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Arbeitsbericht NAB 22-04

TBO Bachs-1-1: Data Report

Dossier III Lithostratigraphy

August 2023

P. Jordan, P. Schürch, M. Schwarz, R. Felber, H. Naef, T. Ibele & F. Casanova

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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:
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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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App. D: Lithostratigraphy patterns, colours, weathering index and symbols for lithostratigraphy

Note: In the digital version of this report the Appendices can be found under the paper clip symbol. In the printed version the appendices are on a flash drive enclosed with the report.

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.

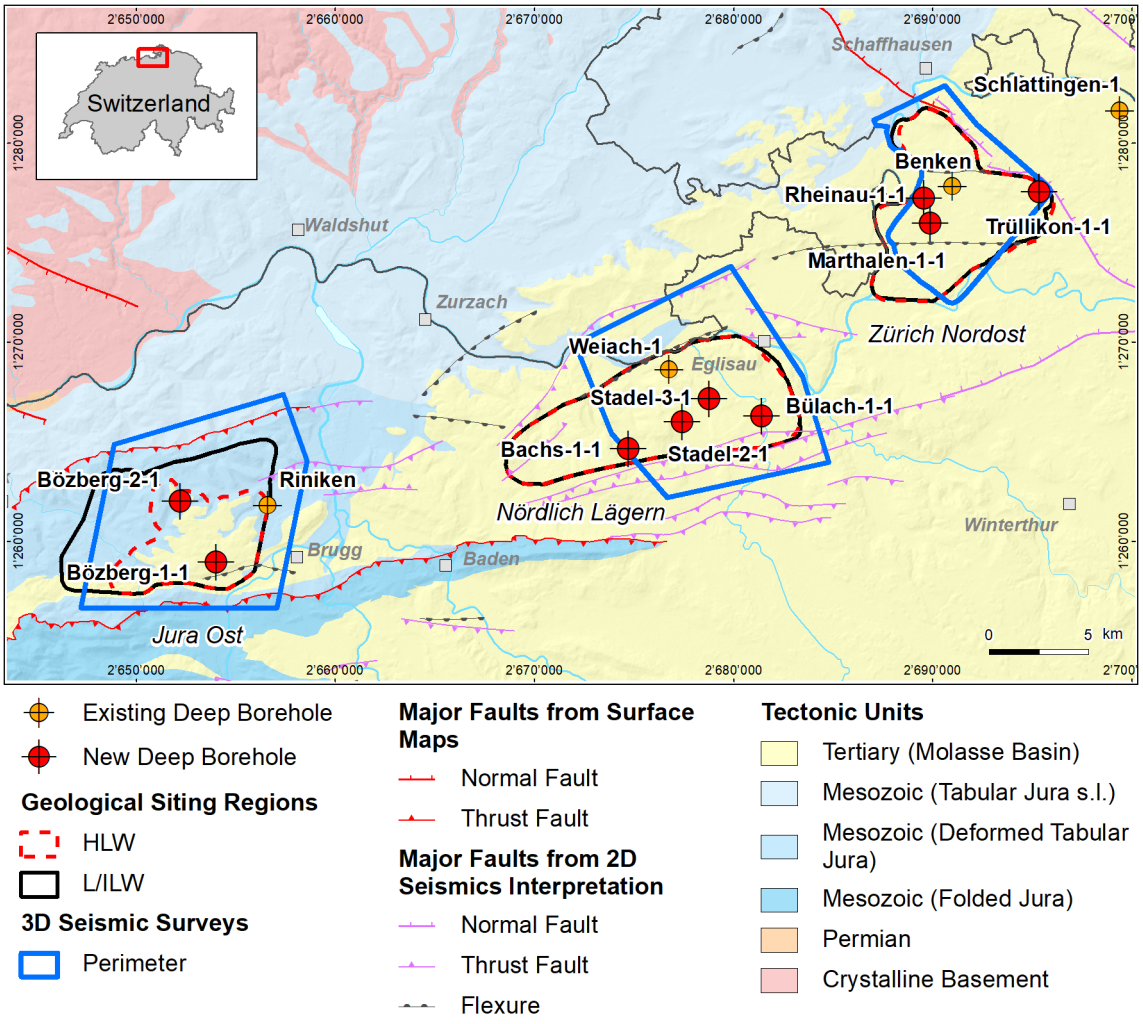


Fig. 1-1: Tectonic overview map with the three siting regions under investigation

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.

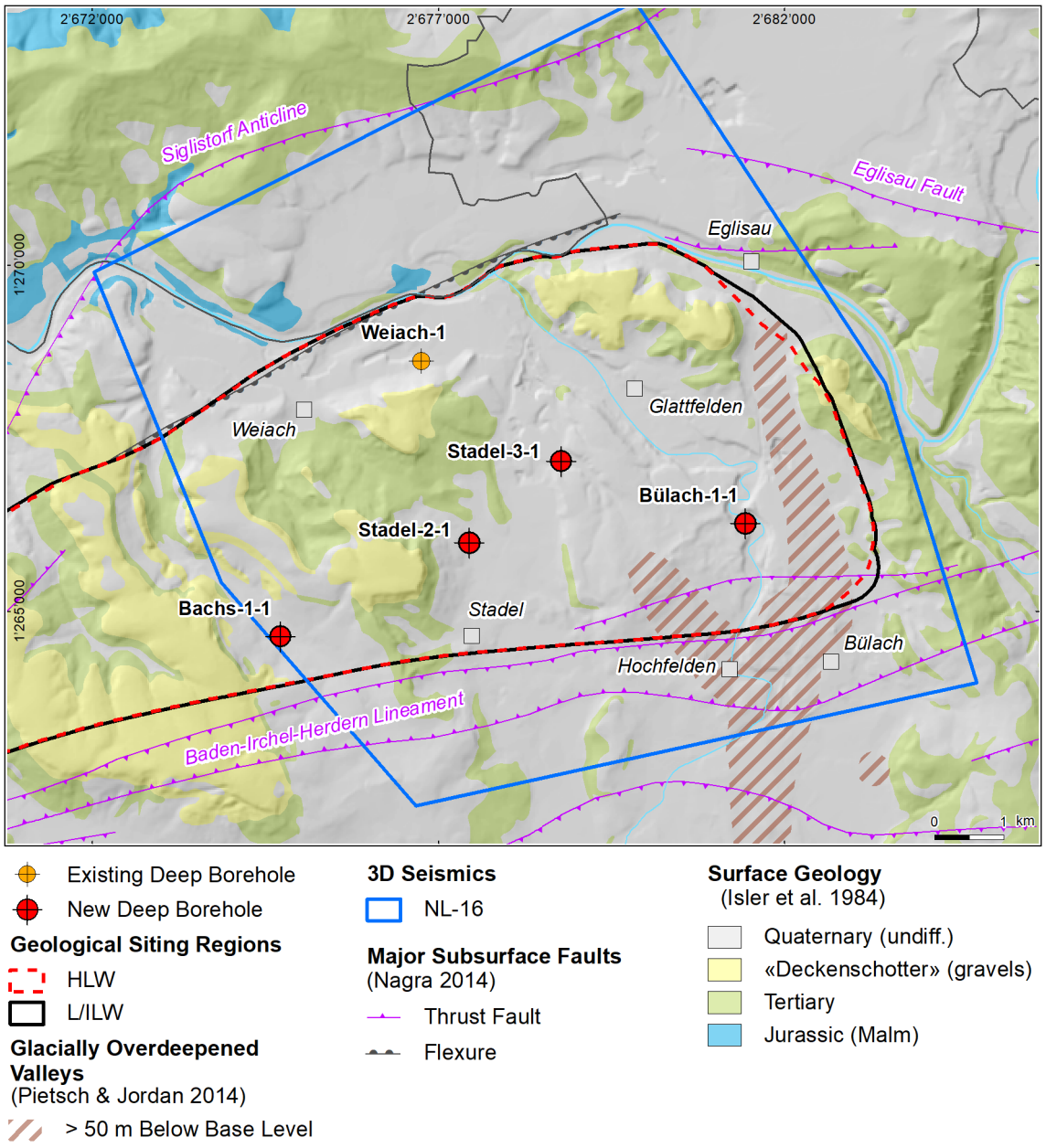


Fig. 1-2: Overview map of the investigation area in the Nördlich Lägern siting region with the location of the BAC1-1 borehole in relation to the boreholes Weiach-1, BUL1-1, STA3-1 and STA2-1

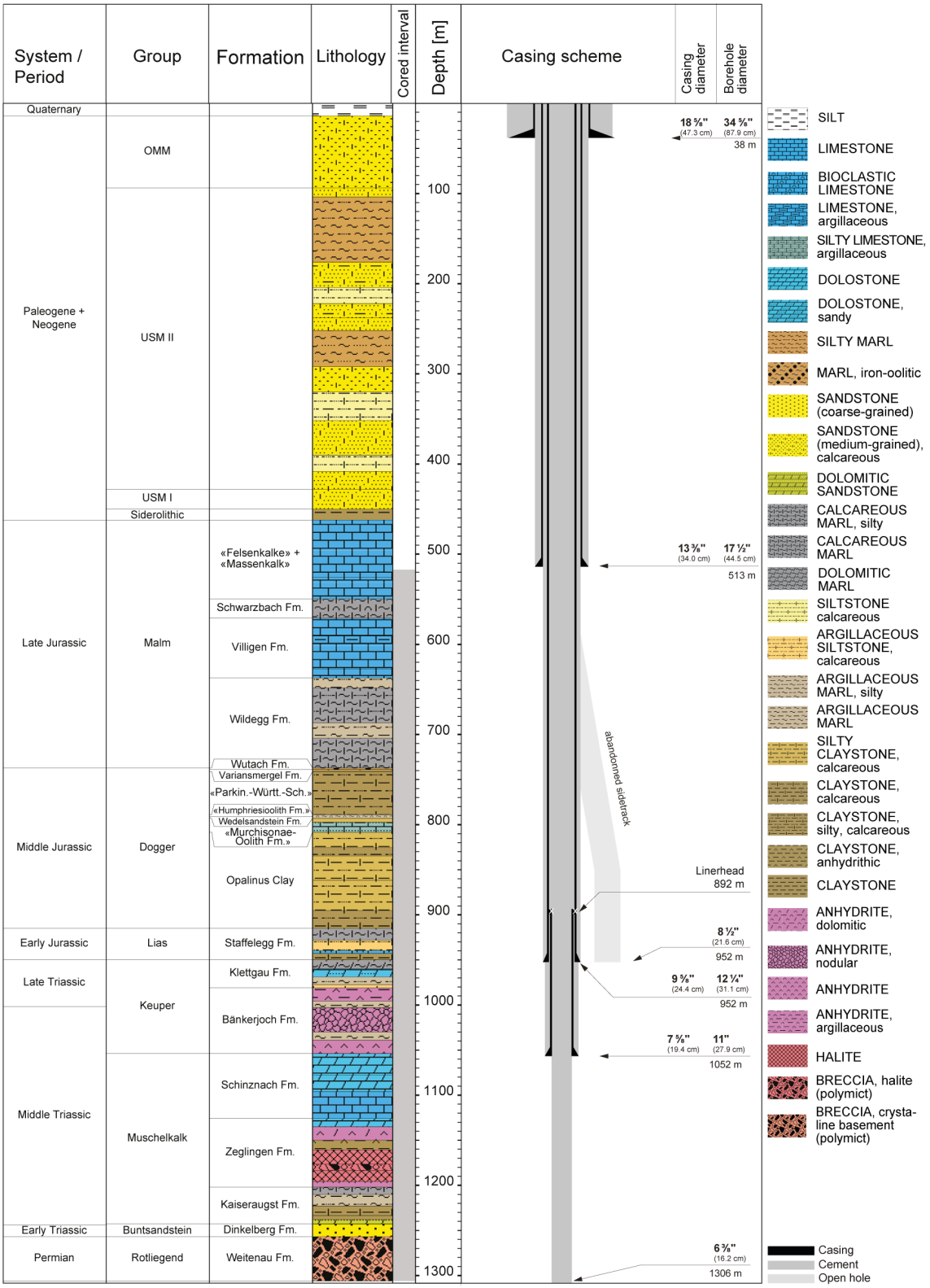


Fig. 1-3: Lithostratigraphic profile and casing scheme for the BAC1-1 borehole[5]

[5] For detailed information about the casing scheme see Dossier I.

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

[6] For details regarding lithostratigraphic boundaries see Chapter 3 and Dossier 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. Schlicken-rieder, 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 documents the work of the lithostratigraphy experts. The objectives of the report are:

- complete, detailed and consistent documentation of the cuttings samples and cores according to the guidelines set out in Naef et al. (2019) and modifications and additions to the procedures (Sections 1.6.2 and 1.6.3)
- stratigraphic classification of drilled strata according to the principles defined in Jordan & Deplazes (2019); if delimitations deviate from these principles, further descriptions are given
- first verification and crosschecking of (macroscopic) findings with additional data from laboratory analyses (XRD mineralogy), thin sections, biostratigraphy and borehole geophysics made available up to data cut-off
- detailed description of lithology and lithostratigraphic units down to member and bed level (if applicable), with the focus on special features and deviations from current knowledge and understanding (Jordan & Deplazes 2019)
- visualisation of lithostratigraphic data as profiles:
  - 1:2'500: Appendix A
  - 1:1'000: Appendix B
  - 1:100: Appendices C-1 to C-5

The level of detail in this dossier is limited by the data availability at data-freeze two months after the end of drilling operations. Some obvious, well-preserved fossils were identified by the lithostratigraphy experts, but this record is neither complete nor exhaustive. A detailed biostratigraphic documentation, as well as thin section (microfacies) and chemostratigraphic analyses can be found in Dossier IV.

1.5 Petrophysical logs available at data-freeze

The logs listed below were available at data-freeze and considered as a supplementary source of information for this report (for more details, see Dossier VI).

- total natural gamma ray corrected for borehole and potassium (GR)
- spectral gamma ray: hostile environment natural gamma ray sonde, standard gamma ray (HSGR) and hostile environment natural gamma ray sonde, computed gamma ray (HCGR)
- Caliper / radius (RD1 to RD6)
- near / array corrected limestone porosity (APLC)
- high resolution formation density (RHO8)
- high resolution formation photoelectric factor (PEF8)
- array laterolog apparent resistivity from computed focusing mode 0 to 5 (RLA1 to RLA5)
- formation microimager (FMI)

1.6 Work undertaken

1.6.1 Timeline and general workflow

Four lithostratigraphy experts worked in turns on the cuttings samples and cores following the procedures detailed in Naef et al. (2019). All findings were originally documented in DIN A3 field logs (manuscript), including a detailed drawing of the lithological column. Following this initial description of the samples, the field logs were checked internally by a second expert and compared to logs of the nearby Weiach, Stadel-2-1, Stadel-3-1 and Bülach-1-1 boreholes (Matter et al. 1988, Jordan et al. 2022, Schürch et al. 2022 and Jordan et al. 2021, respectively; *cf.* Fig. 1-1). This workflow ensured that important features were identified if present and that the stratigraphic classification was consistent with Jordan & Deplazes (2019). Internal complementary notes were made with red ink on the field logs. The Nagra quality control team (QC team) closely monitored this process and progress was discussed a few times with all parties involved, including Nagra project managers. This enabled rapid implementation of improvements to the workflow. The 1:100, 1:1'000 and 1:2'500 profiles were drawn using the TerraStation II software (TERRASCIENCES Inc.). To corroborate the lithological identification and representation in the 1:100 profile, the lithostratigraphy experts received regular updates of the petrophysical logs (Section 1.5) and laboratory analyses.

The lithostratigraphic classification in this dossier is based on system / period, group, formation and member boundaries at the data-freeze on 11.07.2022.

All depths in the core descriptions refer to core depth. Depths in the cuttings section refer to drilling depth.

1.6.2 Description and representation of the cuttings samples

The cuttings samples were taken from the shaker with a sampling interval of 2 m. The samples were then washed, sieved, and roughly described at the drill site by the mud logger for the purpose of operational decisions. The cuttings samples were packed in transparent plastic boxes, labelled and delivered to Nagra's core storage facility in Würenlingen. The different lithologies of a single sample were identified using a microscope, hydrochloric acid as well as colour and grain size charts. An important additional source of information was the operational geology plot produced by the mud logging company, containing data on the rate of penetration (ROP), revolutions per minute (RPM), a quick-look lithological composition of the cuttings from the shale shakers and gas chromatography.

Besides the general limitations associated with the interpretation of cuttings, the following points were specified for this borehole:

1. Fine-grained fractions lost during sample preparation: it was unclear which weight fraction was lost during sampling and sample preparation (washing and sieving) at the drill site. Therefore, the descriptions given in the field logs refer solely to the material in the washed samples and do not consider potentially lost lithologies. Molasse lithologies are often insufficiently lithified and the lost fraction is therefore more likely part of fine-grained clastic lithologies such as siltstone, claystone or marl. As a result, the lithologies presented for the Molasse cuttings sections are systematically overestimated with respect to coarser-grained lithologies such as sandstones.
2. It was agreed to quantify all distinguishable lithologies with a proportion of 10% or more of the total sample volume and to specify the three dominant lithologies in detail. This is also applicable for the description of mixed lithologies and small-scale interbedding of different lithologies.
3. While Molasse rock sequences in outcrops or cores often show a small-scale interbedding of different lithologies, destructive drilling evens out this complexity over the 2 m sample interval. The pattern of the dominant lithology was used for the graphical display in the 1:100 TerraStation profile. Minor lithologies are mentioned in the lithological description only.
4. A detailed description of grain size, sorting, grain shape, colour, cement and accessory minerals was provided for sandstones.
5. Except for GR, no petrophysical logs were available from 0 m to 519 m MD. While each individual sample had to be described in detail for the field logs, samples with the same primary lithology were grouped into larger sections for the 1:100 TerraStation profile and described in a summary form. All lithological boundaries in section I of the TerraStation profile correspond to sample boundaries along the 2 m intervals. Depths in the text and on the profile are rounded to full metres (e.g. 456 m).
6. Coring started at 517.16 m and, from 519 m MD onwards, a full suite of petrophysical logs was available. Therefore, depths in the text and profile in this section are accurate to two significant digits and refer to core depth (e.g. 530.51 m MD core depth), with only one exception. The lithostratigraphic boundary between the Stamberg Member and the Asp Member (Schinznach Formation) was not drilled. Neither core nor cuttings were collected. The boundary was therefore set at 1'057.9 m based on FMI and GR log data.

1.6.3 Description and representation of cores

Core recovery and a first geological description were completed on-site by the mud loggers; this included reassembling, orientating, labelling and packing the core into 1 m long core boxes. The core boxes were periodically moved to the core storage facility in Würenlingen for further investigation.

The lithology manual (Naef et al. 2019) proved to be a good basis for core description. The following modifications and additions to the procedures described in the lithology manual were defined for this borehole:

Depths of features or beds were always measured on the non-red line (i.e. the line with depth marks, usually a yellow line).

Resolution of field logs and profiles: all findings of the experts were documented in the manuscript field logs at a scale of 1:50 covering 10 m of core per DIN A3 page. At this scale, a detailed profile sketch and description is feasible using patterns, symbols and plain text as indicated in Naef et al. (2019). The general objective of the field notes was to ensure a comprehensive documentation of all relevant features visible in the core. The subsequent representation of the field logs in the TerraStation profile at a scale of 1:100 required substantial graphical generalisations and, to some extent, also summaries of lithological descriptions. Beds of 20 cm thickness are 2 mm thick at a scale of 1:100 and still clearly show the lithological colour code from Naef et al. (2019). An individual lithological description is, however, not feasible. For thinner beds (< 20 cm), the patterns are increasingly difficult to identify and eventually collapse into black lines, interrupting the lithological pattern above and below. Nevertheless, within the weathering plot, this may still be a desired visual effect for depicting argillaceous interlayers within more competent rock (e.g. limestone) or thin limestone beds in successions of marl, claystone or siltstone. Therefore, the following rules were defined:

- limestone beds within the Opalinus Clay are always recorded and represented in the profile with actual depths, irrespective of their thickness
- firm- to hardgrounds and iron-oolitic beds within the Opalinus Clay are always recorded with actual depths, irrespective of thickness; thin iron-oolitic layers may be represented with the corresponding symbol instead of a lithological pattern
- breccia and conglomerate patterns must be used for beds with a thickness of more than 50 cm, otherwise the corresponding breccia or conglomerate symbols must be used
- an artificial enlargement of thin but prominent or important beds (e.g. firm- to hardgrounds) for illustration purposes is not allowed
- every depth measured in the recorded data should be reproducible from the core, core photographs or FMI; depth annotations are given with two (generally) or one (where no core was recovered) significant digits, respectively

While lithological boundaries were first identified in the core, the FMI often provided additional information to allow the exact depth range of a given lithology to be determined. In such cases, the upper and lower boundaries of a given lithology were taken from the FMI log and lithology from the field log. The shift between log depth and core depth was assessed by comparing FMI logs and core photographs.

The description of lithologies rich in clay minerals adheres to the principles outlined in Mazurek & Aschwanden (2020). For the sake of brevity, terms such as "clay-rich" or "clay-poor" are used in the following. These terms are used in a mineralogical sense only. The correct (but longer) term would be "rich / poor in clay minerals".

Additional rules for lithology names: lithology names were assigned according to the scheme modified after Füchtbauer (1988). The Füchtbauer scheme was divided into two versions that differ slightly in the way lithological terms are written in profiles and in continuous text (see Fig. 1-4).

While the implementation of the detailed Füchtbauer scheme as defined for the TBO project in Naef et al. (2019) results in more than 60 lithologies and corresponding patterns, the macroscopic assessment focuses on the main lithotypes 1 to 10. Often a more detailed classification is not feasible without further mineralogical / petrographic analyses. However, experts were requested to differentiate the lithologies as far as possible, especially in the lithological column of the graphical field log, and then to generalise them in the TerraStation profile. Finally, considering all macroscopically distinguishable rock types expected in the stratigraphy of Northern Switzerland, Nagra provided a comprehensive legend of 197 lithology patterns (Appendix D).

For the description of limestone, the Folk and Dunham classifications (Folk 1959, 1962, Dunham 1962) were also applied in the best possible manner (see also Naef et al. 2019). However, neither classification is fully suited for a macroscopic classification, because they rely heavily on the distinction of very small components and their abundance in the rock (microfacies). The use of the Folk classification was further refined by the Nagra QC team in order to avoid ambiguous terminology. All Folk classifications in this text and in the profile follow Fig. 1-5.

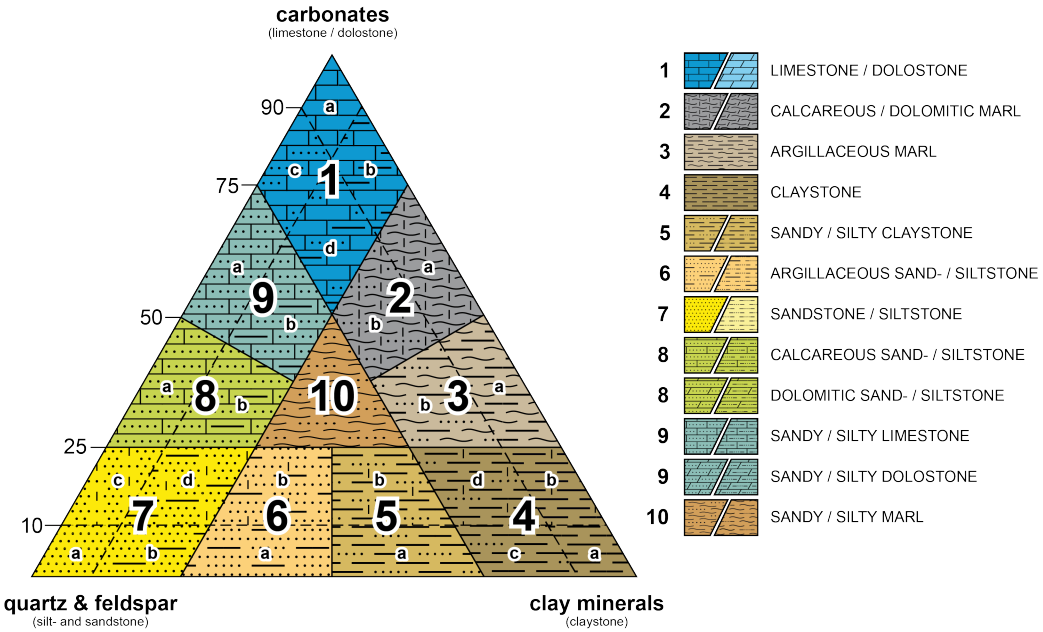
For diagenetically altered limestones composed of small calcite crystals, possibly dolomitised and then dedolomitised, the term "limestone (saccharoidal)" was used exclusively. The term "saccharoidal" was used instead of, or in addition to, the Folk classification.

The description of **breccias and conglomerates** requires details on the matrix and components. The breccia / conglomerate pattern distinguishes between monomict and polymict rocks, while the colour represents the mineralogy of the dominant clast fraction. Since this choice could conflict with evidence from petrophysical logs regarding the matrix mineralogy, such discrepancies are discussed in the lithological description.

The use of the **bituminous shale** pattern was restricted to well-known organic-rich formations such as parts of the Asp Member, Rietheim Member and Schambelen Member. In all other cases the corresponding symbol "bituminous" was used.

Lithological patterns were chosen according to the primary lithotype of a core section. In the field log, all patterns had to be labelled according to the Füchtbauer scheme (see Fig. 1-4) as well as drawn as patterns based on the graphical representation according to Naef et al. (2019). No patterns were used for small-scale interbedding.

XRD mineralogy results come from core samples of 25 cm length. The XRD mineralogy is therefore representative of an average rock composition of the sample which might or might not be comparable to a certain rock type in the vicinity of the sample; careful judgment was necessary.



profile nomenclature	report nomenclature
1a LIMESTONE / DOLOSTONE	1a limestone / dolostone
1b LIMESTONE / DOLOSTONE, argillaceous	1b limestone / dolostone (argillaceous)
1c LIMESTONE / DOLOSTONE, sandy / silty	1c limestone / dolostone (sandy / silty)
1d LIMESTONE / DOLOSTONE, sandy / silty, argillaceous	1d limestone / dolostone (sandy / silty, argillaceous)
2a CALCAREOUS / DOLOMITIC MARL	2a calcareous / dolomitic marl
2b CALCAREOUS / DOLOMITIC MARL, sandy / silty	2b calcareous / dolomitic marl (sandy / silty)
3a ARGILLACEOUS MARL	3a argillaceous marl
3b ARGILLACEOUS MARL, sandy / silty	3b argillaceous marl (sandy / silty)
4a CLAYSTONE	4a claystone
4b CLAYSTONE, calcareous / dolomitic	4b claystone (calcareous / dolomitic)
4c CLAYSTONE, sandy / silty	4c claystone (sandy / silty)
4d CLAYSTONE, sandy / silty, calcareous / dolomitic	4d claystone (sandy / silty, calcareous / dolomitic)
5a SANDY / SILTY CLAYSTONE	5a sandy / silty claystone
5b SANDY / SILTY CLAYSTONE, calcareous / dolomitic	5b sandy / silty claystone (calcareous / dolomitic)
6a ARGILLACEOUS SAND- / SILTSTONE	6a argillaceous sand- / siltstone
6b ARGILLACEOUS SAND- / SILTSTONE, calcareous / dolomitic	6b argillaceous sand- / siltstone (calcareous/dolomitic)
7a SAND- / SILTSTONE	7a sand- / siltstone
7b SAND- / SILTSTONE, argillaceous	7b sand- / siltstone (argillaceous)
7c SAND- / SILTSTONE, calcareous / dolomitic	7c sand- / siltstone (calcareous / dolomitic)
7d SAND- / SILTSTONE, calcareous / dolomitic, argillaceous	7d sand- / siltstone (calcareous / dolomitic, argillaceous)
8a CALCAREOUS / DOLOMITIC SAND- / SILTSTONE	8a calcareous / dolomitic sand- / siltstone
8b CALCAREOUS / DOLOMITIC SAND- / SILTSTONE, argillaceous	8b calcareous / dolomitic sand- / siltstone (argillaceous)
9a SANDY / SILTY LIMESTONE / DOLOSTONE	9a sandy / silty limestone / dolostone
9b SANDY / SILTY LIMESTONE / DOLOSTONE, argillaceous	9b sandy / silty limestone / dolostone (argillaceous)
10 SANDY / SILTY MARL	10 sandy / silty marl

Fig. 1-4: Füchtbauer scheme for lithology names in the geological profiles

Pers. comm. S. Wohlwend modified after Naef et al. (2019)

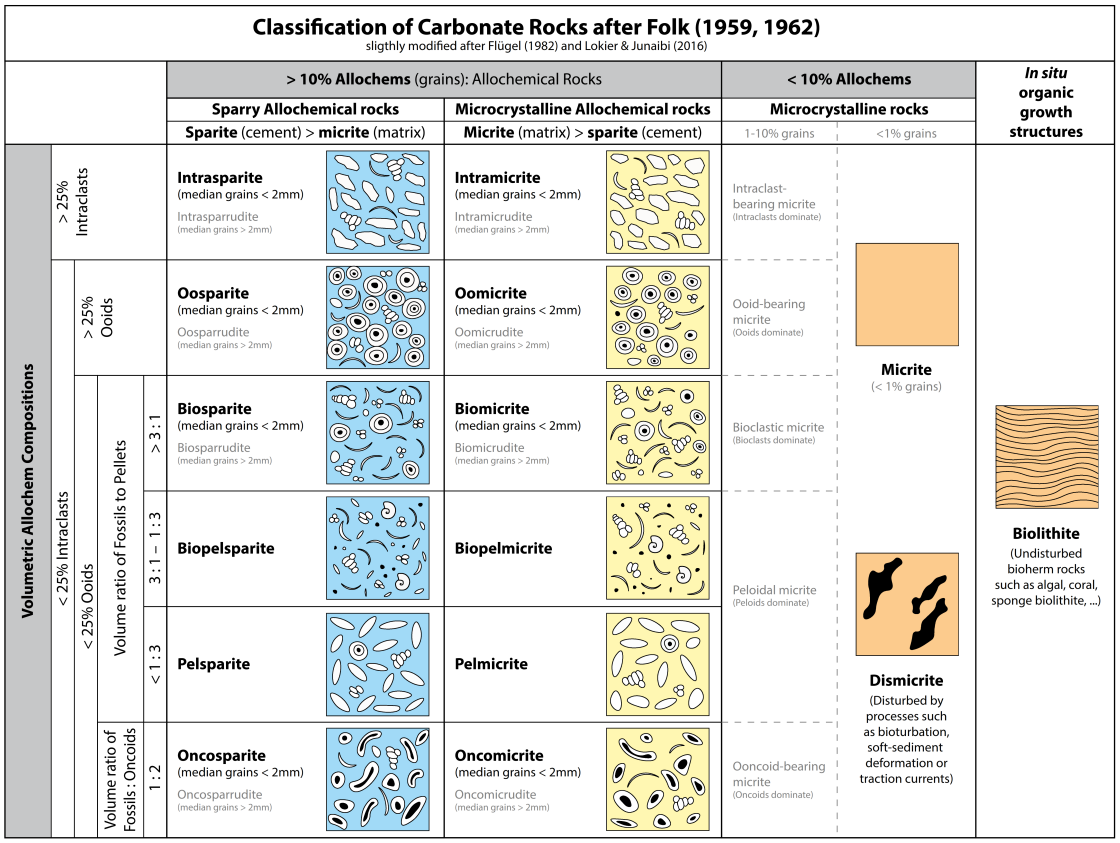


Fig. 1-5: Folk classification as applied to the description of carbonate rocks in BAC1-1

Pers. comm. S. Wohlwend & H.R. Bläsi

Symbols apply either to a whole bed or to a specific feature at a specified depth. For certain individual features, the exact depth had to be recorded in the field log and was subsequently used in the profile at a scale of 1:100. Four columns in the TerraStation profile display symbols: the first column contains "symbols at depth" (single features) and the other three columns contain symbols representative of the whole bed as specified in the lithology column. The symbol for **stylolites** was not used in the TerraStation profile, even if stylolites were diagnostic for a core section, but had to be mentioned in the text instead because stylolites are tectonic features. All symbols used are listed in Appendix D.

The following convention was used for the lithological description in the profile when listing fossil occurrences or other notable features in the core:

"at 556.90 m and from 557.15 m to 557.33 m: lithoclasts;" several lithoclasts found at one depth and in a depth interval

"at 545.42 m, …, 547.10 m and 547.84 m: belemnite;" one single belemnite found at each depth

2 Inventory and quality of cores and cuttings samples

The cuttings quality in terms of lithostratigraphic investigation was good overall (Fig. 2-1). Problems regarding the representativeness of the sample material are discussed in Section 1.6.2 and are related to inherent limitations of destructive drilling, sampling and to the rock properties within the Molasse section.

The core quality in terms of lithostratigraphic investigation was assessed using core photographs and the following qualitative criteria:

1. good core quality = cracks / fractures rarely visible (max. 3 per metre of core), little to no core discing, consistent core diameter
2. medium core quality = few cracks / fractures present (> 3 per metre of core), moderate core discing, mostly consistent core diameter with only slight variations on broken discs
3. poor core quality = many cracks / fractures throughout the core, intense core discing, discs have a highly variable core diameter

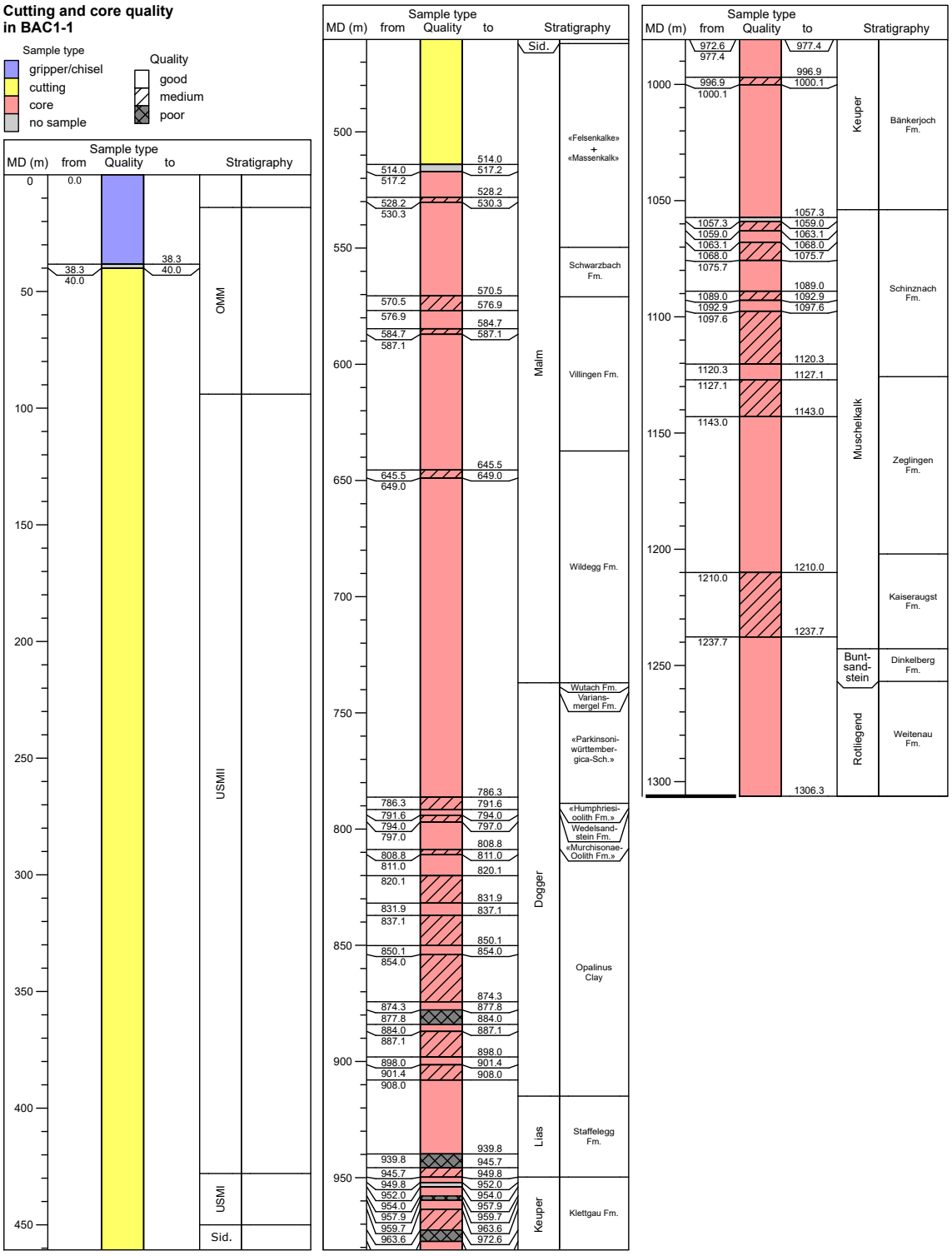


Fig. 2-1: Cuttings and core quality in BAC1-1

Core quality is assessed based on cracks / fractures present, core discing, core shape and core diameter.

3 Stratigraphy and lithology of drilled formations and members

3.1 Unconsolidated rocks (Quaternary), 0 m – 14 m (about 14 m)

Unconsolidated rocks were only encountered in the conductor pipe excavation from 0 m to 14 m. They consist (from bottom to top) of silt (calcareous) with boulders, clay (sandy, calcareous) with gravel, silt (calcareous, argillaceous) with gravel and, finally, gravel (silty, calcareous, argillaceous). This succession is interpreted as a transition from a fluvio-glacial to a lacustrine and, finally, to a fluvial environment. They probably originate from the late glacial to the post-glacial period. However, besides root fragments, no fossils or other time markers have been found.

3.2 Upper Marine Molasse, 14 m – 94 m (about 80 m)

The Upper Marine Molasse (OMM) is composed of sediments with distinct marine facies (Jordan & Deplazes 2019) comprising marine fossils (gastropods, bivalves) and glauconite.

In BAC1-1 the OMM was identified and delimited mainly based on the presence of glauconite (often giving the sediment a greenish-grey hue), found from top (at 14 m) to 72 m, and of marine bivalves, found from 58 m to 72 m. Plant remains, some fragments of pyritised coal and charophyte algae (in the sample from 24 m) document a rather littoral environment at least for the upper part of the succession. The interval from top (at 14 m) to 72 m is characterised by an alternation of fine-, medium and coarse-grained sandstone, mostly poorly sorted.

In the interval from 72 m to 94 m, neither glauconite nor marine bivalves have been found. The argument for attributing this interval to the OMM is its greyish colour, which differs from the rather beige grey to reddish-brown colour of the section below.

The *upper boundary* is set at 14 m with the onset of silt-dominated talus deposits of Quaternary age.

The *lower boundary* is set at 94 m at a significant change in colour from reddish-brown and beige below to light grey and greenish-grey above.

Lithostratigraphic subdivision

Most of the section likely corresponds to the predominantly marine Lucerne Formation (including its transgressional base). The section from 50 m to 72 m probably represents the «Safenwil-Muschelsandstein», a characteristic, semi-formal member of the Lucerne Formation. The upper part (from 14 m to 46 m), with fragments of coal and charophyte algae but also glauconite, rather represents littoral facies of the Lucerne Formation than a transition to the brackish St. Gallen Formation.

The presence of limestone and quartz pebbles in the lower part (from 82 m to 86 m and from 92 m to 94 m) is unexpected. Such limestone pebbles in Molasse sediments indicate a sedimentary provenance in the Jura Mountains. Intermediaries of «Juranagelfluh» (conglomerates of Jura Mountain origin) are known to occur in the uppermost Lower Freshwater Molasse (USM) («Ältere Juranagelfluh») and the upper OMM («Mittlere Juranagelfluh», *cf.* Jordan & Deplazes 2019) but not in the part of the OMM below the «Safenwil-Muschelsandstein».

Lithology

14 m – 28 m	Sandstone (medium-grained) (calcareous), pale yellowish-green, angular, occasionally sub-rounded to rounded, very well sorted, poorly to moderately cemented, with mica, some glauconite, few fragments of pyritised coal and, from 24 m to 26 m, charophytes
28 m – 30 m	Siltstone (calcareous), pale yellowish-green, moderately to strongly cemented, with mica and very few fragments of pyritised coal
30 m – 46 m	Sandstone (medium-grained) (moderately calcareous), pale yellowish-green to light grey, angular to sub-rounded, poorly to moderately sorted, poorly to moderately cemented (calcite), with some mica, some glauconite, sparse pyrite, from 34 m to 38 m pyritised coal and, from 44 m to 46 m, fragments of sparry calcite
46 m – 50 m	Sandstone (predominantly coarse-grained) (calcareous), light grey, poorly sorted, with mica and some glauconite, and siltstone (calcareous), light grey, angular to rounded, poorly sorted and partly sandy
50 m – 58 m	Sandstone (fine- to coarse-grained) (calcareous), light grey, poorly sorted, with mica and some glauconite, and sandstone (fine-grained) (calcareous), light grey, rounded, moderately sorted, with mica, as well as siltstone (calcareous), light grey, angular to rounded, poorly sorted, partly sandy, with, from 54 m to 58 m, carbonised plant remains
58 m – 62 m	Sandstone (coarse-grained) (calcareous), light grey, poorly sorted, with mica, some glauconite, quartz pebbles up to 5 mm, limestone pebbles up to 1 mm and carbonised plant remains, and siltstone (calcareous), light grey, partly sandy. Throughout the section, carbonised plant remains and, from 60 m to 62 m, bivalve imprints (type "Muschelsandstein")
62 m – 72 m	Sandstone (medium- to coarse-grained) (calcareous), light grey, angular to rounded, poorly sorted, moderately cemented (calcite), with mica, some glauconite and very few carbonised plant remains, and sandstone (fine-grained) (calcareous, silty), light grey, rounded, poorly sorted, with mica, some glauconite and, from 68 m to 72 m, bivalve imprints (type "Muschelsandstein")
72 m – 78 m	Sandstone (medium-grained) (calcareous), light grey, angular to sub-rounded, moderately sorted, with mica and a possible tooth fragment, and sandstone (fine-grained) (calcareous, silty), light grey, poorly rounded, poorly sorted, with mica, as well as siltstone, sandy, light grey
78 m – 94 m	Sandstone (medium- to fine-grained) (calcareous), light grey, angular to sub-rounded, poorly sorted, milled to loose sand (poorly cemented) with mica, and sandstone (coarse- to very coarse-grained) (calcareous), light grey, angular to rounded, poorly sorted, milled to loose

sand (poorly cemented), with sparry calcite, and siltstone (calcareous), dark grey to light greenish-grey, with mica, as well as sandstone (fine-grained) (calcareous, silty), light grey, with mica. Occasionally coal flakes

From 82 m to 86 m and from 92 m to 94 m, limestone pebbles, beige and black, and, in the lower interval, also quartz pebbles, reddish (possibly beds of «Juranagelfluh»)

3.3 Lower Freshwater Molasse Group II, 94 m – 428 m (about 334 m)

In central northern Switzerland, the upper part of the Lower Freshwater Molasse (USM II) is characterised by fluvial, quartz-rich sandstone, interlayered with fine-grained lithologies of alluvial to lacustrine origin. Silt- and claystone, as well as marl, often build up variegated sequences of beige, brown, reddish and greenish colours. The sandstone shows a predominantly "granitic composition" (white quartz, reddish feldspar and mica) and represents a period in which mainly crystalline nappes were eroding in the alpine realm; therefore, carbonate detritus is generally rare within the USM II. The USM II is traditionally assigned to the Aquitanian.

The uppermost section of the USM II, known as «Oberaquitane Mergelzone», can commonly be distinguished from the "granitic" lithologies by its higher carbonate and clay content and by its predominantly fine-grained lithologies.

In BAC1-1, the USM II was drilled destructively. The marlier part from the top (at 94 m) to 176 m could correspond to the «Oberaquitane Mergelzone». However, there are other marly intervals below. Beds of the characteristic mostly coarse-grained and poorly cemented «Granitischer Sandstein» (i.e. sandstone with a mineral composition close to that of granite) are found below 238 m. The dominant lithologies, however, are siltstone (calcareous) and mostly fine-grained, occasionally medium-grained sandstone (calcareous) alternating with silty to sandy marl and claystone (silty, calcareous).

The *upper boundary* is set at 94 m at a significant change in rock colour from reddish-brown and beige below to light grey and greenish-grey above.

The *lower boundary* is set at 428 m. It corresponds to the onset (in an upward direction) of sandstone of granitic composition.

Lithology

94 m – 176 m

The uppermost section of the USM II is characterised by the dominance of silty marl, grading into argillaceous siltstone, and fine- to medium-grained sandstone. The main lithologies are:

- Silty, locally argillaceous marl (occasionally sandy), beige to reddish-brown and greyish-pink, with mica. This lithology dominates as it constitutes ca. 50% of the whole section
- Sandstone (fine- to medium- and, locally, coarse-grained) (calcareous, argillaceous), silty, light grey to beige grey and beige to brownish and reddish, with mica, making up about 30% of the whole section
- Argillaceous siltstone, sandy, (calcareous), beige to reddish-brown, occasionally grey, with mica

Secondary lithologies are:

- Claystone (calcareous, partly silty or sandy), reddish-brown, beige, ochre
- Silty claystone (calcareous), beige, light greenish-grey and reddish-orange
- Siltstone (calcareous), partly sandy, light brown to beige and reddish-brown

176 m – 238 m: The next section of the USM II is characterised by the dominance of siltstone (calcareous), locally argillaceous, beige to light brown and sandstone (fine- to medium-grained) (calcareous) as in the section above. Silty marl is still present but significantly less than in the section above

238 m – 428 m: The lowest section of the USM II is diverse and varied with all the lithologies of the overlying two sections but none being dominant. Characteristic are a few thin layers of poorly cemented sandstone (medium- to fine-grained, occasionally coarse-grained), calcareous, light grey to grey, of the type «Granitischer Sandstein». The lower edge of a marly to clayey interval at 292 m is characterised by a significant colour change from ochre and light brown above to light grey below

3.4 Lower Freshwater Molasse Group I, 428 m – 450 m (about 22 m)

The succession of the Lower Freshwater Molasse Group I (USM I) is mainly found and described in subalpine outcrops and deep boreholes within the Molasse Basin, where the USM I may reach a thickness of up 2 km. Towards the external part of the Basin in Northern Switzerland, the basal USM becomes progressively younger, its thickness decreases and it occasionally pinches out in subcrops.

The main lithologies of the USM I are generally very similar to those of the USM II: alluvial sand- and siltstone, variegated marl and claystone of terrestrial or lacustrine origin, with rare layers of organic residuals (coal). The main distinctive lithological feature seems to be the carbonate content, which is considerably higher in the USM I, therefore also called «Karbonatreiche Molasse». The sandstone is present partly as litharenite with carbonate grains ("Kalksandstein") that reflect the erosion of sedimentary units in the source area.

In many boreholes of the external Molasse Basin / Northern Switzerland, a proper definition of the USM I is difficult to impossible without further laboratory analyses, such as heavy mineral analysis. The USM I is traditionally assigned to the Chattian.

In BAC1-1, the section from 428 m to 450 m, associated with the USM I, is dominated by mostly calcareous sandstone with an interval of silty marl. Sandstone of the type «Granitischer Sandstein» is absent.

The *upper boundary* is set at 428 m. It corresponds to the onset (in an upward direction) of sandstone of granitic composition.

The *lower boundary* is set at 450 m with the change in colour from light grey and beige above to ochre, ochre brown and violet below which corresponds to the onset of iron-pisoids in a downward direction.

Lithology

428 m – 450 m	Mostly sandstone (fine- to medium-grained) (mostly calcareous), light grey to beige, subordinate silty marl, partly sandy marl, beige to light brown, and claystone (silty), beige to light brown. Between 440 m and 444 m, silty to sandy marl dominates The two cuttings samples from 448 m and 450 m also contain some calcareous sandstone (partly coarse-grained) of the type "Kalksandstein"

3.5 Siderolithic Group, 450 m – 462 m (about 12 m)

The argument for the delineation of the Siderolithic Group is the presence of dark beige claystone with no carbonate («Boluston»), iron-pisoids («Bohnerz»), pure quartz sand («Glassand») or lacustrine sediments.

In BAC1-1, the Siderolithic Group is easily distinguishable by the characteristic ochre to, occasionally, violet colour and the presence of carbonate-free claystone and few small iron-pisoids.

The *upper boundary* is set at 450 m with the change in colour from light grey and beige above to ochre, ochre brown and violet below which corresponds to the onset of iron-pisoids in a downward direction.

The *lower boundary* is set at 462 m with the first occurrence of marine limestone (mudstone, micrite) in the cuttings.

Lithology

450 m – 462 m	Claystone, partly sandy, dark beige to ochre brown to, occasionally, violet, with few iron-pisoids (reddish-brown) a few mm in diameter. The whole interval is carbonate-free

3.6 Malm Group

3.6.1 «Felsenkalke» + «Massenkalk», 462 m – 549.69 m (about 88 m)

According to the informal stratigraphic scheme for the current deep drilling campaign (Jordan & Deplazes 2019), the Jurassic carbonate rocks above the Schwarzbach Formation are to be attributed to the «Felsenkalke» + «Massenkalk», regarded, in combination, as an informal unit in the rank of a formation.

The «Felsenkalke» summarises a succession of lithostratigraphic units which were formally established as formations in adjacent areas in Germany and used to some extent when recording earlier drilling campaigns performed or assisted by Nagra (e.g. Benken, Nagra 2001a, 2001b, or

Schlattingen-1, Albert et al. 2012). The «Massenkalk» (Massenkalk Formation in Germany, see Geyer et al. 2011) encompasses sponge bioherm facies including closely related, poorly or non-bedded sediments within and adjacent to the bioherms. The «Felsenkalke» represents the mostly well bedded and sponge-free facies between the bioherms. Thus, the two informal units can also be interpreted as two facies units alternating each other laterally and vertically.

In BAC1-1, the «Felsenkalke» + «Massenkalk» has been destructively drilled from 462 m to 517.16 m and cored from 517.16 m to 549.69 m. The characteristic «Massenkalk» facies was not encountered in BAC1-1. The succession corresponds well to the Untere Felsenkalke Formation of the German scheme (see Geyer et al. 2011, LithoLex.brg.de, consulted 24.10.2022).

Lithostratigraphic subdivision

462 m – 528.66 m	A well bedded, medium- to thick-bedded succession of limestone (mudstone to wackestone, micrite and bio(pel)micrite) with some sponges and with mostly thin interlayers and drapes of claystone (silty calcareous) and silty marl («Untere Felsenkalke 4» of the informal German scheme) is observed in the cored section (from 517.16 m downward) and is probable for the cuttings section (from 462 m to 517.16 m)
528.66 m – 530.51 m	Silty marl with glauconite and bioclasts («Glaukonitbank» of the informal German scheme or «Glauconitic Marker Bed» after Gygi 2000)
530.51 m – 537.66 m	A well bedded, medium-bedded succession of limestone (mudstone to wackestone, micrite and biopelmicrite) («Untere Felsenkalke 3»)
537.66 m – 543.87 m	Calcareous marl (silty), with thin beds of limestone (argillaceous) (mudstone, micrite and pelmicrite), some glauconite, fossiliferous (mainly belemnites) («Untere Felsenkalke 2»)
543.87 m – 549.69 m	Thin to medium-bedded succession of limestone (wackestone and packstone, biopelmicrite), glauconite, with sponges, belemnites, ammonites, and other fossils («Untere Felsenkalke 1»)

The *upper boundary* is set at 462 m with the first occurrence of marine limestone (mudstone, micrite) in the cuttings.

The *lower boundary* is set at 549.69 m at the top of the uppermost thicker (> 20 cm) calcareous marl bed with no sponges. This bed is overlain by a thin (11 cm) bioclastic calcareous marl with sponges and bored limestone nodules, transitioning into the overlying limestone-dominated interval of the basal «Felsenkalke» + «Massenkalk».

Lithology (cuttings section)

462 m – 492 m	Limestone (mudstone, micrite), white to light beige, dense, splintery, and limestone (mudstone, micrite), white, chalk-like. From the top (at 462 m) to 466 m, decreasing content of claystone, partly sandy (carbonate-free), dark beige to ochre and ochre brown. Down to 468 m, some cavings from the overlying USM lithologies. Below 476 m, occasionally pyrite. From 490 m to 492 m, recurrence of claystone (carbonate-free), dark beige to ochre and ochre brown (karst cavities or cavings)
492 m – 508 m	Limestone (mudstone, micrite), white to light beige, dense, splintery and limestone (mudstone, micrite), white, chalk-like, as well as saccharoidal, white
508 m – 514 m	Limestone (mudstone, micrite), white, chalk-like; limestone, saccharoidal, white, and limestone (mudstone, micrite), white to light beige, dense, splintery; pyrite
514 m – 517.16 m	Neither core nor cuttings collected

Lithology (cored section)

517.16 m – 523.53 m	Limestone (mudstone and wackestone, micrite, biomicrite and pelmicrite), beige to dark beige medium- to thick-bedded with horizontal stylolites with pyrite, chert nodules, peloids, sponge needles and small bioclasts
523.53 m – 525.63 m	Limestone (mudstone and wackestone, micrite and pelmicrite), beige to dark beige with pyrite, peloids, bivalves, crinoids and vugs, medium-bedded, with thin intervals (a few cm thick) of claystone (calcareous), greyish-green
525.63 m – 526.80 m	Silty marl, dark to medium grey, bioturbated, with dark silt to sand grains, burrows, grading downwards into calcareous marl (silty), medium grey, bioturbated
526.80 m – 528.66 m	Limestone (in the uppermost part silty, argillaceous) (mudstone and wackestone, micrite and pelmicrite), beige grey, bioturbated with peloids (dark grey), occasionally crinoids and bioclasts. Thin- to medium-bedded, with thin interbeds (up to 3 cm thick) of argillaceous marl, dark grey
528.66 m – 530.51 m	Silty marl, dark grey to greyish-green, bioturbated with lithoclasts, peloids, glauconite, pyrite, crinoids and bioclasts, and, from 529.29 m to 529.43 m, limestone (mudstone, pelmicrite), beige grey with crinoids and an ammonite (at 529.93 m). Probably the «Glaukonitbank» or «Glauconitic Marker Bed» after Gygi (2000)

530.51 m – 537.66 m	Limestone (mudstone and wackestone, micrite and biopelmicrite), beige grey, dark beige and dark grey with peloids, pyrite (partly as nodules), glauconite (below 537.11 m), locally crinoids and bioclasts. Mostly medium-bedded, with thin (< 8 cm) interbeds of argillaceous marl, dark grey
	From 536.11 m to 536.48 m and at the base (from 537.14 m to 537.66 m), limestone (argillaceous), medium grey with peloids, glauconite, pyrite and bioclasts including small sponge nodules (up to 3 cm in size)
537.66 m – 540.50 m	Thin- to medium-bedded, partly nodular alternation of calcareous marl, dark grey to greyish-green, bioturbated, occasionally silty with pyrite and glauconite, limestone (argillaceous) to limestone (mudstone and wackestone, micrite and biopelmicrite), beige grey with peloids, pyrite and glauconite. The whole interval occasionally contains belemnites and sponges, bioclasts
540.50 m – 543.87 m	Calcareous marl (silty), dark grey to beige grey, bioturbated with pyrite (partly as nodules), grading locally into argillaceous marl (silty), dark grey, bioturbated with pyrite (partly as nodules), and with several thin interbeds of limestone (argillaceous), in the upper part silty (mudstone, micrite), beige grey. In the whole interval, occasionally belemnites, bivalves and sponges are found
543.87 m – 549.69 m	Limestone (wackestone and packstone, biopelmicrite), beige grey with dark peloids, glauconite, occasionally pyrite, abundant mm-sized rounded biogenic components, sponges (below 546.40 m), belemnites, an ammonite (at 544.60 m) and bioclasts. The interval is medium- to thick-bedded by thin beds of calcareous marl, beige grey to medium grey with abundant bioclasts, occasionally belemnites, bivalves and sponges
	At 546.12 m an erosional surface with lithoclasts above
	At the base (from 549.58 m to 549.69 m) bored limestone nodules

3.6.2 Schwarzbach Formation 549.69 m – 570.98 m (21.29 m)

The Schwarzbach Formation represents a mostly calcareous to argillaceous marl interval within the predominantly calcareous formations of the Middle and Upper Malm Group. As already mentioned by Matter et al. (1988), the change from the basal «Felsenkalke» + «Massenkalk» to the Schwarzbach Formation is gradual rather than abrupt. In BAC1-1, the Schwarzbach Formation is consistently glauconitic and very fossiliferous (ammonites, belemnites, bivalves, some crinoids and, occasionally, sponges).

The *upper boundary* is set at 549.69 m at the top of the uppermost thicker (> 20 cm) calcareous marl bed with no sponges. This bed is overlain by a thin (11 cm) bioclastic calcareous marl with sponges and bored limestone nodules, transitioning into the overlying limestone-dominated interval of the basal «Felsenkalke» + «Massenkalk.

The *lower boundary* is set at 570.98 m at a hardground on top of a thick (79 cm) bed of sponge-rich bioclastic limestone with glauconite. The hardground itself is overlain by calcareous marl with glauconite.

Lithology

549.69 m – 552.77 m

Thin- to medium-bedded alternation of:

- Argillaceous marl (occasionally slightly silty), dark grey, mostly bioturbated, with pyrite and locally with crinoids, repeatedly grading into calcareous marl (occasionally slightly silty), medium grey to beige grey with pyrite, glauconite (in the upper part), an ammonite (at 549.76 m) and abundant bioclasts
- Thin interbeds of limestone (occasionally slightly silty) (wackestone and packstone, biomicrite and biopelmicrite), light grey to beige, partly bioturbated with abundant bioclasts, locally including sponges
- Limestone (argillaceous, occasionally slightly silty) (mudstone and wackestone, micrite), light grey to beige, partly bioturbated

At the base (from 551.79 m to 552.77 m), limestone (wackestone, biopelmicrite), beige grey with dark peloids, belemnites, glauconite and occasionally pyrite

552.77 m – 564.71 m

Alternation of:

- Bioclastic calcareous marl, dark grey to beige, often bioturbated, with peloids, glauconite, pyrite, belemnites, ammonites (at 557.15 m, 557.28 m, 557.58 m, 560.58 m and 562.66 m), locally with burrows, bivalves and a few sponge fragments
- Calcareous marl, in the uppermost part locally trending to argillaceous marl (silty), dark grey, bioturbated with pyrite, glauconite, belemnites, bioclasts and burrows
- Thin (up to 20 cm thick) interbeds of limestone, partly argillaceous, below 560.02 m mostly argillaceous (mudstone and wackestone, biomicrite), bioturbated, with pyrite, some glauconite and occasionally burrows

The lower boundary (at 564.71 m) is formed by a hardground with material from the overlying lithologies found in cavities down to 564.82 m

564.71 m – 568.07 m

Alternation of:

- Calcareous marl, dark grey to beige grey, bioturbated, with pyrite, occasionally glauconite and locally with bioclasts, some belemnites and crinoids
- Argillaceous limestone (mudstone and wackestone, micrite and biomicrite), beige grey, bioturbated, with pyrite and occasionally glauconite

568.07 m – 570.98 m Alternation of:

- Calcareous marl, from 570.85 m to the base bioclastic calcareous marl, dark grey to beige grey, calcareous marl bioturbated and locally with burrows, bioclastic calcareous marl with crinoids, in general with pyrite, glauconite and some belemnites
- Limestone (mudstone, biomicrite), beige grey, and bioclastic limestone (wackestone and packstone, biomicrite), beige grey and white, pyrite, bivalves, echinoderms and belemnites
- From 568.32 m to 568.48 m, breccia (calcareous), monomict, beige grey and with pyrite

3.6.3 Villigen Formation 570.98 m – 637.31 m (66.33 m)

According to Gygi (e.g. 2000), the consistently mostly calcareous (limestone, micrite) Villigen Formation is subdivided into four members in the south-western realm and three members in the north-eastern realm (Jordan & Deplazes 2019). The latter is believed to represent deposition in a deep marine environment characterised by the abundance of sponges. The BAC1-1 borehole can be assigned to the north-eastern facies. This is also the case for the nearby STA2-1 borehole (Jordan et al. 2022) (Fig. 1-1). The adjacent STA3-1 borehole (Schürch et al. 2022) and BUL1-1 borehole (Jordan et al. 2021), however, show a transition to the south-western facies.

The *upper boundary* is set at 570.98 m at a hardground on top of a thick (79 cm) bed of sponge-rich bioclastic limestone with glauconite. The hardground itself is overlain by calcareous marl with glauconite.

The *lower boundary* is set at 637.31 m at the top of the uppermost bed of silty marl of the Effingen Member overlain by limestone (silty) showing the lowermost occurrence of sponges.

3.6.3.1 Wangental Member with «Knollen Bed», 570.98 m – 589.52 m (18.54 m)

In BAC1-1, the Wangental Member is a medium- to thick-bedded succession of limestone (mudstone, micrite), with claystone drapes and, in the upper part, very few thin calcareous to bioclastic argillaceous marl beds. Belemnites and crinoids are found in some beds. Sponges are almost absent.

The main, if not only, argument for separating the Wangental Member from the very similar-looking underlying Küssaburg Member is the existence of the «Knollen Bed», a regional marker according to Gygi (2000). In the BAC1-1 borehole, the interval from 589.42 m to 589.52 m, with its nodular appearance in combination with a significant high glauconite content, can be assigned to the «Knollen Bed».

The *upper boundary* is set at 570.98 m, at a hardground on top of a thick (79 cm) bed of sponge-rich bioclastic limestone with glauconite. The hardground itself is overlain by calcareous marl with glauconite.

The *lower boundary* is set at 589.52 m at the base of the characteristic «Knollen Bed».

Lithology

570.98 m – 571.77 m	Bioclastic limestone (packstone, biomicrite), very fossiliferous (sponges [mostly rounded fragments], crinoids, bivalves, belemnites, brachiopods) with pyrite and glauconite
571.77 m – 586.09 m	Limestone (mudstone, micrite), beige grey to light grey, bioturbated, with pyrite, crinoids and locally belemnites, mostly medium-, locally thin-bedded with thin (up to 1 cm, mostly reduced to stylolite seams) interlayers of claystone to argillaceous marl, dark grey to black From 585.53 m to 585.78 m, the interval is disturbed by a prominent tectonic fault with breccia (calcareous), monomict
586.09 m – 589.42 m	Limestone (mudstone, micrite), medium light grey to beige grey and medium grey, bioturbated, with pyrite and crinoids. From 587.91 m to 588.55 m, pyritisation along subvertical structures From 587.10 m to 587.31 m, calcareous marl, dark grey and beige grey, belemnites From 587.51 m to 587.80 m and from 588.85 m to 588.97 m, limestone (argillaceous) (mudstone, micrite), medium grey to beige grey with pyrite and, in the upper interval, with lithoclasts
589.42 m – 589.52 m	Bed of nodular limestone (mudstone, micrite) embedded in a calcareous marl with glauconite and pyrite («Knollen Bed» *sensu* Gygi 2000)

3.6.3.2 Küssaburg Member, 589.52 m – 627.20 m (37.68 m)

In BAC1-1, the Küssaburg Member is characterised by medium to thick beds of limestone (locally argillaceous) (mudstone, micrite, occasionally pelmicrite) and drapes to beds (occasionally up to 30 cm thick) of calcareous and, locally, bioclastic argillaceous marl. Crinoids are abundant, autochthonous sponges are almost absent.

The main argument for separating the Küssaburg Member from the very similar-looking overlying Wangental Member is the existence of the «Knollen Bed» (see above). The «Knollen Bed» lies on top of a 4.6 m thick interval of mostly nodular limestone (argillaceous) and calcareous marl with glauconite.

The *upper boundary* is set at 589.52 m at the base of the characteristic «Knollen Bed».

The *lower boundary* is set at 627.20 m at the upper limit of the sponge-bearing beds.

Lithology

589.52 m – 594.14 m Thin- to medium-bedded, partly nodular alternation of:

- Limestone (argillaceous) (mudstone, micrite), medium grey to beige grey (locally, when less calcareous, also dark grey), bioturbated, with pyrite, occasionally glauconite, few belemnites and bivalves, and limestone (mudstone, micrite) beige grey, mostly thin-bedded with pyrite
- Calcareous marl, dark grey and beige grey, bioturbated, with pyrite, and occasionally with glauconite

594.14 m – 596.00 m	Limestone (mudstone, micrite), beige grey and medium grey, bioturbated, with crinoids, medium- to thick-bedded, with thin (a few mm), irregularly shaped interlayers of claystone, dark grey to black
596.00 m – 598.50 m	Alternation of: • Limestone (mudstone, micrite), beige grey and medium grey, bioturbated, with pyrite and occasionally with glauconite • Thinner interbeds of calcareous marl, dark grey to beige grey, with pyrite, glauconite, crinoids and irregular to nodular bedding
598.50 m – 602.11 m	Limestone (mudstone, micrite), beige grey and medium grey, bioturbated and with crinoids
602.11 m – 610.66 m	Medium-bedded succession of limestone (mudstone, micrite), beige grey and medium grey, bioturbated, with crinoids and, in the lower part, burrows. With a few thin (up to 8 cm) interlayers of argillaceous marl, dark grey and very thin (a few mm), irregularly shaped interlayers of claystone, dark grey to black
610.66 m – 627.20 m	Limestone (mudstone, micrite), beige grey and medium grey, mostly bioturbated, occasionally with burrows and crinoids. Thin- to medium-bedded, with some thick (up to 27 cm) interlayers of argillaceous marl, dark grey, bioturbated, with crinoids and some belemnites, of limestone (argillaceous) (mudstone, micrite), medium grey to beige grey, and of thin (a few mm), irregularly shaped interlayers of claystone, dark grey to black At the base (from 626.86 m to 627.20 m), small (< 1 cm) rounded (reworked) sponge fragments

3.6.3.3 Hornbuck Member, 627.20 m – 637.31 m (10.11 m)

In BAC1-1, the Hornbuck Member consists of an alternation of sponge- and crinoid-bearing limestone and marl. The medium- to thick-bedded limestone intervals comprise argillaceous, silty and biohermal limestone. The thin- to medium-bedded marly intervals comprise calcareous and silty marl. Although in varying abundance, sponges are common in most sections. Other common fossils are belemnites, bivalves and crinoids.

The *upper boundary* is set at 627.20 m at the upper limit of the sponge-bearing beds.

The *lower boundary* is set at 637.31 m at the top of the uppermost bed of silty marl of the Effingen Member, overlain by limestone (silty) showing the lowermost occurrence of sponges.

Lithology

627.20 m – 628.93 m	At the top (from 627.20 m to 627.85 m), biohermal limestone (packstone and boundstone, biomicrite), beige grey and medium grey, with pyrite, abundant sponges and crinoids Bioclastic calcareous marl, dark grey and beige grey, and limestone (packstone, biomicrite), beige grey and with crinoids, to argillaceous

limestone (wackestone, biomicrite), beige grey, with glauconite, pyrite, sponges, crinoids and belemnites

628.93 m – 632.15 m Medium-bedded alternation of:

- Limestone (mudstone, micrite), beige grey, bioturbated, with pyrite, locally crinoids, belemnites and burrows (in the top bed)
- Calcareous marl, bioclastic, dark grey to beige grey, bioturbated, wavy-bedded, with glauconite, pyrite, crinoids and bivalves

In the lower part (from 631.40 m to the base at 632.15 m), rounded fragments of sponges, crinoids and a regular sea urchin at 632.10 m

632.15 m – 637.31 m Medium- to thin-bedded alternation of:

- Limestone (mudstone and wackestone, micrite and pelmicrite), beige grey and medium grey, partly bioturbated, with peloids, pyrite, sponges (mostly as rounded components), crinoids and belemnites
- Bioclastic calcareous marl grading locally into calcareous marl, dark grey to beige grey, with peloids, pyrite, occasionally glauconite, sponges (mostly as rounded fragments), locally crinoids and belemnites
- Limestone (argillaceous) (mudstone, micrite), beige grey, with peloids, pyrite, sponges (mostly as rounded fragments), belemnites and bioclasts

At the top (632.15 m) and at 635.23 m, firmground to hardground

At the base (from 636.90 m to 637.31 m), limestone (silty) (mudstone, micrite), beige grey to medium grey, with pyrite and small sponge clasts

3.6.4 Wildegg Formation, 637.31 m – 737.05 m (99.74 m)

The Wildegg Formation is made up of the thick Effingen Member and the very thin Birmenstorf Member (including the «Glaukonitsandmergel Bed») at its base.

The *upper boundary* is set at 637.31 m at the top of the uppermost bed of silty marl of the Effingen Member, overlain by limestone (silty) showing the lowermost occurrence of sponges.

The *lower boundary* is set at 737.05 m at the top of a hardground which separates the fossiliferous limestone (iron-oolitic) from an overlying argillaceous marl with abundant glauconite and only a few dispersed iron-ooids.

3.6.4.1 Effingen Member, 637.31 m – 736.40 m (99.09 m)

The Effingen Member is a succession of predominantly calcareous (and subordinately argillaceous) marl. It is repeatedly interbedded with micritic limestone (mostly argillaceous) layers. The most prominent of them is the Gerstenhübel Bed (Gygi 2000). In BAC1-1, it can be localised from 665.88 m to 671.82 m. A second (fossiliferous) calcareous interval combined with hardgrounds is found from 685.95 m to 687.30 m, corresponding to the section from 685.82 m to 687.34 m in STA2-1. Generally, a poor fossil content (crinoids, a few belemnites and bivalves), a continuous occurrence of silt- to sand-sized quartz as well as a repeated occurrence of pyrite are characteristic for most of the Effingen Member (Deplazes et al. 2013). A higher fossil content is observed in the lowermost part of the unit. From 702.23 m to 708.16 m, ammonites are quite abundant. Sponges, as found in the lower part of the Effingen Member in the nearby STA2-1 borehole (Jordan et al. 2022), are virtually absent.

The *upper boundary* is set at 637.31 m at the top of the uppermost bed of silty marl of the Effingen Member, overlain by limestone (silty) showing the lowermost occurrence of sponges.

The *lower boundary* is set at 736.40 m at the top of the characteristic bed of argillaceous marl (glauconitic) with encrusted bioclasts and oncoids, which is overlain by calcareous marl (partly silty).

Lithology

637.31 m – 640.98 m	Argillaceous marl (silty), locally grading into silty marl, dark grey, bioturbated, with mica and pyrite (fine-grained, mostly in burrows) and thin (a few cm) interbeds of limestone (mudstone, micrite), silty, argillaceous, medium grey, and argillaceous siltstone (calcareous), light grey
640.98 m – 643.35 m	Calcareous marl (silty), dark grey, bioturbated, with mica and pyrite (fine-grained, mostly in burrows). Thin interbeds (up to 25 cm) of limestone (mudstone, micrite), mostly silty, argillaceous, medium light grey, with pyrite
643.35 m – 648.40 m	Argillaceous marl (silty to, occasionally, sandy [in fine-grained lenses]), grading into silty marl, dark grey, bioturbated, with mica, pyrite (very fine-grained, mostly in silt lenses), few crinoids (some in coquinas, e.g. from 647.89 m to 647.91 m), and occasionally belemnites; thin (a few cm) interlayers of limestone (silty) (mudstone, micrite), medium grey
648.40 m – 653.37 m	Calcareous marl (mostly silty), dark grey, bioturbated, with mica and fine-grained pyrite. Thin interbeds (a few cm) of limestone (silty, argillaceous) (mudstone, micrite), medium light grey, with pyrite, locally grading into siltstone (calcareous), light grey, with mica and pyrite
653.37 m – 658.53 m	Argillaceous marl (silty), from 653.37 m to 655.23 m silty marl, and, from 657.86 m to 658.15 m, calcareous marl (silty), dark grey, bioturbated, with mica, fine-grained pyrite, occasionally crinoids and a belemnite (at 656.43 m). Thin interbeds (a few cm) to lenses of limestone (silty, argillaceous) (mudstone, micrite), medium light grey,

with pyrite, locally grading into siltstone (calcareous), light grey, with mica and pyrite

658.53 m – 665.88 m — Calcareous marl (mostly silty), dark grey, bioturbated, with mica, fine-grained pyrite, below 659.85 m crinoids and an ammonite at 662.20 m. Abundant thin (up to 4 cm) interbeds of limestone (silty, argillaceous) (mudstone, micrite), medium grey and beige grey, with pyrite

665.88 m – 671.82 m — The following succession can be correlated with the Gerstenhübel Bed:

Limestone (mudstone, micrite), occasionally slightly silty and argillaceous, medium grey, bioturbated, locally flaser bedding, with pyrite, occasionally glauconite, crinoids and a belemnite at 671.22 m (thin section BAC1-1-668.48 is from this lithology). Interbeds of calcareous marl (silty), medium to dark grey, bioturbated, flaser bedding, with glauconite, pyrite and crinoids (locally abundant), and a few interbeds of argillaceous marl (silty), dark grey, bioturbated

671.82 m – 683.12 m — Calcareous marl, mostly silty, dark grey to beige grey, bioturbated with burrows, pyrite and, below 674.50 m, with mica. In the lower part repeatedly grading into argillaceous marl (silty), bioturbated, with mica and pyrite. Few (up to 8 cm thick) interlayers of limestone (argillaceous) (mudstone, micrite). In the upper part an ammonite (at 673.15 m), belemnites, and crinoids

683.12 m – 687.30 m — Two calcareous intervals separated by argillaceous marl:

From 683.12 m to 684.49 m, thin- to medium-bedded alternation of:

- Calcareous marl, dark grey, with mica and pyrite
- Limestone (argillaceous) (mudstone to wackestone, micrite), medium light grey to beige grey, bioturbated, with pyrite

From 684.49 m to 685.95 m, argillaceous marl, dark grey, bioturbated, with mica and pyrite

From 685.95 m to 686.07 m, bioclastic calcareous marl, dark grey, with glauconite, mica, pyrite, sponges and belemnites

From 686.07 m to 687.30 m, limestone (mudstone to wackestone, micrite), medium light grey to beige grey, bioturbated, with pyrite and belemnites, and, in the lower part, bioclastic calcareous marl grading downward into an argillaceous marl, dark grey with glauconite, mica, pyrite, sponges, belemnites and a fragment of an ammonite (at 687.02 m). Bored hardground at the top of the limestone (at 686.49 m)

687.30 m – 698.68 m — Argillaceous marl, mostly silty, locally grading into calcareous marl (partly silty), dark grey, with mica, pyrite, crinoids, belemnites, a reworked fragment of a sponge (at 694.57 m), fine bioclasts (bivalves) and burrows. Few thin to slightly thicker (e.g. from 698.40 m to 698.68 m) interbeds of limestone (argillaceous) (mudstone, micrite), medium grey, with pyrite, crinoids and burrows

698.68 m – 704.02 m	Argillaceous marl (above 702.24 m silty), dark grey, with mica, pyrite, slightly sideritic nodules, crinoids, belemnites, ammonites (at 702.33 m, 702.43 m, 702.95 m and 703.42 m), bivalves, burrows and few thin silty laminae, locally grading into calcareous marl (silty), dark grey, with mica, pyrite, crinoids and burrows. Few thin interbeds of limestone (argillaceous) (mudstone to wackestone), slightly silty, medium grey, with pyrite, bioclasts and burrows
704.02 m – 713.36 m	Calcareous marl, dark grey, with mica, pyrite, crinoids, belemnites, ammonites (at 706.77, from 707.10 m to 707.30 m and at 708.16 m) and burrows. Several thinner and one thicker (up to 82 cm) interbeds of limestone (argillaceous) (mudstone, micrite), light grey, and, locally, limestone (mudstone, micrite), light grey, as well as one thin interbed of argillaceous marl, dark grey, grading to calcareous marl, dark grey, with crinoids and burrows
713.36 m – 723.24 m	Calcareous marl, dark grey, with mica, pyrite, belemnite and burrows, in alternation with argillaceous marl, dark grey, with mica, pyrite, some belemnites, bivalves and burrows. Some (up to 7 cm thick) interbeds (at 718.17 m, 718.29 m, 718.34 m, 720.60 m and 722.25 m) and a thicker interbed (from 721.37 m to 721.50 m) of limestone (argillaceous) (mudstone, micrite), medium light grey
723.24 m – 731.32 m	Calcareous marl, dark grey, with mica, pyrite, locally crinoids, an ammonite (at 725.11 m), a belemnite and burrows. Abundant interbeds (up to 50 cm thick) of limestone (argillaceous) (mudstone, micrite), light grey, with pyrite and burrows
731.32 m – 736.40 m	Calcareous marl (partly silty), dark grey, with mica, pyrite, glauconite (below 732.00 m), about 1 cm greyish sub-rounded lithoclasts (at 732.39 m, 733.28 m and 733.32 m), occasionally siderite, belemnites, locally crinoids, a bivalve, and a sponge fragment. From 732.94 m to 733.22 m interbed of limestone (argillaceous), light grey (mudstone, micrite)

3.6.4.2 Birmenstorf Member and «Glaukonitsandmergel Bed», 736.40 m – 737.05 m (0.65 m)

In BAC1-1, there is no fossiliferous limestone or calcareous marl typical for the Birmenstorf Member at the base of the Wildegg Formation.

The thin interval from 736.40 m to 737.05 m, consisting of argillaceous to calcareous marl with glauconite and comprising oncoids ("mummies") and, in the lower part, disperse iron-ooids, shows affinities with the «Mumienmergel Bed» and «Glaukonitsandmergel Bed» of Gygi (1977, 2000, 2012) found in other places.

The *upper boundary* is set at 736.40 m at the top of the characteristic bed of argillaceous marl (glauconitic) with encrusted bioclasts and oncoids, which is overlain by calcareous marl (partly silty).

The *lower boundary* is set at 737.05 m at the top of a hardground which separates the fossiliferous limestone (iron-oolitic) from an overlying argillaceous marl with abundant glauconite and only a few dispersed iron-ooids.

Lithology

736.40 m – 737.05 m	Argillaceous to calcareous marl, dark grey, with glauconite, bioclasts (in the upper part), oncoids (up to 5 cm in size, limonitic in the centre, glauconitic crust), belemnites and an ammonite (at 736.84 m). In the lower part (below 736.85 m), disperse iron-ooids

3.7 Dogger Group

3.7.1 Wutach Formation, 737.05 m – 738.81 m (1.76 m)

In BAC1-1, the very thin Wutach Formation is characterised by marl (iron-oolitic) sandwiched between two intervals of thin limestone beds (predominantly iron-oolitic), most of them associated with hardgrounds. The succession is generally very fossiliferous. Belemnites dominate; additionally, ammonites and bivalves are found.

The thickness of the Wutach Formation in the BAC1-1 borehole is much smaller than in the neighbouring boreholes (STA2-1: 4.98 m; STA3-1: 3.44 m; and Weiach: 4.90 m; Jordan et al. 2022, Schürch et al. 2022 and Bläsi et al. 2013, respectively, *cf.* Fig. 1-1). In the Nördlich Lägern siting region, only BUL1-1 shows a similar thickness (1.21 m, Jordan et al. 2021).

The *upper boundary* is set at 737.05 m at the top of a hardground which separates the fossiliferous limestone (iron-oolitic) from an overlying argillaceous marl with abundant glauconite and only a few dispersed iron-ooids.

The *lower boundary* is set at 738.81 m at a hardground at the top of an interval of argillaceous marl with brachiopods, which is overlain by an 8 cm thick limestone with iron-ooids and further on by marl (iron-oolitic).

Lithology

737.05 m – 738.81 m	From 737.05 m to 737.14 m and from 737.18 m to 737.36 m, two beds of limestone (iron-oolitic) (thin sections BAC1-1-737.14 and BAC1-1-737.20), light grey, each with iron-oolitic hardgrounds at the top and fossiliferous including belemnites, bivalves, oysters and bioclasts, separated by an interlayer (from 737.14 m to 737.18 m) of calcareous marl, dark grey and reddish-brown, fossiliferous, with iron-ooids and glauconite From 737.36 m to 738.73 m, marl (iron-oolitic), dark grey and reddish-brown, with glauconite and fossiliferous including ammonites (at 737.38 m and at 737.53 m), belemnites, bivalves, oysters and bioclasts. From 737.74 m to 737.77 m, an interlayer of limestone (iron-oolitic), light grey and fossiliferous From 738.73 m to 738.81 m, limestone, reddish-brown, with iron-ooids and two hardgrounds

3.7.2 Variansmergel Formation, 738.81 m – 741.22 m (2.41 m)

In BAC1-1, the Variansmergel Formation comprises a variation from claystone (silty, calcareous) to argillaceous and calcareous marl, all fossiliferous including brachiopods, bivalves and crinoids, partly concentrated in coquinas. Dispersed iron-ooids and limonitic bioclasts are found in the lower part.

The *upper boundary* is set at 738.81 m at a hardground at the top of an interval of argillaceous marl with brachiopods, which is overlain by an 8 cm thick limestone with iron-ooids and further on by marl (iron-oolitic).

The *lower boundary* is set at 741.22 m at a bored erosional surface at the top of the uppermost occurrence of silty to argillaceous marl, which is overlain by argillaceous marl with limonitic bioclasts and a few iron-ooids.

Lithology

738.81 m – 741.22 m

From 738.81 m to 740.16 m, claystone (silty, calcareous), dark grey, with mica, pyrite and burrows alternating with bioclastic argillaceous marl, dark grey, bioturbated, both lithologies fossiliferous including brachiopods

From 740.16 m to 740.43 m, bioclastic calcareous marl to calcareous marl (silty), medium grey and reddish-brown, with iron-ooids, limonitic bioclasts and brachiopods

From 740.43 m to 740.93 m, bioclastic argillaceous marl, dark grey, with iron-ooids, limonitic bioclasts, belemnites and an ammonite (at 740.56 m)

From 740.93 m to 741.10 m, bioclastic limestone (packstone, bio-microsparite), medium light grey and reddish-brown, with the bioclasts being limonitised (thin section BAC1-1-740.96), and with a few iron-ooids and an ammonite (at 741.00 m)

At the base (from 741.10 m to 741.22 m), above a bored erosional surface, bioclastic argillaceous marl, dark grey, limonitic components, a few iron-ooids, fossiliferous including belemnites

3.7.3 «Parkinsoni-Württembergica-Schichten», 741.22 m – 788.92 m (47.70 m)

In BAC1-1, the main characteristic of the «Parkinsoni-Württembergica-Schichten» is a mostly thin- to medium-bedded gradual alternation of silty marl and claystone (silty, calcareous) with thin limestone (silty, argillaceous) beds in the upper part and claystone becoming more prominent in the lower part. Belemnites are abundant throughout the section. Crinoids are prominent in the upper part but also found in the lower part. The whole section is strongly bioturbated including burrows.

The *upper boundary* is set at 741.22 m at a bored erosional surface at the top of the uppermost occurrence of silty to argillaceous marl, which is overlain by argillaceous marl with limonitic bioclast and a few iron-ooids.

The *lower boundary* is set at 788.92 m where bioclastic argillaceous marl rich in belemnites and crinoids is overlain by claystone (silty, calcareous) without larger fossils (a more detailed definition is presented in Dossier IV).

Lithology

741.22 m – 748.26 m	Silty marl to silty claystone (calcareous), medium to dark grey, bioturbated, locally lenticular bedding, locally grading into argillaceous marl (silty), dark grey, partly bioturbated, and into calcareous marl (silty), mica, pyrite, medium grey, flaser bedding, all lithologies with mica, pyrite (partly in nodules), locally siderite (mostly small nodules, rarely up to 1 cm in size), abundant crinoids, a belemnite, a bivalve and some burrows. An additional feature are thin (a few cm to 20 cm thick) beds of calcareous marl (silty) to limestone (silty, argillaceous) (mudstone, micrite), medium grey, bioturbated, lenticular bedding
748.26 m – 755.81 m	Silty claystone (calcareous) to argillaceous marl (silty), dark grey, locally grading into silty marl, dark grey to medium grey, all lithologies bioturbated, locally flaser bedding and with mica, pyrite (partly in aggregates or nodules), a slightly sideritic limestone nodule (at 750.39 m), light-coloured small-sized bioclasts, locally belemnites, some larger crinoids, and a bivalve. Few beds (up to 50 cm thick) of limestone (silty, argillaceous) (mudstone, micrite) transitioning to calcareous marl (silty), medium grey, pyrite, bioturbated, locally flaser bedding
755.81 m – 777.05 m	Claystone (silty, calcareous) to silty claystone (calcareous), dark grey to black, bioturbated, with mica, pyrite (partly in small nodules), some belemnites, locally a few crinoids and burrows, locally grading into silty marl, dark grey, locally lenticular bedding, with mica, pyrite and occasionally burrows, as well as into argillaceous marl (silty), dark grey to black, mica, pyrite At 766.54 m, thin layer of sandstone (fine-grained), argillaceous, light grey
777.05 m – 784.48 m	Bioclastic argillaceous marl (silty), and, in the upper part, silty claystone (calcareous), dark grey and light grey, with bioclastic argillaceous marl formed by a matrix of silty claystone, dark grey, with mica and pyrite and reworked bioclasts, including mostly crinoids, other echinoderms and bivalves, as well as belemnites as macrofossils. Thin nodular beds (up to 20 cm) of bioclastic calcareous marl, dark grey and light grey, with mica, pyrite and limonitic bioclasts, become more abundant towards the base From 779.82 m to 779.89 m and from 783.51 m to 783.55 m, fossiliferous calcareous lens formed by bioclastic limestone with abundant bivalves, echinoderms and belemnites (thin section BAC1-1-779.86) At 780.42 m, coal streak (ca. 2 cm × 8 cm) with pyrite seam From 780.90 m to 782.49 m and from 783.41 m to 783.58 m, abundant limonitic bioclasts (thin section BAC1-1-781.44) and dispersed iron-ooids

784.48 m – 788.92 m

Claystone (silty, calcareous), in the upper part rather claystone (calcareous), dark grey, with mica, pyrite (locally in nodules and aggregates, at 788.73 m forming a thin layer), belemnites, bivalves and burrows. Additionally, intervals (up to 30 cm thick) of bioclastic argillaceous marl, dark grey and light grey, with mica and pyrite, and bioclastic calcareous marl to bioclastic limestone (wackestone, biomicrite), beige grey, with pyrite and bioclasts

At 786.21 m and 786.25 m, two thin (around 1 cm) layers of sandstone (fine-grained), light grey, with pyrite

3.7.4 «Humphriesioolith Formation», 788.92 m – 791.05 m (2.13 m)

In BAC1-1, the «Humphriesioolith Formation» is recognised by biostratigraphic rather than lithostratigraphic evidence (Dossier IV). The upper part of the section is formed predominantly by claystone (silty, argillaceous) rich in burrows and showing great similarities with the overlying base of the «Parkinsoni-Württembergica-Schichten». The lower, much thinner part is formed by bioclastic calcareous marl and marly limestone with some iron-ooids. In terms of thickness of the unit, there is a good agreement with the corresponding sections in the neighbouring Weiach borehole and STA2-1 borehole (2.96 m, Matter et al. 1988, and 1.80 m, Jordan et al. 2022, respectively). However, the intervals assigned to the «Humphriesioolith Formation» differ significantly in terms of content of calcite, silt and iron-ooids from borehole to borehole.

The *upper boundary* is set at 788.92 m where bioclastic argillaceous marl rich in belemnites and crinoids is overlain by claystone (silty, calcareous) without larger fossils (a more detailed definition will be presented in Dossier IV).

The *lower boundary* is set at 791.05 m, based on biostratigraphic evidence (Dossier IV), at the base of the interval of limonitic bioclastic calcareous marl with iron-ooids, partly calcified, overlying limonitic bioclastic argillaceous marl.

Lithology

788.92 m – 791.05 m

Claystone (silty, calcareous), in the upper part rather claystone (calcareous), dark grey, with mica, pyrite (occasionally in aggregates), a sideritic concretion (at 789.02 m), locally (from 788.92 m to 789.22 m) belemnites and crinoids, and burrows. Thin intervals (up to 30 cm) are formed by bioclastic argillaceous marl, dark grey and light grey, with mica and pyrite, and bioclastic calcareous marl to bioclastic limestone (wackestone, biomicrite), beige grey, with pyrite and bioclasts

In the lower part (from 790.75 m to 790.90 m), limestone (argillaceous) (wackestone, biomicrite) to limestone (iron-oolitic) with the iron-ooids being partly calcified (thin section BAC1-1-790.85), and, below 790.90 m, bioclastic calcareous marl, medium light grey to beige grey, partly nodular, with iron-ooids, limonite, pyrite, silicified fossils, thick-shelled bivalves and belemnites

At the very base (from 791.01 m to 791.05 m), encrusted and bored nodules of limestone (mudstone, micrite) to limestone (iron-oolitic) in the same bioclastic calcareous marl as above

3.7.5 Wedelsandstein Formation, 791.05 m – 793.11 m (2.06 m)

In BAC1-1, the Wedelsandstein Formation is recognised by biostratigraphic rather than lithostratigraphic evidence (Dossier IV). The section comprises bioclastic calcareous marl with interbeds of fossiliferous limestone (argillaceous) with two thin limestone interbeds at the base comprising iron-ooids.

The interval is significantly thinner than the sections associated with the same formation in the neighbouring STA2-1 borehole, Weiach borehole and STA3-1 borehole (7.51 m, Jordan et al. 2022; 15.92 m, Matter et al. 1988; 22.97 m, Schürch et al. 2022, respectively). Thin limestone interlayers, burrows and silt lenses, characteristic elements of the Wedelsandstein Formation elsewhere, are barely detectable. However, a certain similarity with the basal layers of the Weiach borehole (from 536.68 m to 539.17 m, Matter et al. 1988) and STA2-1 borehole (from 783.10 m to 786.85 m, Jordan et al. 2022) is recognisable. The fossiliferous interval from 791.98 m to the base (at 793.11 m), comprising a few oysters, could be related to the "Schwamm- und Serpuliden-Kalk mit Austern" and the "Austernpflaster" of the Weiach borehole (Matter et al. 1988), two marker horizons found in an almost identical form also at the base of the Wedelsandstein Formation in the STA2-1 borehole (Jordan et al. 2022).

The *upper boundary* is set at 791.05 m, based on biostratigraphic evidence (Dossier IV), at the base of the interval of limonitic bioclastic calcareous marl with iron-ooids, partly calcified, overlying limonitic bioclastic argillaceous marl.

The *lower boundary* is set at 793.11 m at an erosional surface separating an overlying limestone (argillaceous) with iron-ooids from underlying bioclastic argillaceous marl.

Lithology

791.05 m – 793.11 m	In the upper part (from 791.05 m to 791.84 m), bioclastic argillaceous marl, dark grey, locally comprising siderite nodules and formed by a matrix of claystone, dark grey, and abundant, often rounded bioclasts From 791.84 m to 792.14 m, limestone (argillaceous) (wackestone, biomicrite), medium light grey to beige grey, with pyrite, glauconite, siderite nodules, large bivalves, and, at 791.88 m, vertebra of a crocodile (Dossier IV) In the lower part, within bioclastic argillaceous marl as in the upper part, two beds (from 792.76 m to 792.82 m and from 793.03 m to 793.11 m) of limestone (argillaceous) (wackestone, biomicrite), medium light grey to beige grey, with iron-ooids, pyrite, a bivalve, and an ammonite (at 793.05 m). The base at 793.11 m is erosive

3.7.6 «Murchisonae-Oolith Formation», 793.11 m – 808.34 m (15.23 m)

The situation in BAC1-1 represents a transition from the eastern facies of the «Murchisonae-Oolith Formation» (Bläsi et al. 2013) found in the siting regions Nördlich Lägern and Zürich Nordost, to the facies found in the siting region Jura Ost (Wohlwend et al. 2019). For the sake of clarity, the term «Murchisonae-Oolith Formation» is retained here.

In BAC1-1, the «Murchisonae-Oolith Formation» comprises three distinct sections.

The upper section, from 793.11 m to 793.82 m, is formed by bioclastic argillaceous marl underlain by bioclastic limestone with oncoids. It may be correlated with the iron-oolitic section from 539.17 m to 541.76 m in the Weiach borehole (Matter et al. 1988) and the partly iron-oolitic section from 786.85 m to 788.67 m in the STA2-1 borehole (Jordan et al. 2022).

The middle section, from 793.82 m to 797.22 m, is a silty claystone to claystone (silty). It corresponds well to the argillaceous section in the upper part of the «Murchisonae-Oolith Formation» of the STA2-1 borehole and Weiach borehole (Jordan et al. 2022 and Matter et al. 1988, respectively).

The lower section, from 797.22 m to 808.34 m, is characterised by a significant content of quartz sand (fine-grained) and silt in combination with crinoids, small limonitised clasts and, occasionally, iron-ooids. Sandy (to silty) limestone (argillaceous) to bioclastic limestone (sandy) grades down into an alternation of sandy limestone (argillaceous) with calcareous marl (sandy), and of limestone (sandy, argillaceous) with calcareous marl (sandy) and a bed of sandy limestone (argillaceous) at the base. This lower section may correspond to the «Spatkalke» of the Weiach borehole (from 547.00 m to 554.50 m, Matter et al. 1988) and matches the Sissach Member of the Passwang Formation as described in the area east of the river Aare and at Lägern by Wohlwend et al. (2019).

The *upper boundary* is set at 793.11 m at an erosional surface separating an overlying limestone (argillaceous) with iron-ooids from underlying bioclastic argillaceous marl.

The *lower boundary* is set at 808.34 m at the base of the beige grey interval of bioclastic (mainly crinoids) sandy limestone to limestone (sandy), which coincides with the top of dark grey silty claystone. The delimitation is also supported by FMI and GR log analysis.

Lithology

793.11 m – 797.22 m	At the top, from 793.11 m to 793.55 m, bioclastic argillaceous marl, dark grey, with belemnites and an ammonite in an upright position (at 793.26 m)
	From 793.55 m to 793.82 m, hardground composed of bioclastic limestone (packstone, biomicrite), light medium grey and beige grey, with oncoids (encrusted lithoclasts) to iron-stromatolites, dispersed iron-ooids (partly calcified; thin section BAC1-1-793.63), crinoids and bivalves, and with an erosive contact at the base
	In the main part, from 793.82 m to 797.22 m, silty claystone to claystone (silty), dark grey, with mica, pyrite (partly in aggregates and nodules), abundant large siderite nodules (up to about 5 cm), burrows and a possible ammonite in a pyrite nodule (at 797.18 m)
797.22 m – 800.21 m	At the top, from 797.22 m to 797.30 m, condensed calcareous hardground, sandy, light grey to beige grey, with few iron-ooids and with belemnites, bivalves and crinoids
	In the main part, from 797.30 m to 800.21 m, bioclastic limestone (packstone, biosparite), limonitic, sandy, to sandy (to silty) limestone (packstone, biosparite), locally argillaceous, ochre brown to reddish-brown, cross bedding, with small iron-ooids (e.g. thin sections BAC1-1-797.34, BAC1-1-799.00 and BAC1-1-799.99), and abun-

dant, often limonitised bioclasts (including bivalves and often crinoids), including a thin bed of argillaceous marl, dark grey, and three intervals with abundant limonitised bioclasts

800.21 m – 808.34 m Calcareous marl (sandy to silty) to sandy to silty marl, dark greyish-brown, limonitic, bioturbated, with dispersed small iron-ooids, abundant bioclasts (including crinoids, locally bivalves) and burrows

In the upper part (above 802.75 m) and at the base (below 806.85 m), interbeds of sandy (to silty) limestone to bioclastic limestone (sandy, argillaceous, e.g. thin section BAC1-1-808.11) (packstone, biosparite), dark greyish-brown, bioturbated, with abundant bioclasts, crinoids, locally bivalves, occasionally pellets and burrows

From 802.97 m to 807.63 m, interbeds of limestone (sandy) to bioclastic limestone (sandy; e.g. thin section BAC1-1-806.84) (packstone, biosparite), beige grey, partly iron-oolitic (thin section BAC1-1-803.00), bioturbated, with abundant bioclasts (including crinoids), bioturbation, burrows, and occasionally with pellets

3.7.8 Opalinus Clay, 808.34 m – 914.91 m (106.57 m)

The Opalinus Clay is generally regarded as a monotonous succession of dark grey silty claystone with siltstone and sandstone lenses. It is very sparsely interbedded with thin layers of sandstone and limestone (Wetzel & Allia 2003). Fossils are usually rare aside from a few limestone beds and enriched intervals, mainly in the lowermost section.

The findings in BAC1-1 generally confirm the mostly uniform lithology known from the adjacent STA2-1 borehole and Weiach borehole (Jordan et al. 2022 and Matter et al. 1988, respectively).

The *upper boundary* is set at 808.34 m at the base of the beige grey interval of bioclastic (mainly crinoids) sandy limestone to limestone (sandy), which coincides with the top of dark grey silty claystone. The delimitation is also supported by FMI and GR log analysis.

The *lower boundary* is set at 914.91 m at the top of the uppermost bed of limestone (argillaceous) overlain by the claystone (silty, micaceous) interval of the Opalinus Clay. The abrupt change in carbonate content is clearly visible in the FMI and GR record.

Lithostratigraphic subdivision

Although there is no formal subdivision of the Opalinus Clay, there are several informal attempts (*cf.* Jordan & Deplazes 2019). A recent proposal by Mazurek & Aschwanden (2020) includes four units. They apply to the present section as follows:

808.34 m – 834.57 m «Sub-unit with silty calcareous beds» (26.23 m)

834.57 m – 861.63 m «Upper silty sub-unit» (27.06 m)

861.63 m – 895.17 m «Mixed clay-silt-carbonate sub-unit» (33.54 m)

895.17 m – 914.91 m «Clay-rich sub-unit» (19.74 m)

Lithology

«Sub-unit with silty calcareous beds», 808.34 m – 834.57 m (26.23 m)

This sub-unit is defined by the presence of discrete heterogeneities, in particular silty and calcareous beds and nodules which are also well expressed as excursions in petrophysical logs (Mazurek & Aschwanden 2020).

In BAC1-1, within this sub-unit, two noteworthy intervals are present. In the upper part, a somewhat thicker bed (73 cm) of bioclastic calcareous and argillaceous marl with abundant iron-ooids is located at the top of a conspicuous interval of strongly bioturbated silty marl. In the lower part, three thin beds of limestone (argillaceous) and silty to sandy limestone (argillaceous) are present.

808.34 m – 816.00 m	Section dominated by silty marl with interbeds of bioclastic argillaceous to calcareous marl (silty) to sandy limestone and bioclastic limestone
	At the top, from 808.34 m to 811.19 m, silty claystone (below 809.79 m calcareous), dark grey, bioturbated, with mica, pyrite, occasionally siderite, an ammonite (at 810.64 m) and burrows. Thin and some thicker lenses of sandstone and siltstone are abundant. The transition from silty claystone to silty claystone (calcareous) is marked by a coal layer with pyrite nodules (from 809.78 m to 809.80 m)
	From 811.19 m to 811.45 m, bioclastic argillaceous marl, dark grey and light grey with iron-ooids, pyrite, mica and bioclasts including crinoids
	Below a hardground at 811.45 m and down to the erosive base at 811.92 m, bioclastic calcareous marl to bioclastic limestone, greyish-green with abundant iron-ooids (thin section BAC1-1-811.84), bivalves, ammonites (at 811.50 m, 811.52 m, 811.75 m and 811.90 m) and lithoclasts. Locally, the bioclastic limestone (iron-oolitic) grades into iron-oolite (thin section BAC1-1-811.57)
	From 811.92 m to 816.00 m, section dominated by silty marl, dark grey with mica, pyrite, burrows, and abundant lenses and thin interbeds of silty (to sandy) limestone (argillaceous), medium grey, with mica, pyrite and bioclasts. The thicker beds are bioturbated
	From 815.02 m to 815.12 m interbed of bioclastic limestone (silty) (wackestone, biomicrite) (thin section BAC1-1-815.04), medium grey, bioturbated, with mica and bivalves
816.00 m – 825.39 m	Monotonous section consisting of silty claystone (calcareous) in transition to claystone (silty, calcareous), dark grey, with mica, pyrite (partly as nodules and aggregates), siderite nodules, few bioclasts, bioturbation and burrows (some pyritised)
	From 816.57 m to 816.63 m, single nodule of limestone (silty to sandy, argillaceous)
	At the base (from 825.31 m to 825.39 m), increase of silt and carbonate content

825.39 m – 834.57 m

Section dominated by claystone (silty, partly calcareous) to silty claystone, interrupted by thin beds of calcareous marl and limestone (argillaceous)

At the top (from 825.39 m to 825.59 m), silty claystone (calcareous) above argillaceous to calcareous marl (silty to sandy), beige grey with mica, pyrite, and bored nodules of limestone (mudstone and wackestone, biomicrite). This succession is separated from the underlying lithology (thin sections BAC1-1-825.52 and BAC1-1-825.58), with belemnites and bioclasts, by a hardground at 825.49 m with calcified iron-ooids

From 825.59 m to 829.00 m, claystone (silty, calcareous) to silty claystone (calcareous), dark grey, bioturbated, with mica, pyrite and burrows, and with three thin intervals of septarian nodules

From 829.00 m to 829.19 m, limestone (argillaceous) (wackestone, biomicrite), medium to beige grey, strongly sideritic with few calcified iron-ooids (thin section BAC1-1-829.17), few oncoids and with lithoclasts and bioclasts including bivalves

From 829.19 m to 829.26 m, below a bored surface, argillaceous marl (silty), dark grey with bioclasts and sideritic limestone nodules (wackestone, biomicrite), medium to beige grey with few calcified iron-ooids and bioclasts

From 829.26 m to 832.86 m, claystone (silty, locally calcareous) to silty claystone (calcareous), dark grey, with mica, pyrite, an ammonite (at 831.97 m) and with thin lenses of siltstone, medium grey

From 832.86 m to 832.96 m, nodular bed of calcareous marl to limestone (argillaceous) (wackestone, pelmicrite), medium grey to beige grey, both silty and sideritic (thin section BAC1-1-832.90), with peloids and crinoids and in a matrix of argillaceous marl (silty), dark grey, bioturbated

From 832.96 m to 834.57 m, silty claystone (calcareous), dark grey, with mica, pyrite, bioturbation, burrows, and thin lenses of siltstone

At the base, from 834.47 m to 834.57 m, argillaceous marl (silty), dark grey, bioturbated, with bioclasts including abundant crinoids

«Upper silty sub-unit», 834.57 m – 861.63 m (27.06 m)

This sub-unit is characterised by the frequent occurrence of lenses, typically a few centimetres wide and several millimetres thick, consisting of silty (and partly sandy) quartz grains and calcite cement, resulting in a flaser structure (Mazurek & Aschwanden 2020).

In BAC1-1, the «Upper silty sub-unit» is characterised by silty claystone (calcareous) with thin lenses of silt- and sandstone as well as siderite nodules.

834.57 m – 861.63 m

Silty claystone (calcareous), dark grey, partly bioturbated, with mica, pyrite, siderite nodules, an ammonite (at 840.57 m), some bivalves, burrows and thin lenses of siltstone to sandstone (fine-grained), medium grey

Near the top, at 834.85 m, some crinoids are associated with an erosional surface

«Mixed clay-silt-carbonate sub-unit», 861.63 m – 895.17 m (33.54 m)

This sub-unit represents the section of the Opalinus Clay which is devoid of characteristics typical for the other sub-units (Mazurek & Aschwanden 2020). In BAC1-1, it is very homogeneous and almost exclusively consists of silty claystone (calcareous). Siderite nodules are abundant, accompanied by a few pyrite and calcareous nodules.

861.63 m – 882.00 m	At the top, from 861.63 m to 861.68 m, a hardground and a layer of calcareous marl (silty, bioclastic and sideritic) (thin section BAC1-1-861.65) to argillaceous marl (silty), dark grey. This layer is bored and contains encrusted reworked clasts of limestone (argillaceous, mudstone, micrite), medium to dark grey with partly silicified, fine bioclasts
	The main part is characterised by silty claystone (calcareous), dark grey with mica and pyrite. The section is bioturbated with some burrows
882.00 m – 886.70 m	Interval formed by the same main lithology as above, i.e. silty claystone (calcareous), dark grey with mica, but showing inclined bedding (very prominent from approximately 884 m to 886 m), probably due to slumping or tectonics
886.70 m – 895.17 m	Silty claystone (calcareous), dark grey, mica, bioturbation. Below 890.50 m, siderite nodules are frequent and a few pyrite nodules and occasional lenses of silt- and sandstone, medium grey, are found

«Clay-rich sub-unit», 895.17 m – 914.91 m (19.74 m)

As the name suggests, this dark homogeneous sub-unit has a high content of clay minerals (mostly more than 60 wt.-%). The «Clay-rich sub-unit» marks the base of the Opalinus Clay (Mazurek & Aschwanden 2020).

In BAC1-1, the section is formed by a mostly bioturbated (partly burrows) claystone (silty, mostly calcareous), with quite abundant scattered ammonites and few bivalves.

895.17 m – 901.05 m	Claystone (silty, occasionally calcareous), dark grey, bioturbated, with mica, pyrite, few siderite nodules, ammonites (at 877.74 m, at 899.34 m and at 900.90 m), a bivalve, few coquinas, bioclasts and burrows (some pyritised)
901.05 m – 914.91 m	Claystone (silty, calcareous), dark grey, bioturbated, with mica, pyrite, dispersed bioclasts and burrows. Fossil content includes a possible coral fragment (at 901.06 m), ammonites (at 901.36 m, 901.63 m, 901.82 m, 905.41 m, 914.32 m, 914.41 m, and 914.71 m, the latter two phosphoritised), and a gastropod. At the top, from 901.05 m (thin section BAC1-1-901.06) to 901.88 m, three individual intervals with micritic limestone nodules
	At the base (914.77 m to 914.91 m), argillaceous marl, (silty), dark grey to medium grey

3.8 Lias Group

3.8.1 Staffelegg Formation, 914.91 m – 949.73 m (34.82 m)

The Staffelegg Formation (Reisdorf et al. 2011, Kiefer et al. 2015) is a heterogeneous succession dominated by marl and claystone, some of it bituminous, and includes various thin limestone horizons, some of them iron-oolitic.

The *upper boundary* is set at 914.91 m at the top of the uppermost bed of limestone (argillaceous) overlain by the claystone (silty, micaceous) interval of the Opalinus Clay. The abrupt change in carbonate content is clearly visible in the FMI and GR record.

The *lower boundary* is set at 949.73 m at the erosional surface with calcareous micro-conglomerate fillings in the joints of the dolomitic interval. It coincides with a significant change in colour and lithology, i.e. from the overlying claystone (silty, calcareous), dark grey, to the underlying argillaceous marl (dolomitic), greyish-green to pale green.

3.8.1.1 Gross Wolf Member, 914.91 m – 919.64 m (4. 73 m)

In BAC1-1 the Gross Wolf Member can be divided into two parts. The upper part (from 914.91 m to 916.59 m) is argillaceous marl with few thin beds of limestone (argillaceous). The lower part (from 916.59 m to 919.64 m) represents the typical "Jurensismergel" facies consisting of calcareous marl with mostly nodular beds of limestone (argillaceous).

The *upper boundary* is set at 914.91 m at the top of the uppermost bed of limestone (argillaceous) overlain by the claystone (silty, micaceous) interval of the Opalinus Clay. The abrupt change in carbonate content is clearly visible in the FMI and GR record.

The *lower boundary* is set at 919.64 m with the uppermost occurrence of bitumen. The boundary separates the overlying calcareous marl from the underlying bituminous argillaceous marl.

Lithology

914.91 m – 916.59 m	Argillaceous marl, dark grey, with phosphorite and siderite nodules, some thin and two thicker interlayers of limestone (argillaceous) (mudstone and wackestone, biomicrite) to bioclastic limestone (grainstone, biomicrite) (thin section BAC1-1-914.92), medium light grey, partly nodular. One of these limestone (argillaceous) beds can be found at the top from 914.91 m to 915.03 m. The whole interval is fossiliferous including ammonites (very abundant from 915.06 m to 915.09 m), belemnites (partly phosphoritised and very abundant at the base [at 916.59 m]) and a nautilus (at 915.73 m). All lithologies are bioturbated including frequent burrows
916.59 m – 919.64 m	Calcareous marl, dark grey, with phosphorite and siderite nodules, abundant nodules and mostly nodular layers of limestone (argillaceous) (mudstone and wackestone, biomicrite), medium light grey. Both lithologies are fossiliferous (mainly belemnites, partly phosphoritised, and locally, at 917.97 m and at 918.38 m, ammonites) and bioturbated including burrows

3.8.1.2 Rietheim Member, 919.64 m – 925.49 m (5.85 m)

In BAC1-1, the Rietheim Member is distinctive due to its bitumen content, which increases with depth. The upper part (from 919.64 m to 923.24 m) is characterised by argillaceous marl (partly silty), consistently bituminous (partly grading into bituminous shale) and interrupted by two thin beds of calcareous marl. The lower part (from 923.24 m to 925.49 m) consists of an alternation of laminated bituminous shale and three beds of laminated calcareous marl and limestone (mudstone, micrite), slightly bituminous.

The *upper boundary* is set at 919.64 m with the uppermost occurrence of bitumen. The boundary separates the overlying calcareous marl from the underlying bituminous argillaceous marl.

The *lower boundary* is set at 925.49 m at the top of the uppermost argillaceous marl with glauconite, which is overlain by laminated bituminous shale without glauconite.

Lithology

919.64 m – 923.24 m

Argillaceous marl, bituminous, dark grey to dark greyish-brown, in the upper part (from 919.64 m to 920.40 m) fossiliferous including belemnites, an ammonite (at 923.07 m) and bioclasts, below 920.64 m mostly laminated

From 919.99 m to 920.08 m and from 920.40 m to 920.52 m, two thin interlayers of calcareous marl, dark beige to beige grey, fossiliferous including belemnites, bioclasts (mostly small bivalves), separated by argillaceous marl, dark grey, with bioclasts (small bivalves)

From 921.54 m to 921.70 m, fossiliferous interlayer (mainly belemnites, bioclasts)

923.24 m – 925.49 m

Bituminous shale, dark grey to dark greyish-brown, with an ammonite (at 923.77 m), *Bositra* sp. (abundant from 924.66 m to 925.49 m, occasionally pyritised), belemnites and with three calcareous interlayers:

- From 923.24 m to 923.40 m, calcareous marl, dark beige to dark greyish-brown («Oberer Stein»)
- From 924.01 m to 924.08 m, calcareous marl, dark beige to dark greyish-brown, with abundant shells of the tiny gastropod *Coelodiscus minutus* («Homogene Kalkbänke»)
- From 924.43 m to 924.66 m, limestone (argillaceous) (mudstone, micrite), dark greyish-brown («Unterer Stein»)

3.8.1.3 Grünschholz Member, Breitenmatt Member and Rickenbach Member, 925.49 m – 928.12 m (2.63 m)

Throughout Northern Switzerland, the Grünschholz Member, the Breitenmatt Member and the Rickenbach Member represent a strongly condensed succession. Jordan & Deplazes (2019) recommend describing the three members as one informal stratigraphic unit, since the delimitation of the three thin and predominantly calcareous and fossiliferous members is expected to be difficult. This convention is used here because there are currently no data justifying a reliable subdivision.

In BAC1-1, the generally glauconitic and very fossiliferous (predominantly belemnites) section can be divided in two parts. The upper part (from 925.49 m to 926.29 m) comprises an alternation of calcareous and argillaceous marl. The lower part (from 926.29 m to 928.12 m) is formed by beds of bioclastic limestone (most of them with erosional surfaces at the top) separated by calcareous and argillaceous marl. The distinct peak in the GR log generally associated with the Breitenmatt Member is localised in the upper part. Gryphid oysters are found in the lower part.

The *upper boundary* is set at 925.49 m at the top of the uppermost argillaceous marl with glauconite, which is overlain by laminated bituminous shale without glauconite.

The *lower boundary* is set at 928.12 m at the base of the lowermost bioclastic limestone with glauconite overlying a siltstone (calcareous) without glauconite. The abrupt change in carbonate content is clearly visible in the FMI and GR record.

Lithology

925.49 m – 928.12 m

Upper part, from 925.49 m to a bored surface at 926.29 m, alternation of calcareous and argillaceous marl, medium light grey to dark grey, bioturbated, with glauconite, phosphorite nodules and burrows, fossiliferous including belemnites, an ammonite (at 925.90 m, in a nodule of limestone, argillaceous), bivalves and bioclasts

Middle part, from 926.29 m (bored surface) to 926.70 m, bioclastic limestone, partly argillaceous (wackestone and packstone, biomicrite), beige grey to dark greyish-brown, bioturbated, with burrows and fossiliferous including belemnites, *Gryphae obliqua*, and bioclasts, partly silicified, possibly representing a strongly condensed and reworked section with numerous firm- and hardgrounds

The lower part, from 926.70 m to 928.12 m, is an alternation of:

- Bioclastic limestone, partly argillaceous (wackestone and packstone, biomicrite), beige grey to dark greyish-brown, bioturbated, partly silicified and phosphoritised, partly nodular, with glauconite, bioclasts and burrows
- Argillaceous and calcareous marl, medium light and dark grey, bioturbated, with glauconite, bioclasts and burrows, as well as fossiliferous including belemnites, *Gryphae obliqua*, locally crinoids, coquina formed by very fine shells (at 926.80 m) and bioclasts

3.8.1.4 Frick Member, 928.12 m – 939.52 m (11.40 m)

In BAC1-1, the Frick Member is a uniform succession of argillaceous siltstone (calcareous, locally sandy) with thin beds of siltstone (calcareous) grading downwards into silty claystone (calcareous, locally sandy). Fossils are rare and restricted to a few horizons.

The *upper boundary* is set at 928.12 m at the base of the lowermost bioclastic limestone with glauconite overlying a siltstone (calcareous) without glauconite. The abrupt change in carbonate content is clearly visible in the FMI and GR record.

The *lower boundary* is set at 939.52 m at the top of a thin (11 cm) layer of bioclastic calcareous marl directly overlying a medium-bedded succession of bioclastic limestone. The two calcareous successions are overlain by a thick succession of silty claystone (calcareous, micaceous) of the Frick Member.

Lithology

928.12 m – 935.00 m	Argillaceous silt- to sandstone (calcareous) to silty to sandy claystone (calcareous), medium grey, bioturbated, with mica, pyrite (dispersed, in aggregates and nodules [1 cm to 3 cm in size] and as pyritised burrows), rarely fine bioclasts and burrows. Thin lenses, two thin beds (up to 3 cm) and a thicker bed of calcareous siltstone (argillaceous), medium light grey, with mica
935.00 m – 939.52 m	Silty to sandy claystone (calcareous), medium grey, grading to argillaceous silt- to sandstone (calcareous) in the upper part and to claystone (silty), occasionally calcareous, dark grey to medium grey in the lower part, all lithologies bioturbated and with mica, pyrite (dispersed, in aggregates and nodules [up to 1 cm in size] and as pyritised burrows). Thin lenses and thin beds (up to 3 cm thick) of calcareous siltstone (argillaceous), medium light grey, with mica

3.8.1.5 Beggingen Member, 939.52 m – 943.04 m (3.52 m)

In BAC1-1, the Beggingen Member can be divided into three sections. The upper, most prominent section from 939.52 m to 941.92 m is a medium-bedded succession of bioclastic limestone separated by claystone to argillaceous marl drapes. *Gryphaea arcuata* is found in the middle part and iron-ooids in the lower part.

The middle section, from 941.92 m to 942.32 m, consists of claystone (calcareous) to argillaceous marl with iron-ooids and oncoids. The lower section, from 942.32 m to 943.04 m, is an iron-oolite to limestone (iron-oolitic) with abundant bivalves of the *Cardinia* genus.

The *upper boundary* is set at 939.52 m at the top of a thin (11 cm) layer of bioclastic calcareous marl directly overlying a medium-bedded succession of bioclastic limestone. The two calcareous successions are overlain by a thick succession of silty claystone (calcareous, micaceous) of the Frick Member.

The *lower boundary* is set at 943.04 m at the top of a thin limestone bed, at a complex erosional surface (including bored holes penetrating deeply into the limestone). The boundary corresponds to the onset of iron-oolite in an upward direction.

Lithology

939.52 m – 941.92 m

The upper section comprises:

- At the top, from 939.52 m to 939.63 m, bioclastic calcareous marl, dark grey, with phosphorite and bioclasts but without macrofossils
- In the main part, bioclastic limestone (wackestone, grainstone and packstone, biomicrite and biosparite), medium light grey and light grey, bioturbated, with phosphorite, iron-ooids (below 941.55 m), *Gryphaea arcuata*, bivalves and locally crinoids
- At the base, from 941.75 m to 941.92 m, bioclastic calcareous marl, dark grey, limonitic, with phosphorite, iron-ooids and *Gryphaea arcuata*

941.92 m – 943.04 m

The middle section, from 941.92 m to 942.32 m, is formed by claystone (calcareous) with, from 942.07 m to 942.24 m, an interbed of argillaceous marl with iron-ooids and iron-oncoids

The lower section, from 942.32 m to 943.04 m, is formed by iron-oolite to limestone (iron-oolitic) (packstone, biosparite), light brown to dark reddish-brown, fossiliferous including *Cardinia* sp., crinoids and a solitary coral (at 943.00 m)

At the base, at 943.04 m, lithoclasts (limestone [micrite]) above a bored erosional surface

3.8.1.6 Schambelen Member, 943.04 m – 949.73 m (6.69 m)

In BAC1-1, the Schambelen Member consists of claystone (mostly silty, calcareous) with thin layers of siltstone and dispersed bioclasts, occasionally concentrated in coquinas.

In the lower part, from 948.65 m to 949.00 m (but not at the base) a bed of limestone, iron-oolitic, is found. It grades downwards into the underlying argillaceous marl with iron-ooids overlying an erosional surface. The claystone (calcareous) below this erosional surface is distinctly bituminous.

The *upper boundary* is set at 943.04 m at the top of a thin limestone bed, at a complex erosional surface (including bored holes penetrating deeply into the limestone). The boundary corresponds to the onset of iron-oolite in an upward direction.

The *lower boundary* is set at 949.73 m at the erosional surface with calcareous micro-conglomerate fillings in the joints of the dolomitic interval. It coincides with a significant change in colour and lithology, i.e. from the overlying claystone (silty, calcareous), dark grey, to the underlying argillaceous marl (dolomitic), greyish-green to pale green.

Lithology

943.04 m – 949.73 m

At the top, from 943.04 m to 943.08 m, thin limestone (mudstone, micrite), light grey, capped by an erosional surface strongly bored and filled by iron-ooids from the overlying succession of the Beggingen Member

In the main part, from 943.08 m to 948.65 m, claystone (silty, calcareous), dark grey, with mica and pyrite, and claystone (calcareous), dark grey, locally laminated, locally bioturbated, with mica, pyrite, a few macrofossils including a coquina (at 945.60 m) and with lenses (1 cm to 8 cm in size) of siltstone, light grey

From 948.65 m to 949.00 m, limestone (iron-oolitic), medium grey, and argillaceous marl, dark grey, with mica, pyrite, iron-ooids and bioclasts (including crinoids and bivalves, becoming abundant below 948.89 m). At the base of this interval, from 948.89 m to 949.00 m, encrusted, reworked limonitic lithoclasts above an erosional surface

From 949.00 m to 949.73 m, claystone, dark grey, slightly bituminous, partly bioturbated, with a pyrite aggregate to nodule (at 949.13 m), few bioclasts including bivalves and pyritised burrows

At the base, at 949.73 m, erosional surface with micro-conglomerate fillings in the underlying argillaceous marl, dolomitic

3.9 Keuper Group

3.9.1 Klettgau Formation, 949.73 m – 980.93 m (31.20 m)

The Klettgau Formation is a heterogeneous succession dominated by variegated playa (coastal, sabkha and continental) sediments with mostly silty claystone and dolocretes (Jordan et al. 2016). Interstratified therein are dolostone intervals and fine- as well as coarse-grained siliciclastic sediments representing marine to coastal and fluvial or alluvial intercalations. In BAC1-1, the Belchen Member was not encountered.

The *upper boundary* is set at 949.73 m at the erosional surface with calcareous micro-conglomerate fillings in the joints of the dolomitic interval. It coincides with a significant change in colour and lithology, i.e. from the overlying claystone (silty, calcareous), dark grey, to the underlying argillaceous marl (dolomitic), greyish-green to pale green.

The *lower boundary* is set at 980.93 m at the top of a dolostone bed overlying evaporite facies with anhydrite nodules and layers. The dolostone bed, in turn, is overlain by claystone (sandy, dolomitic) to fine-grained sandstone (dolomitic, argillaceous).

3.9.1.1 Gruhalde Member [above the Seebi Member] 949.73 m – 959.75 m (10.02 m)

In BAC1-1, the lower part of the Gruhalde Member below the Seebi Member could not be identified: dolomitic sandstone, assigned to the Seebi Member, directly overlies dolostone identified as part of the Gansingen Member (see below). Thus, in BAC1-1 the occurrence of the Gruhalde Member is limited to the section above the Seebi Member.

In BAC1-1, the Gruhalde Member is characterised by variegated dolomitic marl with few interbeds of argillaceous marl (dolomitic) and frequent root structures documenting a paleosol.

The *upper boundary* is set at 949.73 m at the erosional surface with calcareous micro-conglomerate fillings in the joints of the dolomitic interval. It coincides with a significant change in colour and lithology, i.e. from the overlying claystone (silty, calcareous), dark grey, to the underlying argillaceous marl (dolomitic), greyish-green to pale green.

The *lower boundary* is set at 959.75 m, where an argillaceous marl (dolomitic) overlies a dolostone (sandy), i.e. with the onset (in a downward direction) of quartz sand.

Lithology

949.73 m – 952.00 m	At the top, from 949.73 m to 950.20 m, argillaceous marl (dolomitic), greyish-green to pale green The main part is formed by dolomitic marl, pale green, greyish-green and greyish-violet, with two horizons of dolostone to dolostone (calcareous), very light grey, partly brecciated, and nodular dolocrete layers (up to 10 cm thick)
952.00 m – 954.00 m	Neither core nor cuttings were collected
954.00 m – 957.60 m	Dolomitic marl, locally slightly silty, pale green, greyish-violet to reddish-brown and, subordinately, greyish-green to pale green (occasionally in reduction halos), some horizons slightly brecciated, locally with plant root remains From 957.26 m to 957.40 m and from 957.50 m to 957.60 m, two intensively brecciated layers of dolomitic marl (silty), greyish-violet to reddish-brown, with lithoclasts and pedogenic structures, separated by argillaceous to dolomitic marl (silty), greyish-violet to reddish-brown
957.60 m – 959.75 m	Dolomitic marl (slightly silty) to argillaceous marl (dolomitic), greyish-violet to reddish-brown and greyish-green to pale green, at the base, from 959.47 m to 959.75 m, with lithoclasts and plant root remains

3.9.1.2 Seebi Member, 959.75 m – 966.03 m (6.28 m)

In BAC1-1, the Seebi Member is characterised by its quartz sand content. The upper part (from 959.75 m to 964.74 m) consists of dolostone (sandy [mostly fine-grained]) with an interlayer of dolomitic marl (silty and sandy). The lower part (from 964.74 m to 966.03 m) comprises dolomitic sandstone (medium- to coarse-grained) and argillaceous to dolomitic marl (with coarse-grained quartz sand). Root structures indicative of a paleosol are abundant throughout the member.

The upper boundary is set at 959.75 m, where an argillaceous marl (dolomitic) overlies a dolostone (sandy), i.e. with the onset (in a downward direction) of quartz sand.

The *lower boundary* is set at 966.03 m at the erosional top of a massive bed of dolostone overlain by a medium- to very coarse-grained dolomitic sandstone.

Lithology

959.75 m – 964.74 m	At the top, from 959.75 m to 960.03 m, dolostone (silty), greyish-green and slightly nodular In the main part, dolostone (sandy), greyish-green to greyish-violet, consisting of mostly fine-grained quartz sand and a pedogenic breccia of dolostone (sandy, silty, partly argillaceous) and some larger quartz pebbles (< 10 cm in size, sub-angular) in a matrix of argillaceous to dolomitic marl (silty), greyish-violet with plant root remains. Two intervals, from 960.75 m to 961.78 m and from 963.58 m to 964.37 m, have a higher proportion of matrix
964.74 m – 966.03 m	In the upper part, from 964.74 m to 965.20 m, dolomitic sandstone (medium- to very coarse-grained), light grey to greenish-grey, angular to sub-rounded, poorly sorted, with intraclasts of dolostone and other lithoclasts, type "Stubensandstein" (thin sections BAC1-1-964.96 and BAC1-1-965.08) and above an erosive base at 965.20 m From 965.20 m to 965.67 m, argillaceous marl (sandy, dolomitic), greyish-violet From 965.67 m to 965.86 m, dolomitic marl (sandy), greyish-violet At the base, from 965.86 m to 966.03 m, dolomitic sandstone (medium- to very coarse-grained), partly argillaceous to sandy dolostone (thin section BAC1-1-965.90), greyish-violet, in the lower part also light green to greyish-green, angular to sub-rounded, poorly sorted, with intraclasts of dolostone and other lithoclasts above an erosive base

3.9.1.4 Gansingen Member, 966.03 m – 968.75 m (2.72 m)

Throughout Northern Switzerland, the Gansingen Member shows evidence of a marine ingression from the west with a strong lateral variation of lithofacies in an E-W direction. The member was locally affected by early post-depositional erosion (Jordan et al. 2016).

In BAC1-1, the Gansingen Member is formed exclusively by dolostone, partly argillaceous, partly laminated by microbial mats, partly brecciated and partly porous.

The *upper boundary* is set at 966.03 m at the erosional top of a massive bed of dolostone overlain by a medium- to very coarse-grained dolomitic sandstone.

The *lower boundary* is set at 968.75 m at the erosional top of the argillaceous marl (silty to sandy) succession overlain by a massive dolostone layer documenting the first marine ingression.

Lithology

966.03 m – 968.75 m

At the top, from 966.03 m to 966.54 m, dolostone, beige grey to beige and greyish-green, with pyrite, microbial mats and locally with vugs

From 966.54 m to 967.31 m, dolostone (argillaceous), alternating (banded) beige grey to beige, greyish-green, and greyish-violet

From 967.31 m to 967.50 m, dolostone, beige grey to beige, with ooids (partly ghosts) and microbial mats (thin section BAC1-1-967.44)

From 967.50 m to 968.25 m, dolostone, beige grey to beige and greyish-green, with pyrite, microbial mats and locally with vugs

From 968.25 m to 968.66 m, breccia, dolomitic (monomict), beige grey to beige, porous, with dolomitic clasts (thin section BAC1-1-968.57), pyrite, vugs and pellets in a matrix formed by argillaceous marl, pale green

At the very base, from 968.66 m to 968.75 m, bed or crust of dolostone, light grey, covering the erosional surface of the underlying interval

3.9.1.5 Ergolz Member, 968.75 m – 980.93 m (12.18 m)

The Ergolz Member comprises a wide variety of lithologies. It reflects deposition in fluvial and alluvial (channel and overspill) to lacustrine depositional environments (e.g. Jordan et al. 2016).

In BAC1-1, the upper part of the Ergolz Member (from 968.75 m to 974.13 m) represents an alluvial overspill facies composed of variegated argillaceous marl (silty to sandy, dolomitic) with nodular dolomitic horizons documenting paleosols. The lower part (from 974.13 m to 980.93 m) is formed by a succession of channels, the uppermost of which is composed of mostly medium-grained sandstone, while the others are composed of fine-grained argillaceous and micaceous sandstone, representing the typical "Schilfsandstein" channel facies. The channels are separated by claystone (sandy, dolomitic).

The *upper boundary* is set at 968.75 m at the erosional top of the argillaceous marl (silty to sandy) succession overlain by a massive dolostone layer documenting the first marine ingression.

The *lower boundary* is set at 980.93 m at the top of a dolostone bed overlying evaporite facies with anhydrite nodules and layers. The dolostone bed, in turn, is overlain by claystone (sandy, dolomitic) to fine-grained sandstone (dolomitic, argillaceous).

Lithology

968.75 m – 974.13 m

Argillaceous marl (silty to sandy, dolomitic), reddish-brown to greyish-violet and greyish-green, with nodules (a few mm up to 7 cm in size) of dolostone (argillaceous), very light grey to beige, and locally abundant plant root remains

From 969.98 m to 970.14 m, nodular layer of dolostone (argillaceous), very light grey

974.13 m – 976.04 m

The main body is formed by sandstone (mostly medium-grained), argillaceous, slightly dolomitic, greyish-brown to beige grey and reddish-brown, sub-rounded, well sorted, polymict (quartz, rock fragments), partly with cross bedding, bioturbated, with few drapes to fine layers of argillaceous marl (silty), dark grey

From 975.62 m to 975.80 m, sandstone (medium- to coarse-grained) (dolomitic, argillaceous), pale green, sub-angular to sub-rounded, poorly sorted, slightly porous and partly cemented by anhydrite (thin section BAC1-1-975.74), polymict (quartz, rock fragments), with few pebbles and drapes of argillaceous marl (silty, dolomitic), dark grey

At the base, from 975.80 m to 976.04 m, two nodular layers of dolostone (silty), beige grey, with peloids, lithoclasts (paleosols) and vugs, separated by argillaceous marl (silty, dolomitic), dark grey

976.04 m – 977.40 m

Claystone (slightly silty, dolomitic), dark grey to black, laminated, occasionally with pyrite and abundant nodules (up to 8 cm in size) of dolostone, beige, locally with pellets and partly porous (paleosols)

From 976.63 m to 976.73 m, interlayer of dolostone (silty), beige

977.40 m – 980.93 m

Argillaceous sandstone (fine-grained) (dolomitic), greyish-green, locally with cross bedding, partly with flaser bedding, partly bioturbated with mica. Few, up to 8 cm thick interbeds of sandstone (fine-grained) to siltstone (slightly dolomitic, locally anhydritic) are found. They are porous (thin section BAC1-1-980.07), greyish-green, locally with cross bedding, with mica, and separated by few drapes to fine layers of claystone to argillaceous marl (sandy, dolomitic), black, occasionally with pyrite nodules

At the base (from 980.57 m to 980.93 m), claystone (sandy, dolomitic), black to greyish-green, with pyrite and thin interlayer of sandstone (fine-grained) (dolomitic, argillaceous), greyish-green, with mica

3.9.2 Bänkerjoch Formation, 980.93 m – 1'053.90 m (72.97 m)

The Bänkerjoch Formation is an evaporitic succession with many complete and incomplete cycles and subcycles, including various sulphate sediments, dolomitic marl, dolostone and sandstone (Dronkert et al. 1990). Some of the dolostone and sandstone sections represent marine ingression and may be used as regional marker beds (e.g. Jordan et al. 2016, Bernasconi et al. 2017).

The *upper boundary* is set at 980.93 m at the top of a dolostone bed overlying evaporite facies with anhydrite nodules and layers. The dolostone bed, in turn, is overlain by claystone (sandy, dolomitic) to fine-grained sandstone (dolomitic, argillaceous).

The *lower boundary* is set at 1'053.90 m at the base of the lowermost, more than 10 cm thick massive anhydrite bed of the overlying Bänkerjoch Formation. Beige to brown dolostone similar to that in the upper part of the Asp Member can also be found in the basal part of the «Dolomite and anhydrite» sub-unit of the Bänkerjoch Formation.

Lithostratigraphic subdivision

There is still no formal subdivision of the Bänkerjoch Formation. The informal subdivision based on earlier core records of Nagra (e.g. Matter et al. 1987, Dronkert et al. 1990, Nagra 2001a, 2001b) is proposed to be used for the campaign by Jordan & Deplazes (2019). All five sub-units could be recognised in BAC1-1:

980.93 m – 1'002.78 m	«Claystone with anhydrite nodules» (21.85 m)
1'002.78 m – 1'029.89 m	«Cyclic sequence» (27.11 m)
1'029.89 m – 1'046.84 m	«Thin-layered anhydrite and claystone sequence» (16.95 m)
1'046.84 m – 1'050.90 m	«Banded massive anhydrite» (4.06 m)
1'050.90 m – 1'053.90 m	«Dolomite and anhydrite» (3.00 m)

Lithology

«Claystone with anhydrite nodules», 980.93 m – 1'002.78 m (21.85 m)

This sub-unit is the most lithologically heterogeneous one of the Bänkerjoch Formation. In BAC1-1, anhydrite (as beds, nodular beds or nodules) and claystone (often dolomitic) are the dominant lithologies. Veins of anhydrite are found in the whole sub-unit except in the uppermost part (from 980.93 m to 984.60 m). A succession of fine-grained sandy dolostone and dolomitic sandstone from 1'000.30 m to 1'001.70 m probably corresponds to the "markerbed 1" of Jordan et al. (2016), also known as «Quarzitische Bank» or «Engelhofen-Horizont». The sub-unit can be described as follows (from top to base):

980.93 m – 981.61 m	Bed of dolostone, medium light grey, grading downwards into dolomitic marl, and claystone (dolomitic), black
981.61 m – 982.90 m	Anhydrite (argillaceous, partly sulpharenitic, partly dolomitic), white, and claystone (dolomitic), black to dark grey, with nodules of anhydrite, white
982.90 m – 984.60 m	Claystone (dolomitic), dark grey to black, with few nodules of anhydrite (argillaceous), white
984.60 m – 985.87 m	At the top, from 984.60 m to 984.90 m, anhydrite, nodular (chicken wire structure), white with black seams In the main part, anhydrite, white, grading into anhydrite (argillaceous), with interlayers of claystone, black, and nodules and veins of anhydrite, white
985.87 m – 991.46 m	Interval characterised by variegated claystone, composed of claystone, (dolomitic and anhydritic), variegated (black, greenish-grey, dark reddish-brown), and anhydrite (argillaceous), formed by veins, nodules and beds of anhydrite, white, in a matrix of claystone (dolomitic), variegated

991.46 m – 995.88 m Anhydrite (argillaceous), formed by nodules and beds of anhydrite, white, in a matrix of claystone (dolomitic), variegated (black, greenish-grey, dark reddish-brown), with anhydrite veins, grading into anhydrite, white, partly nodular (chicken wire structure)

995.88 m – 1'000.30 m Interval characterised by reddish-brown hues composed of:

- Argillaceous marl, occasionally silty, dark reddish-brown and greenish-grey, locally with anhydrite veins and nodules, white
- Claystone (dolomitic), black, occasionally with anhydrite veins and nodules, white
- Dolomitic marl, greenish-grey and dark reddish-brown, occasionally with anhydrite veins and nodules, white
- Anhydrite (argillaceous), variegated
- Anhydrite, white, partly nodular

1'000.30 m – 1'001.70 m Sandy (fine-grained) to silty dolostone, (argillaceous), grading downwards into dolomitic sandstone (fine-grained) (argillaceous) to dolomitic siltstone, medium light grey, bioturbated, with mica, few small nodules (< 2 cm in size) of anhydrite, white, and with fine-grained rock fragments, cemented by anhydrite (thin section BAC1-1-1001.57). This interval corresponds to the marker bed I («Quarzitische Bank»)

1'001.70 m – 1'002.78 m Interval composed of:

- Argillaceous marl, dolomitic, dark grey to greenish-grey, with veins and nodules of anhydrite, white
- Anhydrite (argillaceous), white, dark grey
- Anhydrite, nodular (chicken wire structure), white
- Dolomitic marl, medium light grey

«Cyclic sequence», 1'002.78 m – 1'029.89 m (27.11 m)

This sub-unit consists mainly of a cyclic repetition of anhydrite with varying fabrics and bedding, including beds of densely packed nodules (chicken wire structure), laminated anhydrites with thin claystone and dolostone intervals, and massive anhydrite that lacks internal structures. Clay minerals are distinctly less abundant than in the overlying sub-unit and are concentrated in claystone (partly anhydritic) layers, becoming thicker and more abundant in the lowermost part of the sub-unit. Veins of anhydrite are mostly developed in thicker interbeds of anhydrite with dolostone and claystone interlayers and in claystone (anhydritic). The sub-unit can be described as follows (from top to base):

1'002.78 m – 1'007.82 m Interval dominated by chicken wire anhydrite and composed of:

- Anhydrite, nodular (chicken wire structure), white
- Anhydrite (argillaceous), white and black, occasionally with anhydrite nodules, white

- Anhydrite, white
- Claystone (dolomitic), black to dark reddish-brown and greyish-green, occasionally with anhydrite nodules, white

1'007.82 m – 1'019.96 m Cyclic alternation of:

- Anhydrite, mostly nodular and arranged in a chicken wire structure, white
- Laminated to fine-bedded layers of anhydrite (dolomitic, and, locally, argillaceous), white and medium grey with abundant thin sulpharenite interlayers
- Claystone to claystone (anhydritic), black, with abundant veins and some nodules of anhydrite, white

1'019.96 m – 1'024.35 m Interval characterised by chicken wire anhydrite and anhydrite veins in the upper part (from 1'019.96 m to 1'022.55 m) and lower part (from 1'022.55 m to 1'024.35 m), respectively. The lower part, defined as anhydrite (argillaceous), is formed by anhydrite veins, white, in a matrix of claystone, black, occasionally with anhydrite nodules

1'024.35 m – 1'029.89 m Partly cyclic alternation of nodular anhydrite (chicken wire texture), laminated layers (up to 2 cm) of claystone, black, anhydrite, white and sulpharenite, white, dolomitic, and claystone, black, with anhydrite veins, white. They were summarised in the following lithologies:

- Nodular anhydrite (chicken wire texture), white
- Anhydrite, (argillaceous, dolomitic (sulpharenitic)), forming laminated sections
- Anhydrite (argillaceous), white and black, if more than 25% anhydrite veins in claystone matrix
- Claystone (anhydritic) black and white, if less than 25% anhydrite veins in claystone matrix

«Thin-layered anhydrite and claystone sequence», 1'029.89 m – 1'046.84 m (16.95 m)

This sub-unit is characterised by numerous beds of claystone (mostly anhydritic and dolomitic) and, subordinately, dolostone (argillaceous), dolomitic, and calcareous marl. The sub-unit can be described as follows (from top to base):

1'029.89 m – 1'033.53 m Thin-bedded (up to 2 cm) and partly laminated alternation of:

- Anhydrite (argillaceous), white, formed by sulpharenite, white, and claystone interlayers, black, occasionally with anhydrite veins
- Anhydrite (dolomitic) formed by thin layers of sulpharenite, white, dolostone, beige, and claystone, black, occasionally with anhydrite veins

- Anhydrite nodules (chicken wire structure), white
- Claystone (dolomitic), black, with anhydrite veins, white

1'033.53 m – 1'034.11 m Anhydrite, white, massive, vertical anhydrite veins

1'034.11 m – 1'035.91 m At the top (from 1'034.11 m to 1'034.20 m), below an erosive base, dolomitic marl to claystone (dolomitic), black to medium light grey, with reworked clast

From 1'034.20 m to 1'034.32 m, dolostone, beige grey, with cracks filled by dolo- and sulpharenite, and claystone (dolomitic), black to medium light grey

From 1'034.32 m to 1'034.42 m, dolostone (argillaceous), pale green, bioturbated

The main body consists of argillaceous marl, greyish-green, dolomitic, and dolomitic marl, pale green to greyish-green, with anhydrite veins

At the base, at 1'035.91 m, dolostone nodules, beige

1'035.91 m – 1'039.15 m Variegated interval formed by:

- Claystone (occasionally anhydritic, silty or sandy), greenish-grey, grey violet and dark reddish-brown, partly bioturbated, mostly with anhydrite veins, white, occasionally with anhydrite nodules, white
- Anhydrite (argillaceous) to anhydrite (dolomitic), white and greyish-green, occasionally with anhydrite veins and nodules, white
- Few thin beds of dolostone (argillaceous)

From 1'038.76 m to 1'038.90 m, argillaceous marl, silty, dolomitic

At the base (from 1'038.90 m to 1'039.15 m), dolomitic marl (silty), with anhydrite veins and nodules

1'039.15 m – 1'040.75 m At the top, from 1'039.15 m to 1'039.47 m, below an erosional surface, dolostone (argillaceous), beige grey (dolomitic marker bed)

Main body formed by an alternation of anhydrite, white, and argillaceous marl (dolomitic), greyish-green, bioturbated, with anhydrite nodules and veins

At the base, from 1'040.68 m to 1'040.75 m, dolostone, beige

1'040.75 m – 1'044.09 m Interval characterised by thin-layered sulpharenite, partly with fine ripple structures and enterolitic folding (at 1'042.56 m). Lithologies are anhydrite (argillaceous), white, greyish-violet and dark grey. with anhydrite nodules, and anhydrite (sulpharenite), white

1'044.09 m – 1'046.84 m	Anhydrite (sulpharenite), white, massive, and interlayers of dolomitic marl to calcareous marl (dolomitic), beige to medium grey with nodules of anhydrite, white, as well as anhydrite (argillaceous), white and beige grey. Enterolitic folding (at 1'044.20 m)

«Banded massive anhydrite», 1'046.84 m – 1'050.90 m (4.06 m)

This sub-unit shows by far the highest amount of anhydrite in the entire Bänkerjoch Formation. It contains the thickest beds of massive (i.e. featureless or slightly banded) anhydrite. The sub-unit can be described as follows:

1'046.84 m – 1'050.90 m	Anhydrite, white, massive, and between 1'047.69 m and 1'049.21 m banded by claystone drapes, black. Enterolitic folding at 1'047.20 m

«Dolomite and anhydrite», 1'050.90 m – 1'053.90 m (3.00 m)

Dolomitic marl is dominant in the upper part of this sub-unit, including a few beds of dolostone (argillaceous). The lower part of the sub-unit (corresponding to the «Grundgipsschichten» of the German stratigraphic scheme) is characterised by massive anhydrite with thin dolostone beds. The sub-unit can be described as follows (from top to base):

1'050.90 m – 1'052.44 m	At the top, from 1'050.90 m to 1'051.26 m, dolostone (argillaceous, anhydritic), beige to beige grey, with anhydrite nodules, white The main body consists of dolomitic marl to argillaceous marl (dolomitic), dark grey to black, with anhydrite nodules, white At the bottom, from 1'052.25 m to 1'052.44 m, dolostone (argillaceous, anhydritic), beige to beige grey, with anhydrite nodules, white, and a few lithoclasts
1'052.44 m – 1'053.90 m	Anhydrite, white, and an interlayer (from 1'053.69 m to 1'053.79 m) of dolostone, beige, with cracks filled by anhydrite, white and beige

3.10 Muschelkalk Group

3.10.1 Schinznach Formation, 1'053.90 m – 1'125.75 m (71.85 m)

The Schinznach Formation and its members are not consistently congruent with the stratigraphic units «Lettenkohle», «Trigonodusdolomit» and «Hauptmuschelkalk» used for the description of boreholes in previous Nagra and Nagra-supported campaigns. Pietsch et al. (2016) and Jordan & Deplazes (2019) provide a correlation between the current formal scheme and older lithostratigraphic concepts.

The *upper boundary* is set at 1'053.90 m at the base of the lowermost, more than 10 cm thick massive anhydrite bed of the overlying Bänkerjoch Formation. Beige to brown dolostone similar to that in the upper part of the Asp Member can also be found in the basal part of the «Dolomite and anhydrite» sub-unit of the Bänkerjoch Formation.

The *lower boundary* is set at 1'125.75 m at an erosional surface where non-laminated limestone (dolomitic) overlies laminated limestone (dolomitic) with anhydrite veins.

3.10.1.1 Asp Member, 1'053.90 m – ca. 1'057.9 m (ca. 4.0 m)

The Asp Member generally shows a two-part composition. The upper part of the member is dominated by dolostone which, in outcrops, is often cavernous ("Rauhwacke") or even brecciated (e.g. Merki 1961). The lower part of the member is composed of a fossiliferous, often bituminous shale or a claystone with thin dolostone interbeds also known as «Estherienschiefer» (Pietsch et al. 2016).

In BAC1-1, only the dolostone interval was cored. It contains small anhydrite nodules (causing the formation of "Rauhwacke" in the near-surface domain). For technical reasons, neither core nor cuttings could be collected from 1'057.25 m to 1'059.0 m. As can be seen from the FMI log, the missing section includes the base of the dolomitic upper part and the complete clayey lower part of the Asp Member and the very top of the Stamberg Member.

The *upper boundary* is set at 1'053.90 m at the base of the lowermost, more than 10 cm thick massive anhydrite bed of the overlying Bänkerjoch Formation. Beige to brown dolostone similar to that in the upper part of the Asp Member can also be found in the basal part of the «Dolomite and anhydrite» sub-unit of the Bänkerjoch Formation.

The *lower boundary* is set at 1'057.9 m within a section where neither core nor cuttings were collected. The boundary is thought to coincide with a change from bituminous shale to dolostone which is clear in both the FMI log and the GR log. Log depth is shifted to core depth.

Lithology

1'053.90 m – 1'057.25 m	Dolostone, dark greyish-brown, with dispersed small anhydrite nodules and nodular layers, and, subordinately, dolostone (argillaceous), beige to beige grey, also with dispersed small anhydrite nodules, with thin interlayers (from 1'054.59 m to 1'054.65 m, from 1'056.76 m to 1'056.79 m and from 1'057.22 m to 1'057.25 m) of claystone (dolomitic), to argillaceous marl (dolomitic), black
1'057.25 m – 1'057.9 m	Neither core nor cuttings were collected. The boundary between the Asp Member and the Stamberg Member at 1'057.9 m is set based on FMI and GR log data shifted to core depth

3.10.1.2 Stamberg Member, ca. 1'057.9 m – 1'095.95 m (ca. 38.1 m)

The definition of the Stamberg Member follows a petrographic approach (Pietsch et al. 2016). Its lower boundary is the base of a post-sedimentary, persistent and complete dolomitisation. The succession of dolostone is usually rather poor in macrofossils, bedded in the lower part and rather featureless and often porous in the upper part. The member often includes oolitic intervals, some of which are of regional extent and recognised as lithostratigraphic marker beds (e.g. Merki 1961, Paul 1971).

In BAC1-1, the Stamberg Member can be divided into two parts based on lithology and fossil content.

The upper part from 1'059.00 m to 1'077.78 m is a quite monotonous, partly porous, succession of dolostone with claystone drapes, abundant anhydrite nodules and few fossils.

The lower part from 1'077.78 m to 1'095.95 m is a quite fossiliferous succession of often porous dolostone and, locally, dolostone (argillaceous). Glauconite is found in the lower part. Fossils are mostly concentrated in coquinas and include brachiopods, bivalves and, in the lowermost part, occasionally crinoids.

The *upper boundary* is set at 1'057.9 m within a section where neither core nor cuttings were collected. The boundary is thought to coincide with a change from bituminous shale to dolostone which is clear in both the FMI log and the GR log. Log depth is shifted to core depth.

The *lower boundary* is set at 1'095.95 m at the lower boundary of the persistent and complete dolomitisation. This coincides with a colour change from the beige hues of the Stamberg Member above to the grey hue of the Liedertswil Member below, accompanied by a pronounced downward increase in the apparent resistivity (FMI log).

Lithology

1'057.9 m – 1'059.00 m	Neither core nor cuttings were collected. The boundary between the Asp Member and the Stamberg Member at 1'057.9 m is set based on FMI and GR log data shifted to core depth
1'059.00 m – 1'061.53 m	Dolostone, beige, slightly to moderately porous (irregularly shaped, mm-sized pores), with abundant small (< 1 cm in size) and some larger (2 cm to 3 cm in size) anhydrite nodules, white, and with layer-parallel (2 cm to 3 cm thick) silicified intervals and nodules
1'061.53 m – 1'063.86 m	Dolostone, beige grey to dark greyish-brown, slightly to moderately porous (irregularly shaped, mm-sized pores), few small (1 cm to 2 cm in size) anhydrite nodules, white, and few larger vugs (a few mm wide), and, at the base, from 1'063.73 m to 1'063.86 m, bioclasts including larger bivalves and few crinoids
1'063.86 m – 1'068.19 m	Dolostone, beige grey, locally dark greyish-brown, with peloids, smaller and few larger (> 2 cm in size) anhydrite nodules, white, few chert nodules, few bioclasts and with claystone drapes (now mostly stylolite seams)
1'068.19 m – 1'068.89 m	Poor core quality. Dolostone, beige grey to dark greyish-brown
1'068.89 m – 1'072.91 m	Dolostone, beige, locally dark greyish-brown, with abundant single, and clusters of, anhydrite nodules, white
1'072.91 m – 1'077.78 m	Dolostone, beige grey, locally dark greyish-brown, locally bioturbated, with flasery drapes of dolomitic marl, dark grey, and open vugs. Single, or clusters of, mostly cm-sized anhydrite nodules, white, and fissures with anhydrite fill, white From 1'076.86 m to 1'077.25 m, dolostone (argillaceous), dark greyish-brown
1'077.78 m – 1'082.83 m	Dolostone, dark greyish-brown to medium grey, locally arenitic, slightly porous, with open vugs (up to a few mm wide), some pyrite, occasionally some black peloids and a few bioclasts including *Coenothyris vulgaris*, crinoids and brachiopods. Flaser bedding with interlayers of dolomitic marl up to 2 cm thick

1'082.83 m – 1'087.12 m Dolostone, medium light grey to medium grey (thus marking a significant change in colour with respect to the interval above), medium-to thick-bedded, with mm (top part) to a few cm thick (lower part) interlayers of dolomitic marl. Locally argillaceous marl (dolomitic), dark grey. Throughout the succession, few tiny pyrite nodules, local bioturbation resulting in a nodular fabric and few large single vugs (up to 7 cm × 3 cm in size) partly filled by sulphate minerals. From 1'085.00 m to 1'085.03 m and from 1'085.07 m to 1'085.15 m, coquina with brachiopods and open vugs

1'087.12 m – 1'089.02 m Dolostone, medium light grey to medium grey, bioturbated, medium- to thick-bedded, with interlayers in the lower part (from 1'088.67 m to 1'089.02 m) of dolostone (argillaceous) to dolomitic marl, dark grey, bioturbated and with bioclasts. From 1'088.90 m to 1'088.95 m pyrite and glauconite, from 1'088.48 m to 1'088.59 m a coquina including brachiopods, and at 1088.51 m an open vug (3 cm in size) partly filled with calcite

1'089.02 m – 1'092.62 m Dolostone, medium light grey to medium grey and beige grey, intensely bioturbated, medium- to thick-bedded by thin interlayers of dolomitic to argillaceous marl (dolomitic), locally with glauconite and pyrite, more often with lithoclasts and larger vugs (mostly open, locally filled by idiomorphic calcite). Also interlayers (up to some cm thick) of dolostone, medium light grey, bioturbated, bioclastic (mostly formed by coquinas) with open vugs, lithoclasts and brachiopods

1'092.62 m – 1'093.96 m Dolostone, medium light grey to medium grey and medium-bedded by thin interlayers of dolomitic to argillaceous marl (dolomitic). Intensely bioturbated, with bioclasts, and an open vug (at 1'193.82 m)

1'093.96 m – 1'095.95 m Dolostone, medium light grey to medium grey, bioturbated (down to 1'095.31 m), medium-bedded by some thin and one thicker interlayer of dolostone, bioclastic, very light grey to medium grey. The succession contains pyrite (partly in aggregates), galena, bioclasts, bivalves, few brachiopods and is locally porous

3.10.1.3 Liedertswil Member, 1'095.95 m m – 1'100.66 m (4.71 m)

The Liedertswil Member represents the undolomitised to partially dolomitised interval between the Stamberg Member and the Kienberg Member (Pietsch et al. 2016).

In BAC1-1, the penetration of post-sedimentary, persistent and complete dolomitisation corresponds to that found in the surrounding Weiach borehole, STA3-1 borehole and BUL1-1 borehole (Matter et al. 1988, Schürch et al. 2022 and Jordan et al. 2021, respectively), but is significantly deeper than in the adjacent STA2-1 borehole (Jordan et al. 2022). The Liedertswil Member of BAC1-1 is formed by a thin- to medium-bedded succession of bioturbated glauconitic limestone with some coquinas. Fossils include bivalves, brachiopods and some crinoids.

The *upper boundary* is set at 1'095.95 m at the lower boundary of the persistent and complete dolomitisation. This coincides with a colour change from the beige hues of the Stamberg Member above to the grey hue of the Liedertswil Member below, accompanied by a pronounced downward increase in the apparent resistivity (FMI log).

The *lower boundary* is set at 1'100.66 m at the top of the uppermost bioclastic bed thicker than 10 cm and containing more than 10% crinoids (Pietsch et al. 2016).

Lithology

1'095.95 m – 1'097.12 m	Limestone (dolomitic) (mudstone to wackestone, micrite to biomicrite), medium light grey to medium grey, locally bioturbated, occasionally bioclastic and locally with pyrite and glauconite From 1'096.47 m to 1'096.62 m, limestone (argillaceous), medium grey with bivalves and burrows
1'097.12 m – 1'098.97 m	Heterogeneous, thin- to medium-bedded succession of: • Limestone (dolomitic) (mudstone, micrite), medium light grey to beige grey, bioturbated, with a vug (up to more than 10 cm × 3 cm in size) at 1'098.09 m • Bioclastic limestone (packstone, biomicrite), very light grey, with some pyrite, locally glauconite, occasionally lithoclasts, and locally crinoids and bivalves (partly in coquinas) • Limestone, partly argillaceous (mudstone, micrite), medium light grey to beige grey, occasionally with bioclasts
1'098.97 m – 1'100.66 m	Limestone, occasionally slightly dolomitic (mudstone, micrite, below 1'099.58 m wackestone, biomicrite), medium light grey to beige grey, locally with bioclasts, some larger crinoids and few burrows

3.10.1.4 Leutschenberg Member and Kienberg Member, 1'100.66 m – 1'125.75 m (25.09 m)

According to Jordan & Deplazes (2019), the Leutschenberg Member and the overlying Kienberg Member should be combined for the present purpose, because a separation may be not possible at all locations in question. Both members generally consist of a bedded succession of limestone with a varying content of biogenic components. Crinoids and shell debris are especially enriched in the Kienberg Member, which often results in an alternation of limestone and bioclastic limestone. The Leutschenberg Member is divided in an upper part with few fossils and no crinoids and a lower fossiliferous part, with crinoids, that is often partly dolomitised.

In BAC1-1, this threefold division can be well observed with the intermediate, non-fossiliferous section ranging from 1'111.17 m to 1'116.07 m and probably corresponding to the upper part of the Leutschenberg Member. The bed on top of this section (from 1'110.81 m to 1'111.17 m), including brachiopods (*Coenothyris vulgata*) but no crinoids, probably corresponds to the Saalhof Bed (Pietsch et al. 2016).

The *upper boundary* is set at 1'100.66 m at the top of the uppermost bioclastic bed thicker than 10 cm and containing more than 10% crinoids (Pietsch et al. 2016).

The *lower boundary* is set at 1'125.75 m at an erosional surface where non-laminated limestone (dolomitic) overlies laminated limestone (dolomitic) with anhydrite veins.

Lithology

1'100.66 m – 1'107.78 m

Medium- to thick-bedded alternation of:

- Limestone (mudstone, micrite), occasionally dolomitic, very light grey to light grey and medium light grey, with few bioclasts including crinoids, burrows, chert nodules (up to 3 cm × 1 cm in size) and a large, vug (up to 3 cm × 1 cm in size)
- Limestone (wackestone, biomicrite), medium light grey to light grey and medium grey, slightly bioturbated, with scattered crinoids and other bioclasts
- Bioclastic limestone (packstone and grainstone, biomicrite and biosparite), medium grey to very light grey, porous to vuggy, slightly bioturbated, occasionally with limestone lithoclasts, very fossiliferous (coquinas), mainly large crinoids (often up to 7 mm, some up to 20 mm in size), bivalves and brachiopods

1'107.78 m – 1'110.81 m

Medium-bedded alternation of:

- Limestone (mudstone, micrite), very light grey to light grey and medium light grey, with few intraclasts including crinoids
- Limestone (wackestone, biomicrite), medium light grey to light grey and medium grey, slightly bioturbated with scattered crinoids and other bioclasts
- Bioclastic limestone (packstone and grainstone, biomicrite and biosparite), medium grey to very light grey, porous to vuggy, slightly bioturbated and very fossiliferous including coquinas, large crinoids (> 5 mm in size), bivalves and brachiopods

From 1'109.00 m to 1'109.08 m, a coquina consisting almost exclusively of bivalves and no crinoids

1'110.81 m – 1'116.07 m

At the top, from 1'110.81 m to 1'111.17 m below an erosional surface, two beds of limestone (mudstone, micrite, and wackestone, biomicrite). In the lower bed, from 1'110.96 m to 1'111.17 m, brachiopods (*Coenothyris vulgata*) but no crinoids; this interval may therefore correspond to the Saalhof Bed

The main body consists of limestone (mudstone, micrite), light grey to medium light grey, bioturbated, with many stylolites and several large open vugs (up to 3 cm × 2 cm in size)

1'116.07 m – 1'117.68 m

Limestone (often slightly dolomitic) (mudstone, micrite), medium light grey to beige grey, bioturbated with vugs partly filled by anhydrite at the top (from 1'116.08 m to 1'116.10 m)

At the base, from 1'117.02 m to 1'117.68 m, limestone (wackestone, biomicrite), medium light grey to beige grey, bioturbated and with bioclasts including crinoids

1'117.68 m – 1'119.09 m	Limestone (mudstone, micrite), medium light grey to medium grey, with a chert nodule (3 cm in size), and, from 1'118.34 m to 1'118.67 m, scattered crinoids and other bioclasts From 1'118.16 m to 1'118.32 m, bioclastic limestone (packstone and grainstone, biomicrite and biosparite), strongly bioturbated, with irregularly shaped chert nodules
1'119.09 m – 1'121.88 m	Limestone (often slightly dolomitic) (mudstone, micrite), medium grey to beige grey, bioturbated, locally with chert nodules, and some open vugs (1 cm in size) From 1'119.90 m to 1'120.00 m, limestone (argillaceous), medium grey, bioturbated From 1'120.81 m to 1'120.91 m, bioclastic limestone (packstone and grainstone, biomicrite and biosparite) with crinoids and bivalves Below 1'121.33 m and above an erosive base, at 1'121.88 m, dolostone, (slightly calcareous), medium grey to greyish-brown and beige grey, with open elongated vugs at 1'121.67 m and large clasts of dolostone, beige, at 1'121.88 m
1'121.88 m – 1'125.75 m	Limestone (arenitic, partly bioclastic) (wackestone to packstone, biomicrite, diagenetically overprinted), beige grey and very light grey to light grey, locally with a breccia-like fabric with beige grey micritic matrix, open vugs and scattered crinoids From 1'121.88 m to 1'122.38 m, bioclastic limestone (biomicrite, recrystallised), beige grey, with abundant open vugs, crinoids and bivalves From 1'122.38 m to 1'122.60 m, limestone (argillaceous) (mudstone, micrite), light grey to beige From 1'123.10 m to 1'124.12 m, limestone (arenitic, partly bioclastic), as above, with oncoids of cortoid type (< 1 cm in size) and locally limestone clasts (mudstone, micrite) From 1'124.12 m to 1'124.76 m, irregularly shaped anhydrite nodules, black, and calcite nodules, translucent to white From 1'124.76 m to 1'125.05 m, limestone (arenitic, partly bioclastic), as above, with scattered large (3 cm × 2 cm in size) oncoids At the base, from 1'125.05 m to 1'125.75 m, limestone (dolomitic) (mudstone, micrite) beige grey, occasionally dark greyish-brown, locally laminated by microbial mats and with an erosional surface at the base

3.10.2 Zeglingen Formation, 1'125.75 m – 1'202.03 m (76.28 m)

The Zeglingen Formation (Jordan 2016) is an evaporite sequence with anhydrite, rock salt and dolostone. In BAC1-1 it is characterised above all by its great thickness in general and its high content of rock salt (see below).

The *upper boundary* is set at 1'125.75 m at an erosional surface where non-laminated limestone (dolomitic) overlies laminated limestone (dolomitic) with anhydrite veins.

The *lower boundary* is set at 1'202.03 m at the base of the lowermost thick and massive anhydrite interval and at the top of the uppermost bed of dolostone, whereby argillaceous marl, dolomitic, also occurs in the lowermost part of the overlying formation. Anhydrite nodules are found down to 1'203.15 m.

Lithostratigraphic subdivision

There is no formal subdivision of the Zeglingen Formation. The traditional lithological subdivision into four informal units (*cf.* Widmer 1991, Jordan & Deplazes 2019) applies to BAC1-1 as follows:

1'125.75 m – 1'134.87 m «Dolomitzone» (9.12 m)

1'134.87 m – 1'160.56 m «Obere Sulfatzone» (25.69 m)

1'160.56 m – 1'195.79 m «Salzlager» (35.23 m)

1'195.79 m – 1'202.03 m «Untere Sulfatzone» (6.24 m)

The delimitation between the «Dolomitzone» and the «Obere Sulfatzone» is set at the top of the uppermost thick (> 50 cm) bed of anhydrite.

The existence of a thick «Salzlager» (delimited by the uppermost and lowermost occurrence of rock salt) corresponds to the findings of the nearby STA2-1 borehole and STA3-1 borehole (27.43 m, Jordan et al. 2022, and 39.56 m, Schürch et al. 2022, respectively) but contrasts with the findings of the Weiach borehole a few kilometres to the north-east, where the «Salzlager» is completely missing (Matter et al. 1988).

Lithology

«Dolomitzone», 1'125.75 m – 1'134.87 m (9.12 m)

1'125.75 m – 1'128.46 m At the top (from 1'125.75 m to 1'126.12 m, below an erosional surface), limestone (dolomitic) (mudstone, micrite), beige grey to dark greyish-brown, laminated

Dolostone, beige to dark beige, mostly laminated, locally with chert nodules and anhydrite veins, white

From 1'126.12 m to 1'126.44 m, above an erosional surface, dolostone (argillaceous), dark greyish-brown

1'128.46 m – 1'129.74 m	Dolostone, beige grey to dark greyish-brown, laminated in the upper part, with abundant silicified layers and small (< 1 mm in size) anhydrite nodules, white
1'129.74 m – 1'132.05 m	Dolostone, beige grey, locally dark greyish-brown to beige grey, laminated, with anhydrite nodules and nodular layers, white. From 1'130.03 m to 1'130.14 m and at the base (from 1'131.75 m to 1'132.05 m), massive layers of anhydrite, white
1'132.05 m – 1'133.33 m	Dolostone, beige grey, mostly featureless, locally laminated and some large anhydrite nodules At the base (from 1'132.89 m to 1'133.33 m), dolostone, partly oolitic, dark reddish-brown and locally very light grey, with some ooids (mostly recrystallised and silicified), lithoclasts of dolostone, beige, and various, partly steeply inclined erosional surfaces
1'133.33 m – 1'134.87 m	Dolostone (anhydritic), locally laminated, with colour changing from top to base from beige grey to medium grey to greyish-brown and back to medium grey From 1'133.94 m to 1'134.21 m, argillaceous marl (dolomitic), dark grey to dark greyish-brown, grading downwards into underlying dolostone (anhydritic)

«Obere Sulfatzone», 1'134.87 m – 1'160.56 m (25.69 m)

1'134.87 m – 1'137.28 m	Anhydrite (partly dolomitic), with thin layers and lenses of dolostone, white to light grey From 1'135.75 m to 1'136.14 m, dolostone and dolomitic marl, beige grey to dark beige, with abundant anhydrite nodules, white At the base, from 1'136.14 m to 1'137.28 m, claystone (anhydritic and dolomitic), dark grey and white to light grey, with anhydrite nodules, white
1'137.28 m – 1'138.72 m	Dolostone, beige grey to dark greyish-brown, with anhydrite nodules and veins, white
1'138.72 m – 1'142.99 m	Heterogeneous alternation of: • Dolostone (argillaceous, anhydritic), light to medium grey, partly laminated • Claystone (anhydritic and dolomitic), dark grey to black, partly with anhydrite nodules, white • Argillaceous marl (dolomitic, anhydritic), dark greyish-brown, partly with anhydrite nodules, white • Dolomitic marl, (anhydritic), medium grey, partly with anhydrite nodules, white • Anhydrite, white, in thin massive layers

1'142.99 m – 1'146.50 m Anhydrite, white to very light grey, with enterolitic folding at 1'143.40 m and from 1'144.14 m to 1'144.45 m

From 1'145.35 m to 1'145.48 m, claystone (anhydritic and dolomitic), black and white, with anhydrite nodules, white

At the base, from 1'145.90 m to 1'146.50 m, anhydrite (argillaceous), medium grey

1'146.50 m – 1'150.01 m Anhydrite, white to very light grey, massive

At the base, from 1'149.86 m to 1'150.01 m, claystone (anhydritic and dolomitic), dark grey to dark greyish-brown

1'150.01 m – 1'152.64 m Alternation of:

- Anhydrite (argillaceous), white to light and dark grey
- Anhydrite, white to light grey

From 1'151.70 m and 1'152.10 m, enterolitic folding

At the base, from 1'151.75 m to 1'152.64 m, claystone (anhydritic), light and dark grey, with anhydrite nodules, white

1'152.64 m – 1'156.05 m Alternation of:

- Anhydrite (argillaceous), white to light and dark grey, mostly with anhydrite nodules, white
- Claystone (anhydritic), medium grey to dark grey, mostly with anhydrite nodules, white

From 1'153.85 m to 1'154.60 m and from 1'155.00 m to 1'155.07 m, enterolitic folding

1'156.05 m – 1'160.56 m Alternation of:

- Anhydrite (argillaceous), white to light and dark grey, mostly with anhydrite nodules, white
- Claystone (anhydritic), medium grey to dark grey, mostly with anhydrite nodules, white
- Anhydrite, white

From 1'156.05 m to 1'156.98 m, at 1'157.52 m and from 1'159.08 m to 1'159.45 m, enterolitic folding

At the base (from 1'160.45 m to 1'160.56 m), halite lenses and veins

«Salzlager», 1'160.56 m – 1'195.79 m (35.23 m)

1'160.56 m – 1'164.62 m Halite, translucent and colourless in the upper and lower part, opaque, white to medium and dark grey in the middle part, massive and almost pure, with few claystone drapes, black, and very few angular fragments of anhydrite and claystone (up to 4 cm in size)

1'164.62 m – 1'169.73 m Anhydrite, white to very light grey, laminated to banded by mm-thick claystone drapes, black, with enterolitic folding at 1'164.95 m, from 1'166.29 m to 1'166.37 m and from 1'168.25 m to 1'168.70 m

At the base, from 1'169.57 m to 1'169.73 m, claystone (anhydritic), dark grey to black and white, with anhydrite nodules, white

1'169.73 m – 1'176.34 m Halite, predominantly translucent and colourless, at the base, from 1'175.56 m to 1'176.34 m, increasingly opaque with white and greyish hues, with fragments of anhydrite (up to 6 cm × 3 cm in size) at 1'170.00 m

From 1'175.47 m to 1'175.56 m, anhydrite, white to light grey, with claystone drapes, black

1'176.34 m – 1'179.69 m Breccia (halite) (polymict), with halite, mostly translucent and colourless, locally opaque and then white to grey, forming the matrix and thus the largest volume. The randomly oriented components are predominantly various anhydrite rock types and claystone fragments such as:

- Anhydrite, white, massive, fragments up to 20 cm in size
- Anhydrite, white to very light grey, laminated by claystone drapes
- Claystone, dark grey to black, as fragments and secondary seams

1'179.69 m – 1'181.87 m Halite (argillaceous) formed by halite matrix, mostly translucent and colourless, and fragments mainly of claystone, black, and anhydrite, white, as irregular interlayers of claystone, black to dark grey

From 1'181.00 m to 1'181.28 m, breccia (halite) (polymict), as in the intervals above and below

1181.87 m – 1183.55 m Breccia (halite) (polymict) formed by halite matrix, mostly translucent and colourless but also opaque and white, and fragments of:

- Anhydrite, white
- Claystone, black
- Halite, opaque, white to reddish-brown, with fragments of anhydrite and claystone
- Anhydrite, white, laminated (by claystone drapes), nodular

1'183.55 m – 1'184.47 m Halite (argillaceous) formed by halite matrix, mostly translucent and colourless, and fragments and thin layers of claystone, black to dark grey

1'184.47 m – 1'187.31 m Halite, mostly translucent, colourless, in the lower part also opaque, white and reddish-brown, with claystone drapes, black, and an anhydrite rock fragment, white, at 1'187.27 m

From 1'185.26 m to 1'185.75 m, anhydrite (argillaceous), white, laminated to banded

1'187.31 m – 1'189.73 m Claystone (anhydritic), dark grey to dark greyish-brown with anhydrite nodules, anhydrite veins and halite, and claystone, dark grey to dark greyish-brown, with dispersed anhydrite, white

From 1'187.67 m to 1'189.30 m, nearly vertical vein of halite, reddish-brown

From 1'188.30 m to 1'188.85 m, halite (argillaceous), reddish-brown to dark grey and dark greyish-brown

From 1'189.37 m to 1'189.73 m, anhydrite, white, and anhydrite (argillaceous), medium to dark grey and white

1'189.73 m – 1'194.14 m Halite, mostly translucent, rarely opaque, light grey to medium grey, at the top also reddish-brown, with abundant fragments and layers of claystone, black, and, rarely, anhydrite, white

1'194.14 m – 1'195.79 m Halite (argillaceous), brecciated, with halite, mostly translucent, light to dark grey, and claystone, black to dark grey. Fragments of anhydrite, white, and claystone, black

At the base, from 1'195.08 m to 1'195.79 m, breccia (halite) (polymict), with matrix of halite, translucent, colourless to medium grey, and fragments of white anhydrite and black claystone

«Untere Sulfatzone», 1'195.79 m – 1'202.03 m (6.24 m)

1'195.79 m – 1'202.03 m Anhydrite, white to light grey, massive, locally (from 1'197.25 m to 1'197.61 m and from 1'197.75 m to 1'198.29 m) enterolitic folding, with interbeds of anhydrite (argillaceous), medium to dark grey, formed by claystone drapes, black, in anhydrite, white, anhydrite (dolomitic), white to light grey and beige, and anhydrite, nodular (chicken wire structure), light grey

From 1'201.05 m to 1'201.49 m, argillaceous marl (dolomitic), dark greyish-brown to beige grey and medium grey, with small anhydrite nodules

3.10.3 Kaiseraugst Formation, 1'202.03 m – 1'242.82 m (40.79 m)

The Kaiseraugst Formation is usually a succession of claystone (calcareous, silty) to argillaceous marl (silty), partly bituminous in the upper part, and of dolomitic marl in the lower part (Jordan 2016). Interbeds of limestone, dolostone and sandstone may occur throughout the unit; the latter two particularly in the lowermost part of the formation. Some of these interbeds are lithostratigraphic marker horizons. There is no formal subdivision of the Kaiseraugst Formation yet. Jordan (2016) suggests provisionally maintaining the traditional subdivision of the German stratigraphic scheme (from the top): «Orbicularismergel», «Wellenmergel», «Wellendolomit».

Apart from the lowermost section, the Kaiseraugst Formation of BAC1-1 meets expectations in terms of lithology, thickness and facies, as established from boreholes and outcrops between the Wutach region and the lower course of the Aare River (e.g. Paul 1971, Matter et al. 1987, Becker et al. 1997). The «Wellendolomit» is typically divided into a calcareous upper part and a dolomitic lower part. However, in BAC1-1 the upper part is formed predominantly by claystone (calcareous) to calcareous marl and the lower part is formed by dolomitic sandstone, sandy dolostone

and sandy marl. Thus, it shows some similarities (but also significant differences) to the «Wellendolomit» of the nearby STA2-1 borehole (Jordan et al. 2022).

The *upper boundary* is set at 1'202.03 m at the base of the lowermost thick and massive anhydrite interval and at the top of the uppermost bed of dolostone, whereby argillaceous marl, dolomitic, also occur in the lowermost part of the overlying formation. Anhydrite nodules are found down to 1'203.15 m.

The *lower boundary* is set at 1'242.82 m at the uppermost bed of sandstone (medium- to coarse-grained) overlain by dolomitic sandstone (fine-grained, argillaceous).

Lithostratigraphic subdivision

The traditional subdivision into three informal units and their informal marker beds (*cf.* Jordan & Deplazes 2019) can be applied to the present cored interval:

1'202.03 m – 1'210.01 m	«Orbicularismergel» (7.98 m) including the «Geislingen-Bank» from 1'207.15 m to 1'209.14 m
1'210.01 m – 1'233.50 m	«Wellenmergel» (23.49 m) possibly including the «Spiriferinabank» from 1'217.81 m to 1'217.89 m and the «Terebratelnbank» somewhere between 1'223.56 m and 1'224.56 m
1'233.50 m – 1'242.82 m	«Wellendolomit» (9.32 m) including the «Bleiglanzbank» (*sensu lato*) from 1'233.50 m to 1'234.45 m

The boundary between the «Orbicularismergel» and the «Wellenmergel» is set at the base of the thin limestone interval from 1'209.91 m to 1'210.01 m. This interval is correlated with the «Orbicularisbänkchen» traditionally marking the base of the «Orbicularismergel» (Becker et al. 1997, Nagra 2001a, Jordan et al. 2022).

The boundary between the «Wellenmergel» and the «Wellendolomit» is set at 1'233.50 m. This corresponds to the top of the «Bleiglanzbank» (*sensu lato*), a regional marker horizon consisting of various beds of a bioclastic limestone to calcareous and argillaceous marl, most of them with conspicuous crystals of galena.

Lithology

«Orbicularismergel», 1'202.03 m – 1'210.01 m (7.98 m)

1'202.03 m – 1'205.57 m	At the top, from 1'202.03 m to 1'202.49 m, dolostone, dark greyish-brown to beige grey and medium grey, with small anhydrite nodules
	From 1'202.49 m to 1'202.83 m, dolomitic marl, dark greyish-brown
	From 1'202.89 m to the base (at 1'205.57 m), calcareous marl, medium grey to dark greyish-brown, with very few micas, scattered anhydrite nodules (down to 1'203.23 m) and, below 1'204.50 m, with increasing abundance of thin claystone drapes and layers, dark grey

1'205.57 m – 1'207.15 m Argillaceous marl, mostly silty, mainly dark grey and medium grey, partly laminated, with lenses of calcareous sandstone (fine-grained), very light grey (at 1'206.79 m)

At the base, from 1'206.87 m to 1'207.15 m, argillaceous marl (silty), including intervals and lenses of sandy marl (fine-grained), light grey, and calcareous sandstone (fine-grained), very light grey, as well as small anhydrite nodules and a coquina with *Neoschizodus orbicularis* (from 1'206.91 m to 1'206.98 m)

1'207.15 m – 1'209.14 m Anhydrite interval («Geislingen-Bank») formed by:

At the top, from 1'207.15 m to 1'207.78 m, anhydrite, nodular (chicken wire structure), white

From 1'207.78 m to 1'208.03 m, anhydrite, white, moderately nodular

At the base, from 1'208.03 m to 1'209.14 m, anhydrite (dolomitic), white

1'209.14 m – 1'210.01 m Argillaceous marl, dark grey, with calcareous marl, medium grey, bioclastic at the top (from 1'209.14 m to 1'209.35 m) and two thin beds (from 1'209.52 m to 1'209.57 m and from 1'209.91 m to 1'210.01 m) with basal bioclastic limestone (coquina) grading upwards into calcareous marl. The lower bed at the base is correlated with the «Orbicularisbänkchen»

«Wellenmergel», 1'210.01 m – 1'233.50 m (23.49 m)

1'210.01 m – 1'217.89 m Argillaceous marl (silty, occasionally slightly silty), locally with very few micas, thin siltstone to sandstone (fine-grained) lenses, very light grey, with coquinas, ripples and thin (mostly a few cm thick) interlayers of calcareous marl, medium grey

From 1'213.78 m to 1'213.85 m, bioclastic limestone, white to very light grey, consisting exclusively of bioclasts in a sand fraction

From 1'215.65 m to 1'215.83 m, calcareous marl (silty), medium grey, with sub-angular to sub-rounded bioclasts (including brachiopods) and limestone lithoclasts above an erosional surface at 1'215.78 m

From 1'217.25 m to 1'217.43 m, calcareous marl (sandy), medium grey, nodular, above an erosional surface

At the base, from 1'217.81 m to 1'217.89 m, bioclastic limestone, light to medium light grey, above an erosional surface. Based on a GR correlation with the STA2-1 borehole, this interval may correspond to the «Spiriferinabank»

1'217.89 m – 1'222.90 m Argillaceous marl (silty), dark grey, to claystone (silty, calcareous), dark grey, locally bioturbated, with mica, lenses of siltstone to sandstone (fine-grained), very light grey, ripples, and a few thin bioclastic layers

1'222.90 m – 1'231.00 m Claystone (calcareous), dark grey, alternating with claystone (silty, calcareous), dark grey, with mica, abundant large bivalves, bioclasts and lenses of siltstone to sandstone (fine-grained), very light grey, with ripples

From 1'223.56 m to 1'223.63 m, bioclastic limestone (packstone, biomicrite) composed of coquinas and limestone interlayers

From 1'224.32 m to 1'224.42 m and from 1'224.51 m to 1'224.56 m, bioclastic limestone, light and dark grey, comprising several coquinas including brachiopods

Based on a GR correlation with the STA2-1 borehole, one of the three bioclastic limestone beds between 1'223.56 m and 1'224.56 m may correspond to the «Terebratelnbank».

From 1'225.47 m to 1'225.72 m, argillaceous marl, dark grey

From 1'226.23 m to 1'226.41 m, limestone (sandy [fine-grained]), light grey, with ripples (foresets)

From 1'230.42 m to 1'230.50 m, bioclastic limestone, light grey and black, comprising a coquina

1'231.00 m – 1'233.50 m Claystone and claystone (silty), dark grey and medium grey, with mica, bioclasts including a coquina (at 1'232.81 m, 2 cm thick) dispersed bivalves and a lens of siltstone, very light grey with ripples

«Wellendolomit», 1'233.50 m – 1'242.82 m (9.32 m)

1'233.50 m – 1'237.95 m At the top, from 1'233.50 m to 1'234.45 m, alternation of:

- Sandy limestone (argillaceous), medium light grey, with mica and, in the uppermost bed, also galena («Bleiglanzbank»), fossiliferous (partly coquina) with bivalves
- Argillaceous siltstone (calcareous), dark grey, flaser bedding

Main body formed by claystone (silty), dark grey, with mica and thin lenses of siltstone to sandstone (fine-grained), very light grey with ripples, and interbeds of argillaceous siltstone to argillaceous sandstone (fine-grained) medium light grey, with mica and, from 1'237.39 m to 1'237.64 m, also some galena

1'237.95 m – 1'241.03 m Two successions (from 1'237.95 m to 1'238.92 m and from 1'238.92 m to 1'241.03 m) formed by sandy dolostone and dolomitic sandstone, respectively, overlying argillaceous sand- to siltstone:

- Sandy (fine-grained) to bioclastic dolostone, sandy (fine-grained), very light grey to light grey, with mica
- Dolomitic sandstone (fine-grained), very light to light grey, with mica, to sandstone (dolomitic) (fine-grained), medium grey, with mica, flaser bedding
- Argillaceous sandstone (dolomitic) (fine-grained), medium grey to dark grey, with mica, flaser bedding

- Argillaceous siltstone (dolomitic), dark grey, with mica, flaser bedding

At the base, from 1'240.95 m to 1'241.03 m, large angular lithoclasts of the underlying dolostone above an erosional surface

1'241.03 m – 1'242.82 m

At the top, from 1'241.03 m to 1'241.25 m, dolostone, very light grey to greenish-grey

From 1'241.25 m to 1'241.72 m, sandy marl (fine-grained) (dolomitic), light grey to medium and greenish-grey, with mica and wavy bedding

From 1'241.72 m to 1'242.15 m, dolomitic sandstone (fine-grained) (argillaceous), very light to dark and greenish-grey, with few micas and microbial mats (teepee structures)

From 1'242.15 m to 1'242.49 m, dolomitic sandstone (fine-grained), white to medium grey, with microbial mats

At the base, from 1'242.49 m to 1'242.82 m, dolomitic sandstone (fine-grained), argillaceous, medium grey to greenish-grey, with microbial mats, vugs and anhydrite nodules

3.11 Buntsandstein Group

3.11.1 Dinkelberg Formation, 1'242.82 m – 1'256.86 m (14.04 m)

The Dinkelberg Formation consists of siliciclastics with a predominance of sandstone. The sandstone displays a moderate to high degree of compositional as well as textural maturity.

The *upper boundary* is set at 1'242.82 m at the uppermost bed of sandstone (medium- to coarse-grained) overlain by dolomitic sandstone (fine-grained, argillaceous).

The *lower boundary* is set at 1'256.86 m at an erosional surface on top of the first occurrence of polymict breccia of crystalline basement origin overlain by sandstone (coarse-grained) with lithoclasts up to 5 cm in size.

Lithostratigraphic subdivision

There is presently no formal subdivision of the Dinkelberg Formation. Jordan (2016) suggests provisionally maintaining the traditional subdivision of the German stratigraphic scheme (from top to base): «Rötton», «Plattensandstein», «Vogesensandstein».

In BAC1-1, this division is not clearly recognisable. The «Rötton» is obviously missing. The interval from 1'247.11 m to 1'247.47 m may correspond to the «Karneol-Dolomit-Horizont VH4». In this case, the interval from 1'242.82 m to 1'247.11 m would correspond to the «Plattensandstein» and the interval below this would then be the marker horizon to the «Vogesensandstein».

Lithology

1'242.82 m – 1'247.11 m

At the top, from 1'242.82 m to 1'243.07 m, sandstone (medium- to coarse-grained), white, sub-angular to sub-rounded, medium sorted, almost monomict (quartz) and well cemented

Main body formed by sandstone (medium- to coarse-grained, below 1'246.70 m only coarse-grained), variegated (pale yellowish-green, light greenish-grey, pale green, dark reddish-brown, reddish-brown, white, greyish-violet), sub-angular to sub-rounded, medium sorted, nearly monomict (quartz), partly cemented with sparse claystone matrix. With chert and anhydrite nodules

At the base (from 1'245.04 m to 1'247.11 m), calcareous concretions, white, partly in clusters

1'247.11 m – 1'248.88 m

Sandstone (mostly medium-grained), at 1'248.08 m and below 1'248.67 m also coarse-grained, very light grey, greyish and reddish-brown, sub-angular to sub-rounded, medium to well sorted, almost monomict (quartz), well cemented and, below 1'248.67 m, poorly cemented (and porous) with abundant claystone coats

At the top (from 1'247.11 m to 1'247.47 m), sandstone (fine-grained), light greyish-green, greyish-violet and reddish-brown, medium sorted, well cemented, with chert ("Karneol") and dolostone concretions. This horizon may correspond to the «Karneol-Dolomit-Horizont VH4»

1'248.88 m – 1'256.86 m

Sandstone (coarse-grained), to sandstone (medium-, rarely fine-grained), locally sandstone (very coarse-grained) and, from 1'251.77 m to 1'252.28 m, conglomerate, siliciclastic (monomict). White, light grey and pale pink to reddish-brown and dark reddish-brown colours, sub-angular to sub-rounded, medium sorted and nearly monomict (quartz) components, poorly and, rarely, partly cemented, porous, locally with vugs. Occasionally normally graded, thick-bedded (mostly about 1 m), at the base, from 1'254.00 m to 1'256.86 m, cross bedding

From 1'256.25 m to 1'256.31 m, claystone, dark reddish-brown, with abundant mica

At 1'256.86 m, erosive base overlain by lithoclasts (up to 5 cm in size)

3.12 Permo-Carboniferous sediments

3.12.1 Weitenau Formation, 1'256.86 m – 1'306.26 m (> 49.40 m)

The Weitenau Formation (*cf.* Jordan & Deplazes 2019) was defined to unite the three informal units «Oberer Schuttfächer», «Playa-Serie» and «Unterer Schuttfächer». They are traditionally regarded as representing the upper part of the Permian in Northern Switzerland (Blüm 1989).

The *upper boundary* is set at 1'256.86 m at an erosional surface on top of the first occurrence of polymict breccia of crystalline basement origin overlain by sandstone (coarse-grained) with lithoclasts up to 5 cm in size.

The *lower boundary* of the Weitenau Formation was not encountered until the final depth of the borehole at 1'306.26 m.

Lithostratigraphic subdivision

In BAC1-1, the bored section is very homogeneous and monotonous showing no further subdivision.

Lithology

1'256.86 m – 1'306.26 m Monotonous succession of breccia (crystalline basement) (polymict), mainly dark reddish-brown, occasionally reddish-brown, clast-supported, with components comprising angular to sub-rounded pebbles to cobbles of quartz, feldspar, gneiss, granite, schist, chert, very micaceous mafic rocks, large angular quartz clasts (up to 5 cm in size), and a matrix formed by siltstone (argillaceous) to sandstone (argillaceous) (mostly fine-grained), dark reddish-brown, rarely reddish-brown

From 1'257.60 m to 1'257.86 m, from 1'261.20 m to 1'261.70 m and from 1'278.00 m to 1'278.32 m, intervals with smaller (up to 1 cm in size) pebbles

From 1'281.82 m to 1'281.86 m, reduction horizon, greyish-blue green, slightly porous

From 1'285.55 m to 1'285.57 m, siltstone, dark reddish-brown

4 Comparison with the forecast profile

The results of the BAC1-1 borehole deviate only moderately from the forecast (Nagra 2020). This is not surprising because the forecast for this borehole could be adjusted according to the initial result of the drilling campaign, in particular the findings of the BUL1-1 borehole and the BUL1-1B sidetrack (Jordan et al. 2021). There is a good agreement with the findings of the nearby STA2-1 borehole (Jordan et al. 2022), located some 3 km to the east of BAC1-1 (Fig. 1-1). On the other hand, there are many similarities but also some significant deviations from the findings in the nearby Weiach borehole, located some 4 km to the north-east of BAC1-1 (Matter et al. 1988).

The Molasse bedrock was found at a significantly shallower depth (14 m) than expected (25 m). Since the lower boundary was encountered at a slightly shallower depth than expected (450 m instead of 455 m), the total thickness of the Molasse Supergroup turned out to be only slightly thicker than expected (436 m instead of 430 m). The base of the OMM (Upper Marine Molasse) was effectively found at the predicted depth (94 m instead of 95 m), given that the prediction was given to the nearest 5 m. The forecast did not specify the thickness of the USM II (Lower Freshwater Molasse) and USM I. It is assumed here that most of the USM belongs to the USM II and the USM I is only represented by a thin interval at the base.

The thickness of the Siderolithic Group was very uncertain in the forecast (0 m to 10 m). The finding (12 m) is slightly above the larger endmember.

The «Felsenkalke» + «Massenkalk» (88 m) and the Schwarzbach Formation (21 m) turned out to be thicker than expected (85 m in total in the forecast). This excess thickness comes at the expense of the upper formation which is almost exclusively represented by the «Felsenkalke» facies. The thickness of the Schwarzbach Formation corresponds approximately to the regional value (e.g. 27 m in the STA2-1 borehole, Jordan et al. 2022), which is indicated graphically in the forecast profile but not shown numerically.

Conversely, the total thickness (a total of 180 m is shown in the forecast) of the Villigen Formation (66 m) and Wildegg Formation (100 m) is less than expected. As a result of these deviations from the forecast which counteract each other, the base of the Malm Group was reached almost exactly at the expected depth (737.05 m instead of 730 m). A comparison with the Weiach borehole and the STA2-1 borehole (Matter et al. 1988 and Jordan et al. 2022, respectively) shows similar values for the Villigen Formation (71 m in STA2-1, 75 m in Weiach), but a significant increase in the thickness of the Wildegg Formation with respect to STA2-1 (81 m) and Weiach (87 m).

In BAC1-1, the thickness of the upper part of the Dogger Group, the so-called «Brauner Dogger», is 71 m. This is slightly less than the expected 75 m, or than the thickness of the corresponding interval in the STA2-1 borehole (73 m) and the Weiach borehole (76 m) (Jordan et al. 2022 and Matter et al. 1988, respectively). The forecast shows graphically how the expected total thickness may be distributed among the six formations. In this context, it is noteworthy that the «Parkinsoni-Württembergica-Schichten» are thicker than expected. The other formations tend to be thinner than expected. An exception is the thick «Murchisonae-Oolith Formation». The «Herrenwis Unit» encountered in the STA2-1 borehole, STA3-1 borehole and BUL1-1 borehole (Jordan et al. 2022, Schürch et al. 2022 and Jordan et al. 2021, respectively), is not present in BAC1-1, as expected from the forecast.

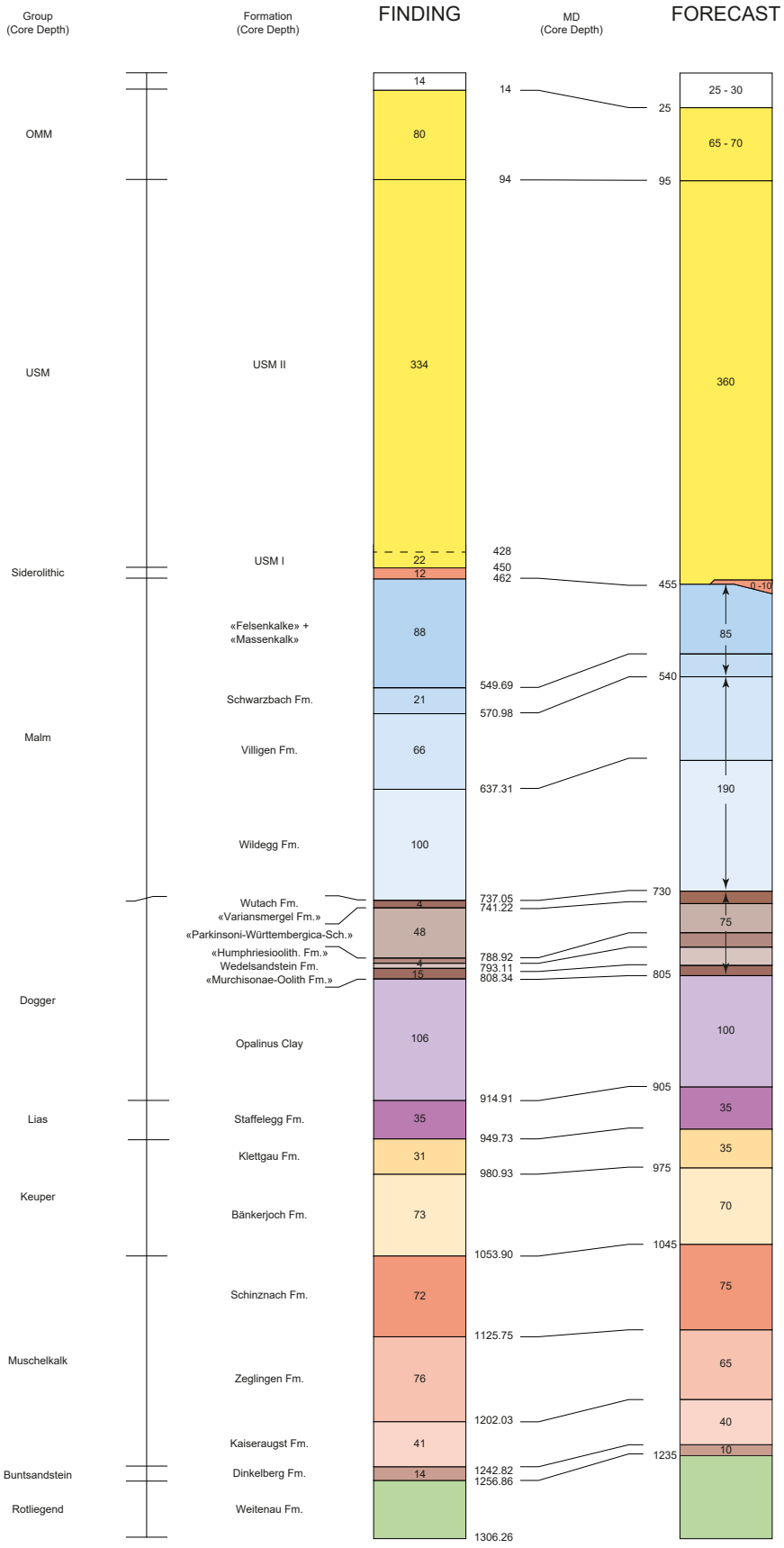


Fig. 4-1: Comparison of the forecast with the actual findings of BAC1-1

The top of the Opalinus Clay was found at almost the expected depth (808.34 m instead of 805 m). Its facies correspond to the expectations. Its thickness (106 m) is slightly greater than expected (100 m). Thus, the depth of its base deviates about 10 m from the prediction (914.91 m instead of 905 m). The thickness of the Opalinus Clay in BAC1-1 corresponds almost exactly to the value from STA2-1 (Jordan et al. 2022). It is slightly thinner than in Weiach (111 m, Matter et al. 1988).

The next deeper formations, the Staffelegg Formation (35 m, as expected), Klettgau Formation (31 m instead of 35 m) and Bänkerjoch Formation (73 m instead of 70 m), correspond to the expectations in terms of facies and total thickness. Consequently, the depth of the top of the Muschelkalk Group is, again, almost a decametre deeper than predicted (1'053.90 m instead of 1'045 m). The thicknesses of the three formations of the Muschelkalk Group in BAC1-1 almost exactly match the values in the STA2-1 borehole (36 m, 29 m, and 73 m, respectively, Jordan et al. 2022) and are slightly smaller than in the Weiach borehole (39 m, 35 m, and 74 m, respectively, Matter et al. 1988).

The thickness of the Schinznach Formation is constant over a wide area (Jordan 2016). Hence the 72 m encountered in BAC1-1 corresponds nearly to the forecast (70 m). The value is 1 m less than in the STA2-1 borehole (Jordan et al. 2022) and 2 m less than in the Weiach borehole (Matter et al. 1988).

The thickness of the Zeglingen Formation (76 m) turned out to be significantly greater than predicted (65 m). This is partly due to a rock salt deposit («Salzlager», thickness: 35 m) significantly thicker than expected. The existence of a thick rock salt deposit in the area under investigation was first uncovered in the STA3-1 borehole (40 m out of 79 m of total thickness of the Zeglingen Formation, Schürch et al. 2022) and later confirmed in the STA2-1 borehole (27.5 m out of 69 m of total thickness of the Zeglingen Formation, Jordan et al. 2022). Rock salt in the Zeglingen Formation is missing in the Weiach borehole and in the BUL1-1B borehole (Matter et al. 1988 and Jordan et al. 2021, respectively).

The thicknesses of the underlying Kaiseraugst Formation (41 m) and Dinkelberg Formation (14 m) are slightly greater than expected (40 m and 10 m, respectively) and also greater than the thicknesses in the STA2-1 borehole (39 m and 13 m, respectively, Jordan et al. 2022) and the Weiach borehole (37 m and 10 m, respectively, Matter et al. 1988).

Consequently, the base of the Mesozoic (1'256.86 m) was found about 22 m deeper than expected (1'235 m). For the Weitenau Formation, the prediction was very uncertain. The 50 m drilled consist of breccias only and thus diverge from the nearby boreholes, where the uppermost 50 m consist partly or fully of fine-grained sediments.

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