nagra

Arbeitsbericht NAB 22-04

TBO Bachs-1-1: Data Report

Summary Plot

August 2023

National Cooperative for the Disposal of Radioactive Waste

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

nagra.ch

Arbeitsbericht NAB 22-04

TBO Bachs-1-1: Data Report

Summary Plot

August 2023

Keywords:
BAC1-1, Nördlich Lägern, TBO, deep drilling campaign, wireline, cores, cuttings, casing, lithostratigraphy, structural geology, logging, petrophysics, mineralogy, packer testing, pore water chemistry, natural tracers, laboratory testing, geomechanics, rock properties, stress indicators

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 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.

The composite plot was set up and designed by D. Arndt, P. Burgert, M. Gysi, H.R. Müller and M. Schnellmann based on the information contained in Dossiers I to X.

The following Nagra project managers, responsible for the individual dossiers, provided technical input: P. Hinterholzer-Reisegger (Dossier I), Hp. Weber (Dossier II), F.Casanova (Dossier III and V), G. Deplazes (Dossier IV), R. Garrard (Dossier VI), A. Pechstein (Dossier VII), D. Traber (Dossier VIII) and J.K. Becker (Dossier X).

Editorial works: M. Unger and P. Blaser

Copyright © 2023 by Nagra, Wettingen (Switzerland) / All rights reserved.
All parts of this work are protected by copyright. Any utilisation outwith the remit of the copyright law is unlawful and liable to prosecution. This applies in particular to translations, storage and processing in electronic systems and programs, microfilms, reproductions, etc.

Table of Contents

Table of Contents I
List of Tables II
List of Figures II
List of Appendices II

1 Introduction 1
1.1 Context 1
1.2 Location and specifications of the borehole 2
1.3 Documentation structure for the BAC1-1 borehole 6
1.4 Scope and objectives of this dossier 7

2 Short explanation of the attached summary plot 9
2.1 Metres MD 9
2.2 System / Period / Group / Formation / Member 9
2.3 Depth interval 9
2.4 Lithology 9
2.5 Weathering plot with GR 9
2.6 Cuttings & core photos 9
2.7 Cored interval 9
2.8 Tadpole plot (bedding) 10
2.9 Fracture density class 10
2.10 P32 fault & fracture density 10
2.11 Casing 10
2.12 Caliper 10
2.13 Resistivity 11
2.14 FMI static 11
2.15 Neutron porosity / Density 11
2.16 Natural gamma ray / Temperature 12
2.17 Clay mineral content 12
2.18 Multi-mineral interpretation 12
2.19 Clay mineralogy 12
2.20 Porosity 12
2.21 Chloride 13
2.22 Stable isotopes of porewater (δ^2H, $\delta^{18}O$) 13
2.23 Hydraulic conductivity 13
2.24 (Apparent) hydraulic head 15
2.25 Sonic / Peak strength 15
2.26 Stress magnitudes 15
2.27 Stress indicators 15

3 References 17

List of Tables

Tab. 1-1: General information about the BAC1-1 borehole.. 2

Tab. 1-2: Core and log depth for the main lithostratigraphic boundaries in the BAC1-1 borehole.. 5

Tab. 1-3: List of dossiers included in NAB 22-04 6

Tab. 2-1: Tested specimens characteristics and mineralogical composition.......................... 14

Tab. 2-2: Hydraulic conductivity (k) from constant head and consolidation theory.............. 15

List of Figures

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

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 3

Fig. 1-3: Lithostratigraphic profile and casing scheme for the BAC1-1 borehole 4

List of Appendices

App. A: Summary Plot

Note: In the digital version of this report the appendix can be found under the paper clip symbol.

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.

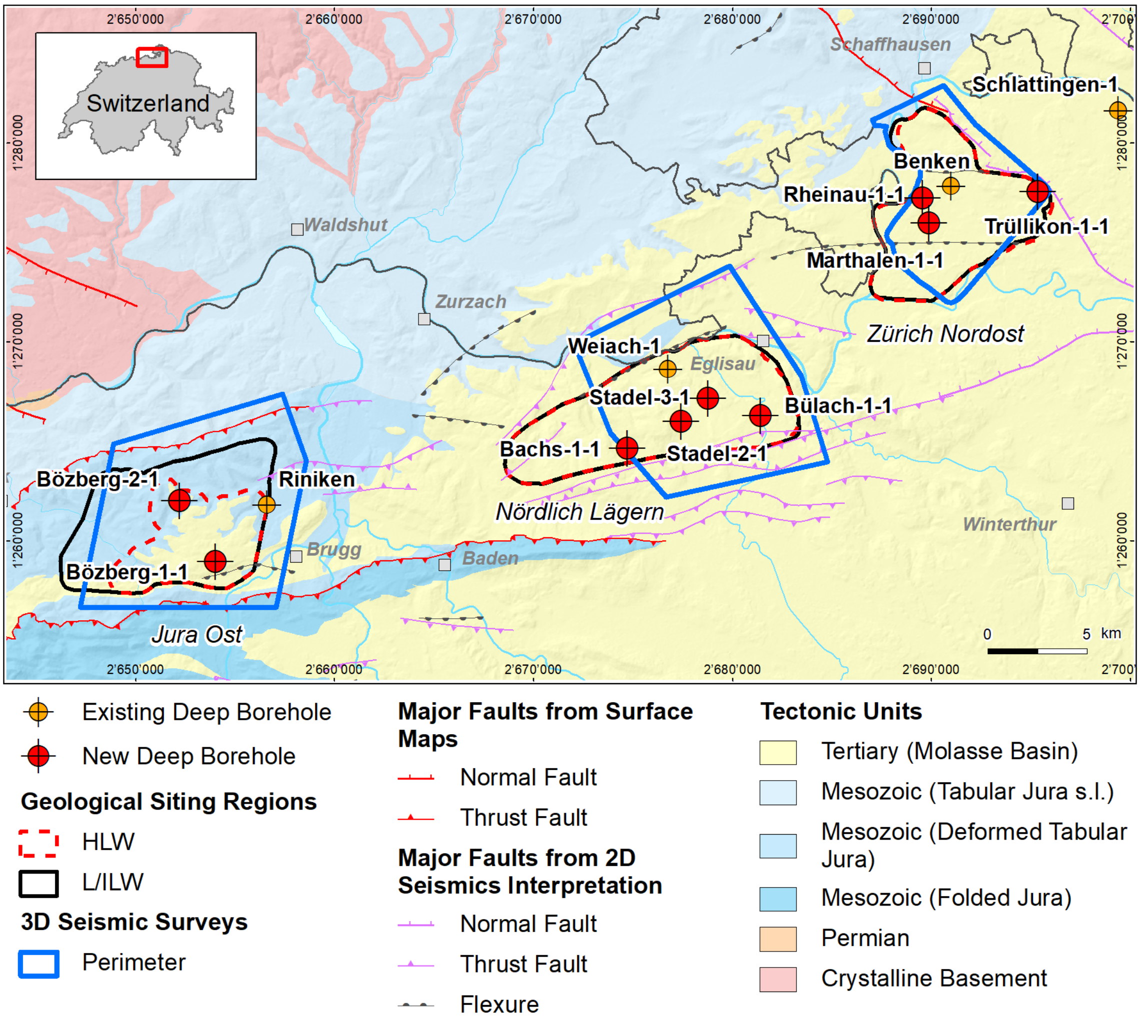

Fig. 1-1: Tectonic overview map with the three siting regions under investigation

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 Dossier I.

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 Dossier I.

[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.

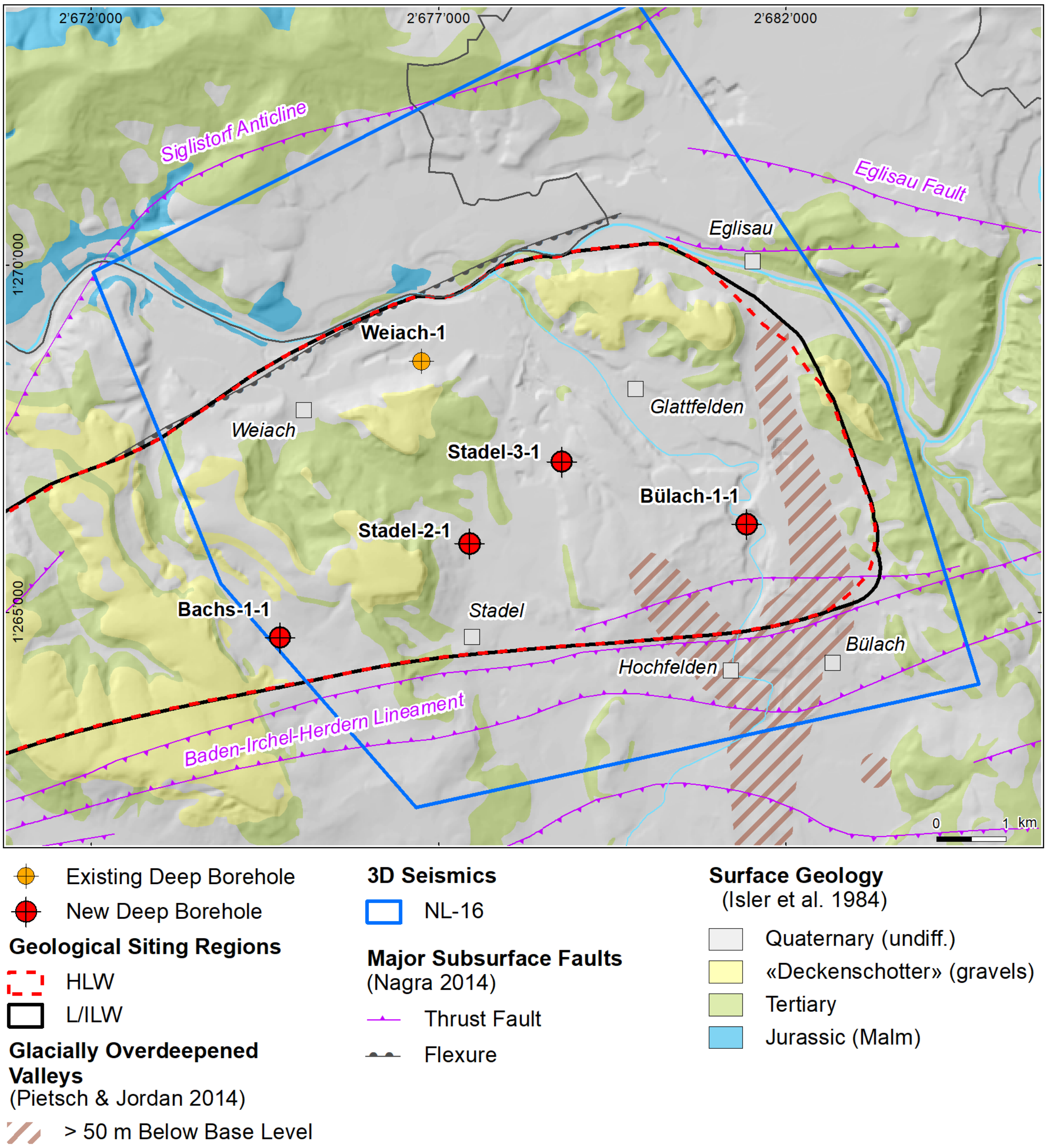

Fig. 1-2: Overview map of the investigation area in the Nördlich Lägern siting region with the location of the BAC1-1 borehole in relation to the boreholes Weiach-1, BUL1-1, STA3-1 and STA2-1

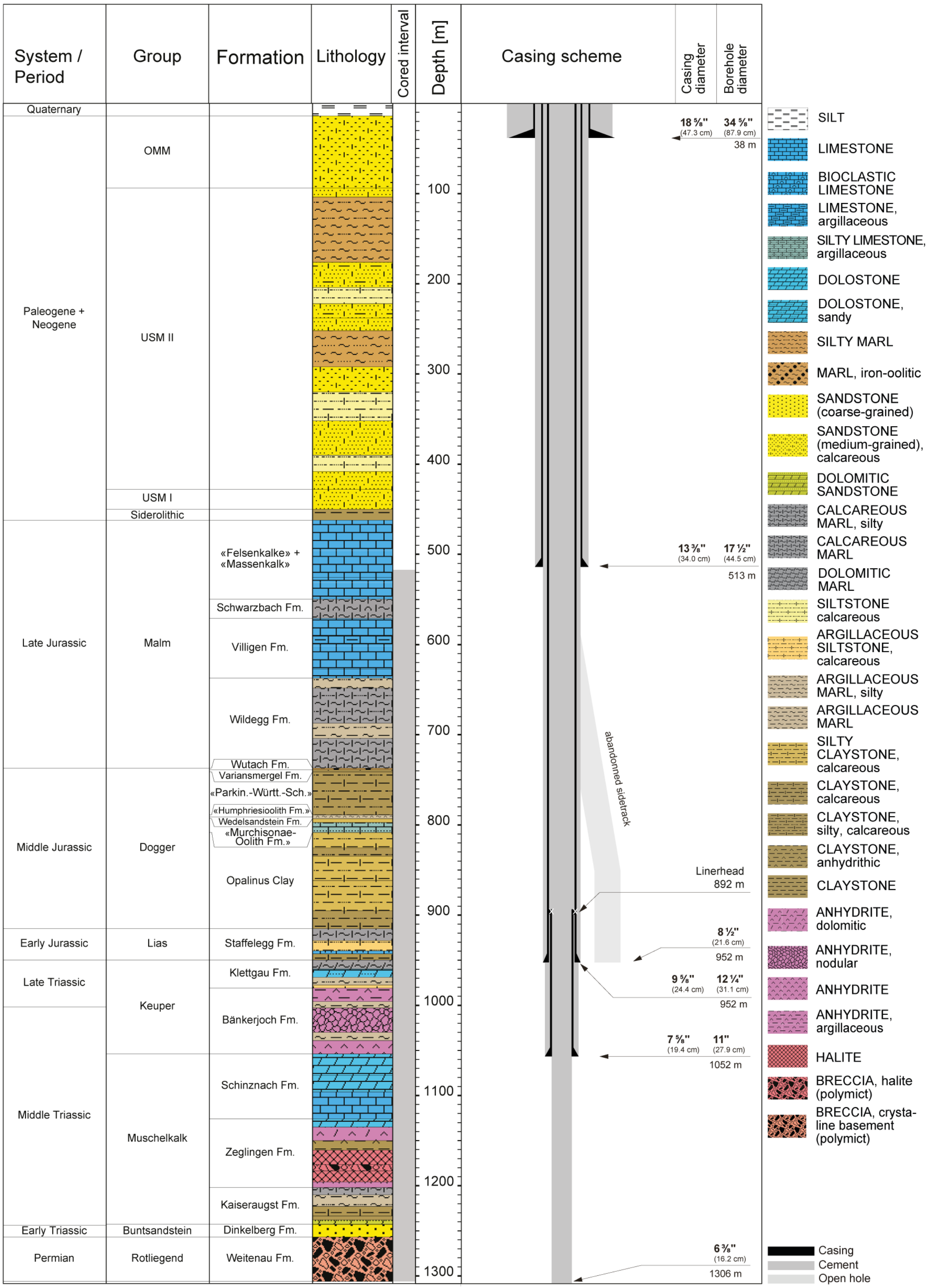

Fig. 1-3: Lithostratigraphic profile and casing scheme for the BAC1-1 borehole[5]

[5] For detailed information see Dossier I and 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 summarises the most important results in the form of a composite plot (Appendix A). A short technical explanation of the information displayed is given in Chapter 2, column by column from left to right.

Note that for the Bachs-1-1 borehole no undisturbed temperature profile is available (no post completion temperature and no long-term monitoring temperature data acquired). Consequently, no temperature log is shown in the summary plot. The temperatures measured during the main logging campaign are shown in Dossier VI. Note that these temperatures are influenced by drilling and mud circulation and do thus not represent the undisturbed rock temperature.

The geomechanical campaign in BAC1-1 was limited to two oedometric tests. Hence, no dedicated Dossier IX was produced for NAB 22-04 and no p-wave velocity and peak strength lab data are shown in the summary plot. However, the hydraulic two conductivity values derived from the oedometric tests are documented in this Summary Plot.

2 Short explanation of the attached summary plot

2.1 Metres MD

Measured depth (MD) refers to the position along the borehole trajectory, starting at ground level, which for the TBO boreholes 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. All information shown in the summary plot refers to MD.

2.2 System / Period / Group / Formation / Member

Detailed information regarding the lithostratigraphic classification can be found in Dossier III.

2.3 Depth interval

The numbers in this column refer to the position of the lithological boundaries displayed in the neighbouring columns in metres (m) MD core depth. Core depth refers to the depth marked on the drill cores.

2.4 Lithology

The displayed colours and patterns represent the primary lithology, simplified and upscaled from the original 1:100 to a 1:5'000 profile; for details see Dossier III.

2.5 Weathering plot with GR

The weathering plot visualises the relative resistance of different lithologies to weathering; the larger the bars in black from left to right, the more resistant the lithology to weathering. The different styles of the horizontal separation lines indicate different lithological boundary types; for details see Dossier III.

The total natural gamma ray (GR_KCOR) measurement, a qualitative indicator for clay content and hence an indicator for weathering, is visualised for comparison in green. Please note that the scale is reversed (decreasing values from left to right) compared to the GR measurement displayed in the column "Natural gamma ray"; for details see Dossier VI.

2.6 Cuttings & core photos

Photos taken from cuttings and drill cores are shown in this column. Please note that the scale of the photos is different for the x- and the y-axis in order to fit the plot; white gaps represent sections where no drill cores were obtained (e.g. for technical reasons). The reference is the core depth as displayed in the column "Lithology". For a high-resolution version of these photos see Dossier II.

2.7 Cored interval

This column indicates which sections of the borehole were (wireline) cored and which were drilled destructively, resulting in cuttings. Please note that smaller core losses are not indicated in this column; for details see Dossier I.

2.8 Tadpole plot (bedding)

A tadpole plot is a graphical method for displaying the orientation of (in this case) bedding planes. The circles indicate the dip angle of the bedding at the respective positions (between 0° = horizontal and 90° = vertical) and the lines originating from the circles indicate the dip direction of the bedding (upwards = north, right = east, down = south, left = west).

Green stands for undifferentiated bedding, red for cross-bedding and magenta for deformed bedding. Unfilled circles show sections where correct core orientation (with the help of the FMI based on core goniometry) was not possible and therefore the dip azimuth, even though displayed, refers to an artificial true north. The dip, however, is correct for these features; for details see Dossier V.

2.9 Fracture density class

Where (parts of) the drill cores were heavily disintegrated, it was not possible to accurately assess the density of natural fractures. For these sections, the fracture density was estimated using the classification scheme of Bauer et al. (2016): fracture density class (FDC) 2 in orange (spacing of fractures = 5 – 10 cm), FDC 3 in orange with vertical lines (spacing of fractures = 1 – 5 cm), FDC 4 in red (spacing of fractures < 1 cm); for details see Dossier V.

2.10 P32 fault & fracture density

The parameters displayed in these columns were recorded separately for brittle structures with shear indications and brittle structures without shear or slip indications. The so-called P32 value is obtained by dividing the summarised discontinuity area along the drill cores by the volume. Therefore, the P32 value reflects the area of discontinuities per unit of rock volume (m^2/m^3), possibly highlighting the degree of tectonic overprinting. A high P32 value for fault planes, for example, can indicate the presence and position of a fault zone; for details see Dossier V.

2.11 Casing

Details regarding the drilling process (such as bit size, casing diameter, cementation scheme etc.) can be found in Dossier I.

2.12 Caliper

The caliper measurement performed during geophysical wireline logging gives the diameter of the borehole in inches (1 inch = 2.54 cm) at the time of measurement for several (here 6) azimuthal directions obtained by different measurement arms (RD1 to RD6); for details see Dossier VI.

BS stands for bit size. In a perfect borehole, the measured diameter from the caliper log should equal the bit size. Strongly simplified, variations in the borehole diameter, such as washouts and breakouts, can be associated with the drilling process and/or result from unstable borehole sections. Some borehole measurements can be affected by variations in the borehole diameter.

2.13 Resistivity

The resistivity measurement performed during geophysical wireline logging gives the electrical resistivities at different depths of investigation in the formation in Ohm metres (ohmm). Processing allows the extrapolation of the resistivity measurements far into the formation, providing the true formation resistivity (RT_HRLT), as well as close to the tool, providing the micro-resistivity or resistivity close to the borehole wall (RXO_HRLT).

Less resistive formations, for example, can indicate a higher clay content and/or a higher porosity filled with conductive fluids (such as saline porewater); for details see Dossier VI.

2.14 FMI static

The formation microimager (FMI) provides a high-resolution, micro-resistivity measurement of the borehole wall performed during geophysical wireline logging, showing not only changes in lithology (brighter = more resistive), but (on a smaller scale) also discontinuities in the case of mineral or fluid filling; for details see Dossier VI.

The 360° measurement result from the borehole wall is displayed as an unwrapped, planar plot with the 180° mark indicating the side of the borehole facing towards south. Due to the unwrapping, discontinuities (inclined compared to the borehole axis) can be identified as sinusoidal curves, which can be used to assess the dip direction and the dip angle of the associated discontinuities. For a vertical borehole, the amplitude of the curves is smaller the more horizontal the orientation of the intersecting discontinuity is.

Among others, the FMI was used for the core goniometry (*cf.* column "Tadpole plot – bedding") and the analysis of breakouts and drilling-induced fractures (*cf.* column "Stress indicators").

2.15 Neutron porosity / Density

This column shows results from the geophysical wireline logging using a radioactive neutron source for assessing the porosity and a radioactive gamma source for obtaining bulk densities of the rock formations surrounding the borehole. After corrections, the displayed results are:

- represented as dark blue lines: epithermal neutron hydrogen index (APLC) as a proportion of the total volume (v/v), which times 100 equals a percentage; a measurement of the "neutron porosity", with higher values possibly indicating more porous lithologies (pore-filling water contains hydrogen). The "neutron porosity" is also influenced by the clay content, hydrogen-rich minerals, hydrocarbons and chlorine-rich formation fluids.
- represented as a black line: high resolution bulk densities (RHO8) in grams per cubic centimetre (g/cc), a measurement of the bulk density of the formation (minerals and fluid volumes). Higher values can indicate lower porosity or denser minerals.

Bulk density is usually used in combination with "neutron porosity" to quantify the fluid volume (porosity), as a lithological indicator (e.g. clays, limestone, dolostone, sandstone, anhydrite, salt) and as fluid indicator (pores filled with water, gas or hydrocarbons).

2.16 Natural gamma ray

A standard measurement during geophysical wireline logging, used as an indicator for clay content and for depth calibration by identifying lithological marker horizons, is the natural total gamma ray (GR_KCOR) measurement. By measuring the total natural gamma radiation along the borehole, GR gives an indication of the clay content of the rock formations surrounding the borehole. The further left the line or the higher the number on the American Petroleum Institute calibrated scale (API), the higher the GR measurement, which usually correlates with higher clay contents.

2.17 Clay mineral content

The filled circles in black show the clay mineral content in weight percent (wt.-%) obtained from laboratory measurements on rock samples; for details see Dossier VIII.

The curve in dark grey represents the clay mineral content in weight percent (wt.-%) obtained from a combined interpretation ("multi-mineral interpretation") of several geophysical wireline logging measurements and available laboratory measurements on core samples. In the case of data gaps in the geophysical wireline logging, data from a Multi-Sensor-Core-Logger (MSCL) were taken into account; for details see Dossier X.

2.18 Multi-mineral interpretation

This column shows the "multi-mineral interpretation" (MM) of the mineral content in weight percent (wt.-%) as a stacked overview plot. For the MM, data from geophysical wireline logging and laboratory measurements on core samples as well as measurements with a Multi-Sensor-Core-Logger (MSCL) are taken into account; for details see Dossier X.

Displayed are the following minerals: pyrite (MM_PYRITE), halite (MM_HALITE), siderite (MM_SIDER), anhydrite (MM_ANHYDR), calcite (MM_CALCITE), dolomite (MM_DOLOMITE), silicates[7] (MM_QF_SILICATES) and clay minerals (MM_DRY_CLAY).

2.19 Clay mineralogy

Displayed is the content of the individual clay minerals in weight percent (wt.-%) obtained from laboratory measurements on core samples; for details see Dossier VIII.

Displayed are the clay mineral endmembers: chlorite (CM_CHLORITE), kaolinite (CM_KAOLINITE), smectite (CM_SMECTITE) and illite (CM_ILLITE).

2.20 Porosity

This track combines the porosities derived from "multi-mineral interpretation" and laboratory measurements.

---

[7] Quartz and feldspars.

The filled circles in black represent the water loss porosity, calculated based on the gravimetric water content (oven-dried at 105 °C) and the bulk wet density, whereas the empty circles indicate the pycnometer porosity, calculated based on the bulk dry and the grain density. All laboratory measurements were performed on core samples and are given in percent (%); for details see Dossier VIII.

The dark blue curve represents the result of the "multi-mineral interpretation" of porosity (MM_PHIT) as a volume fraction (v/v), which times 100 equals a percentage; for details see Dossier X.

2.21 Chloride

The circles in black show the chloride content in mg/L of porewater (based on aqueous extraction scaled to anion-accessible porosity); horizontal lines represent the propagated analytical error. The filled squares in blue indicate the results from water samples taken from the borehole during pumping tests; vertical blue lines mark the length of the test interval. For details see Dossier VIII.

2.22 Stable isotopes of porewater (δ^2H, $\delta^{18}O$)

The circles show the porewater stable isotope composition (δ^2H, $\delta^{18}O$ in ‰ V-SMOW) based on the diffusive-exchange method; horizontal lines represent the analytical error. The filled squares in blue indicate the results from water samples taken from the borehole during pumping tests; blue vertical lines mark the length of the test interval. For details see Dossier VIII.

2.23 Hydraulic conductivity

The hydraulic conductivity obtained from hydraulic packer testing is presented in black. Note that hydraulic conductivity was calculated from the measured transmissivity by division by the interval length. The vertical lines indicate the depth of the measurement interval in the borehole. The log (10^{-x}) of hydraulic conductivity is given in metres per second (m/s). The parameter range is shown with horizontal error bars; lower hydraulic conductivities plot on the left and higher hydraulic conductivities plot on the right side of this column; for details see Dossier VII.

The circles in dark green denote values obtained from advective displacement tests on core samples. Blue indicates hydraulic conductivities derived from oedometric laboratory tests on core samples, using consolidation theory and covering a range of effective stresses from 5 to 30 MPa.

The geomechanical campaign in BAC-1-1 was limited to two specimens. Hence, no dedicated Dossier IX was produced for BAC-1-1. The results of the hydraulic conductivity investigations are here synthesised. For further details on methods, see Dossier IX of previous boreholes.

Two cylindrical specimens, an S and a P geometry, of dimensions 12.5 mm in height and 35 mm in diameter were tested. The two specimens were subjected to oedometric compression tests, performed in a one-dimensional apparatus. The characteristics of the tested specimens and their mineralogical compositions are reported in Tab. 2-1, and include the core ID, the specimen depth and geometry, the water content measured on a trimming piece (wtrim), the initial water content (w_0), bulk density (ρ_{bulk}), porosity (n), void ratio (e) and degree of saturation (S_r), and final water content (w_f).

The oedometric test consists of a series of subsequent loading stages (up to about 30 MPa), followed by unloading in steps down to the initial stress value. Each loading and unloading step was analysed using consolidation theory, which enables a quantification of the hydraulic conductivity.

At the maximum stress level achieved, the test was halted to perform a constant head permeability test, imposing a pressure gradient between the top and bottom ends of the specimens.

Results of the hydraulic conductivity measurements from the consolidation theory (for the axial effective stress range 6.95 – 27.95 MPa) and the direct measurements (constant head tests at 27.95 MPa) are reported in Tab. 2-2. It is noted that constant head permeability tests were likely affected by a short circuit between ring and specimen, as indicated by the unusual large discrepancy with the results from the values derived from the consolidation theory. The constant head permeability tests are therefore not included in the summary plot.

Tab. 2-1: Tested specimens characteristics and mineralogical composition

			D01_OED_BAC1_1	D02_OED_BAC1_1
Specimens Characteristics	Core ID		BAC1-1-798.23/25-OD	BAC1-1-798.23/25-OD
	Specimen depth	[m]	798.43	798.40
	Geometry		S	P
	w_{trim}	[%]	9.11	6.80
	w_0	[%]	5.57	4.58
	ρ_{bulk}	[g/cc]	2.46	2.50
	w_f	[%]	8.14	7.28
	ρ_s	[g/cm^3]	3.04	3.04
	n	[-]	0.233	0.213
	e	[-]	0.304	0.270
	Sr	[%]	0.56	0.52
Mineralogical Analysis	S	[wt.-%]	< 0.1	< 0.1
	C(inorg)	[wt.-%]	8.20	9.00
	C(org)	[wt.-%]	0.20	0.20
	Quartz	[wt.-%]	4.90	4.31
	K-feldspar	[wt.-%]	-	-
	Plagioclase	[wt.-%]	-	-
	Calcite	[wt.-%]	58.05	66.11
	Dolomite / Ankerite	[wt.-%]	9.47	8.19
	Siderite	[wt.-%]	-	-
	Anhydrite	[wt.-%]	-	-
	Celestite	[wt.-%]	-	-
	Pyrite	[wt.-%]	< 0.2	< 0.2
	Clay minerals	[wt.-%]	7.30	10.26
	Haematite	[wt.-%]	1.28	1.28
	Goethite	[wt.-%]	18.81	9.66

Tab. 2-2: Hydraulic conductivity (k) from constant head and consolidation theory

* Values are likely to be affected by water flowing between the ring and tested specimens.

			D01_OED_BAC1_1	D02_OED_BAC1_1
Constant head permeability test	Effective stress	[MPa]	27.95	27.95
	k	[m/s]	2.85E-11*	6.39E-11*
Hydraulic conductivity from consolidation	Effective stress range	[MPa]	6.95 – 27.95	6.95 – 27.96
	k_{av}	[m/s]	1.60E-13	1.57E-13
	k_{min}	[m/s]	9.06E-14	5.95E-14
	k_{max}	[m/s]	2.42E-13	3.02E-13

2.24 (Apparent) hydraulic head

In this column, the (apparent) hydraulic head obtained from hydraulic packer testing is presented. The vertical lines indicate the depth of the measurement interval in the borehole. The results are given in metres above sea level (m asl) and hydraulic head is shown as freshwater head. The horizontal error bars show the range of parameters. The height of the ground level at the position of the borehole is marked with a dashed vertical line; for details see Dossier VII.

2.25 Sonic

The velocities of seismic waves (V_p) travelling through the different rock formations surrounding the borehole can be derived from sonic measurements performed during geophysical wireline logging. These measurements are used, for example, to assess rock strength properties and to support the calibration of seismic surveys. The results are given in metres per second (m/s) with e.g. porous or fractured lithologies usually showing slower travel times; for details see Dossier VI.

2.26 Stress magnitudes

The blue curve represents the vertical stress (SV) in Megapascal (MPa) from integrated density according to Dossier VI.

The circles indicate the position of micro-hydraulic fracturing measurements in the borehole giving closure pressures in Megapascal (MPa) with error bars, which under certain conditions can be interpreted as the minimum principal stress magnitudes. Additionally, the closure pressure in relation to the vertical stress can give an indication of the stress regime; for details see Dossier VI.

2.27 Stress indicators

Borehole wall images obtained during geophysical wireline logging (i.e. using the FMI) are used in post-processing to identify so-called stress indicators; their position on the 360° borehole wall is shown in this column.

One can differentiate between breakouts (indicated by filled circles in red) and centreline fractures (indicated by filled circles in black). Drilling-induced fractures are typically orientated in the direction of the maximum horizontal stress and breakouts perpendicular to this direction.

3 References

Bauer, H., Schröckenfuchs, T. & Decker, K. (2016): Hydrogeological properties of fault zones in a karstified carbonate aquifer (Northern Calcareous Alps, Austria). Hydrogeology Journal 24, 1147-1170.

Isler, A., Pasquier, F. & Huber, M. (1984): Geologische Karte der zentralen Nordschweiz 1:100'000. Herausgegeben von der Nagra und der Schweiz. Geol. Komm.

Nagra (2014): SGT Etappe 2: Vorschlag weiter zu untersuchender geologischer Standortgebiete mit zugehörigen Standortarealen für die Oberflächenanlage. Geologische Grundlagen. Dossier II: Sedimentologische und tektonische Verhältnisse. Nagra Technischer Bericht NTB 14-02.

Pietsch, J. & Jordan, P. (2014): Digitales Höhenmodell Basis Quartär der Nordschweiz – Version 2013 (SGT E2) und ausgewählte Auswertungen. Nagra Arbeitsbericht NAB 14-02.