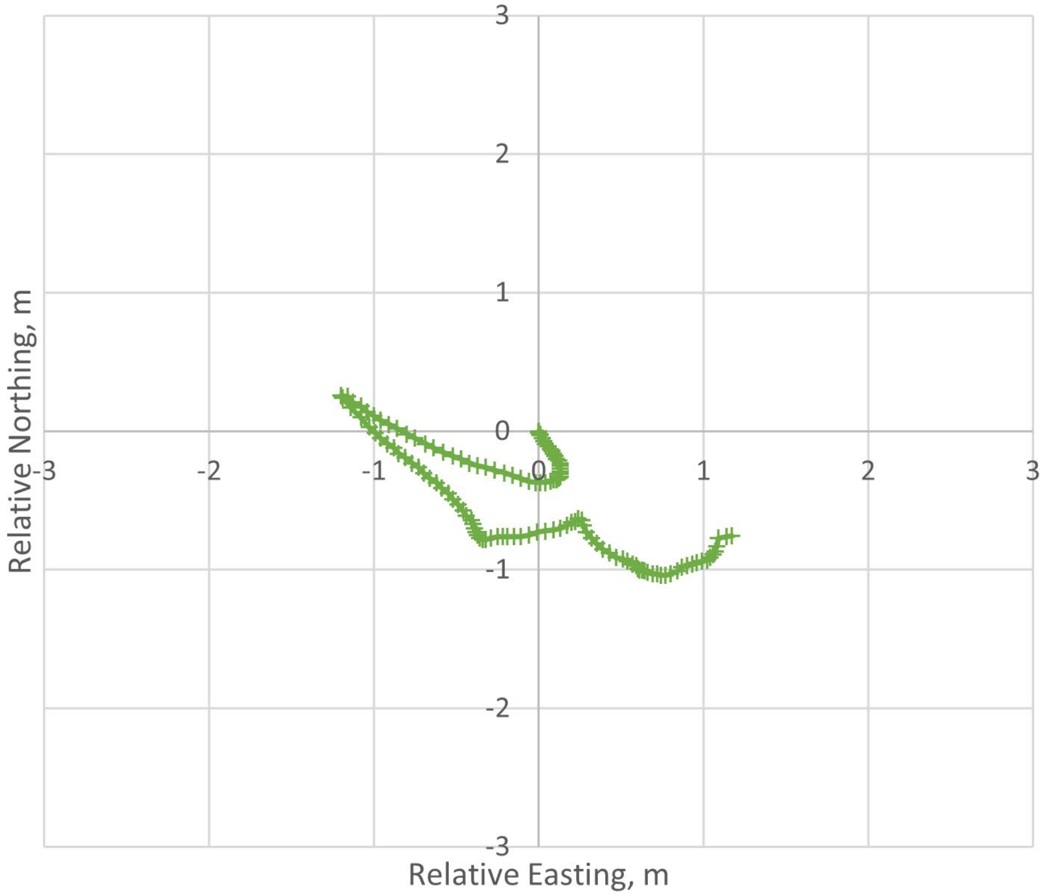

Fig. 3-17: Plan view: relative easting – relative northing

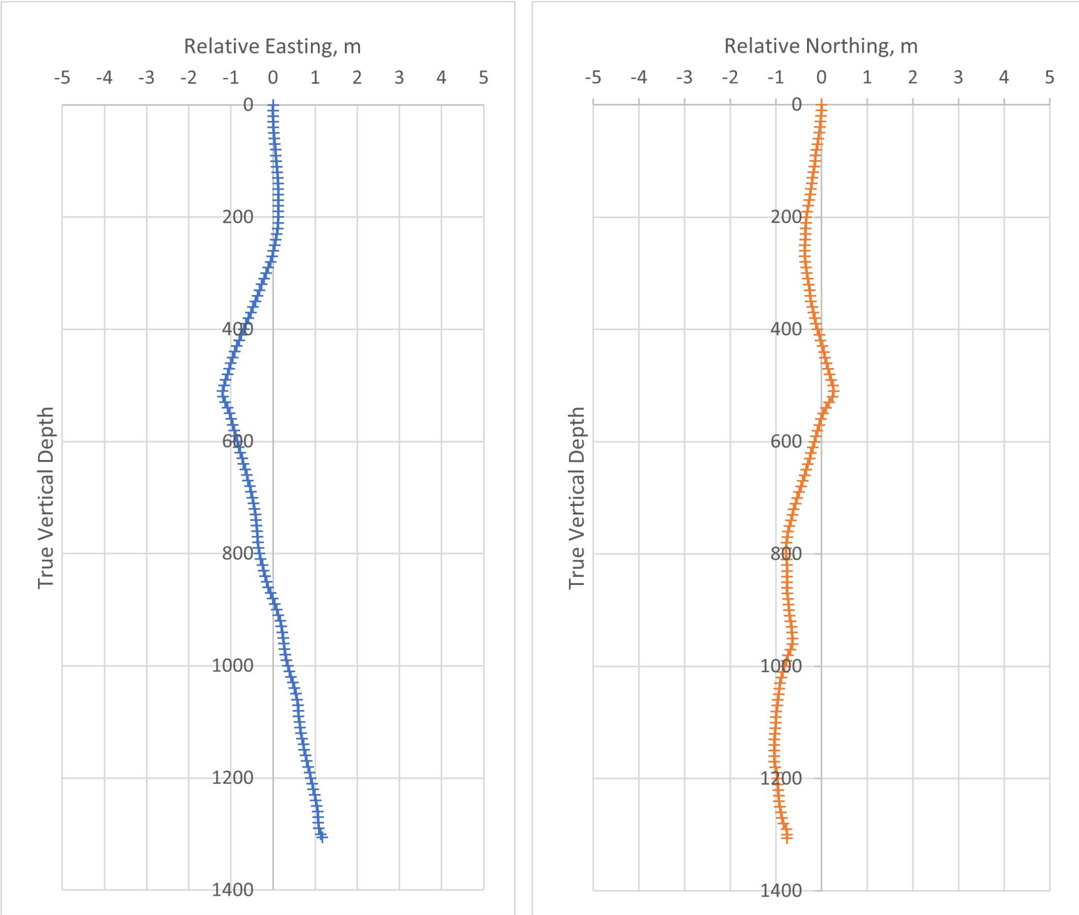

Fig. 3-18: Profile view: relative northing and relative easting – relative elevation (TVD)

4 Health, safety and environment

4.1 Health and safety

The health and safety of employees, contractors and subcontractors of Nagra are of vital importance. Therefore, several measures were taken during planning and performance of the drilling campaign to reduce hazards to a minimum and to create safe working conditions.

All drill sites were fenced to protect workers from external influences and to define a clear barrier for people and animals which are not allowed to access the drill site. Additionally, the drill site was permanently guarded by a security service during the entire drilling phase. The security guards were also responsible for performing detailed access controls.

To respect the different ATEX zones around the drilling rig, the drill site was divided into a restricted area and a non-restricted area. Access to the restricted area was allowed only with the correct personal protective equipment (PPE), consisting of:

- Overall / Jacket
  - anti-flammable
  - anti-static
  - high visibility
- Safety shoes
  - S3
  - mid height
- Safety helmet
- Safety glasses
- Safety gloves

Within the restricted area, it was not permitted to have any non-explosion-proof electrical devices to prevent hazardous sparks within the ATEX zone.

A firefighting and rescue plan with specific procedures for emergency situations was in place for the drill site. Furthermore, the drill site was equipped with emergency exits, muster points, fire-extinguishers, first aid kits and alarm signals. Evacuation drills and trainings were carried out with the onsite personnel on a weekly basis to practice correct behaviour in emergency situations.

Daily shift changes always started with pre-job safety meetings to make the rig crew aware of potential hazards on location. Special jobs such as cementing required additional safety meetings together with subcontractors to address all planned work steps and further safety instructions.

Life-saving rules were implemented which everyone visiting or working at the drill site had to follow. These rules set out the minimum requirements for controlling the risk of serious injury from common activities.

The drilling contractor had a STOP card system in place that allowed all persons onsite to address positive and/or negative observations at the drill site related to HSE. These STOP cards were collected and analysed to pinpoint problems that needed to be addressed and improved for the future. Good cards served as feedback and motivation on excellent performance.

During the entire duration of the drilling phase in BAC1-1, no restricted work cases and no first-aid cases were reported. Having zero lost time incidents (LTI) proved that the regular emergency training of the personnel onsite was successful.

As for previous boreholes, additional safety rules were implemented due to the COVID-19 pandemic. Measures and instructions of the Federal Office of Public Health (FOPH) were strictly followed, not only to be able to continue drilling operations but also to protect the personnel on the drill site. Meetings were held twice a day to communicate current hygiene regulations, discuss the importance of social distancing and how to organise tasks where distance normally cannot be maintained. Body temperature measurements were performed when accessing the site and the number of people onsite was restricted to a minimum. No infections were recorded on the drill site during the entire project.

4.2 Environment

4.2.1 Environmental supervision and monitoring

Due to official regulations, the entire project had to be accompanied by an environmental supervisor. This supervisor was responsible for advising and informing Nagra about environmental aspects and bringing in external experts if necessary.

The tasks of the environmental supervisor during the drilling phase were:

- communicating transport routes
- verifying whether environmental requirements and protective measures for transports and drilling activities were respected
- checking if the drainage concept was working properly and respected
- checking if the lighting concept was being respected and whether further measures were necessary
- checking the machinery list and particle filters of all vehicles and machines
- checking the storage of hazardous substances
- checking the emergency power generator and its leakage detection system
- conducting leakage tests of wastewater and sewage pipes
- checking storage, separation and disposal of waste at the drill site
- checking if legal noise limits were complied with
- checking the amphibian protection fence
- checking the completeness of camouflage covers of the containers for landscape protection

The drill site was inspected on a regular basis. No major findings were identified, and official regulations were all fulfilled.

4.2.2 Wastewater

A dewatering concept was prepared according to official regulations and approved by the cantonal authorities. The water collected on the drill site within the asphalted area was originally collected over a roof pitch, passed through a scum collector and an oil separator and was finally pumped into the settling tank. Two further tanks (each with a volume of 40 m^3) were connected in series to the settling tank, which had a CO_2 neutralisation system installed to regulate the pH value and the turbidity. The last tank had a connection to the local sewage system, whereas the drainage of the collected water was strictly regulated by the wastewater concept. The three tanks were placed at the northern side of the drill site.

After completing drilling operations, the dewatering tanks and the CO_2 neutralisation system were removed as the drill site was immediately reconstructed after rig down.

4.2.3 Pedological site support

The drill site was constructed in an agricultural zone. Several official regulations thus had to be fulfilled during the construction and drilling phase. The project was accompanied by a pedological site support specialist, and a soil protection concept was developed to define the pending work steps.

The soil removed during the construction phase was stored along the access route to the drill site. This soil was temporarily stored to be reused for the decommissioning phase.

The pedological site support team was responsible for maintaining and checking the quality of the soil on a regular basis. No findings were reported by the pedological site support team during the entire duration of the project.

4.2.4 Landscape protection

At the drill site for the BAC1-1 borehole it was necessary to camouflage the most visible containers with natural colours to not interfere with the surrounding landscape. Therefore, all containers located around the fence were laminated with camouflage panels (see Fig. 3-19 and Fig. 3-20).

Fig. 3-19: Camouflage panels on the containers at the north-western side of the drill site

Fig. 3-20: Camouflage panels on the containers at the north-eastern side of the drill site

4.2.5 Noise

Because the drill site for the BAC1-1 borehole is located very close to the village of Bachs, noise protection measures were deemed necessary from the beginning of the project. Noise predictions confirmed the necessity of noise protection at the south-eastern side of the drill site. Therefore, noise protection walls were installed already during rig up around the mud pumps and the hydraulic power unit.

During the entire drilling phase, the legal limits of the Noise Abatement Ordinance had to be complied with at the nearest residential properties to the drill site. For the BAC1-1 borehole, short-term and long-term noise measurements were performed by a specialised company around the drill site to evaluate the average noise emissions of the work carried out.

Because drilling operations were carried out around the clock, it was important to stay within the legal limits for day and night. The limit was 60 dB(A) during daytime and 50 dB(A) during nighttime.

After starting the drilling operations, several noise complaints were made by local residents, whereupon a bigger noise wall was constructed at the south-eastern side, outside the fence, to protect the village from noise emissions (see Fig 3-21). The results of the noise measurements after the additional measures showed that the legal limits were respected.

Fig. 3-21: Noise protection wall at the south-eastern side of the drill site

4.2.6 Lighting

Beside noise emissions, light emissions were also relevant for the drill site. Proper lighting at the workspace is indispensable in terms of safety for the crew but must not affect the surrounding environment. Therefore, a lighting concept was prepared, and warm-white LED lamps were installed at the site to reduce the harmful blue content in the emitted spectrum, being more environmentally friendly for wildlife and people.

At the drill site for the BAC1-1 borehole, special attention has been paid to lighting because it was located in a valley close to the village of Bachs and in the midst of habitat for bats. The number of lamps was reduced to an absolute minimum and orientation and intensity of the radiation were configured and verified by a lighting expert. Nightshift personnel were equipped with headlights on their safety helmets.

In addition, covering the containers with camouflage panels and installing the noise wall at the south-eastern side of the drill site significantly reduced light emissions.

4.2.7 Waste management

Waste material from the drilling process was categorised and disposed of according to the regulations of the Federal Office for the Environment (FOEN).

In every section of the borehole, a detailed analysis of the cuttings and drilling fluid was performed at a specified laboratory to classify the waste materials. For each analysis two samples were taken: first to determine the texture and mechanical modularity and second for eluate investigations.

4.2.8 Mud losses

A volume of 15 m^3 of potassium silicate mud was lost in Section II while coring at around 807 m MD. In Section IV, 763 m^3 of water polymer and NaCl polymer mud were lost, plus 83 m^3 of NaCl polymer mud before back-cementation.

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