

Arbeitsbericht NAB 22-01

**TBO Stadel-3-1:
Data Report**

**Dossier III
Lithostratigraphy**

June 2022

**National Cooperative
for the Disposal of
Radioactive Waste**

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description, drill cores, cuttings

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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 report was finalised in March 2023.

This Dossier was prepared by a project team consisting of:

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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: The appendices are only included in the digital version of this report and can be found under the paper clip symbol.

1 Introduction

1.1 Context

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

In this report, we present the results from the Stadel-3-1 borehole.

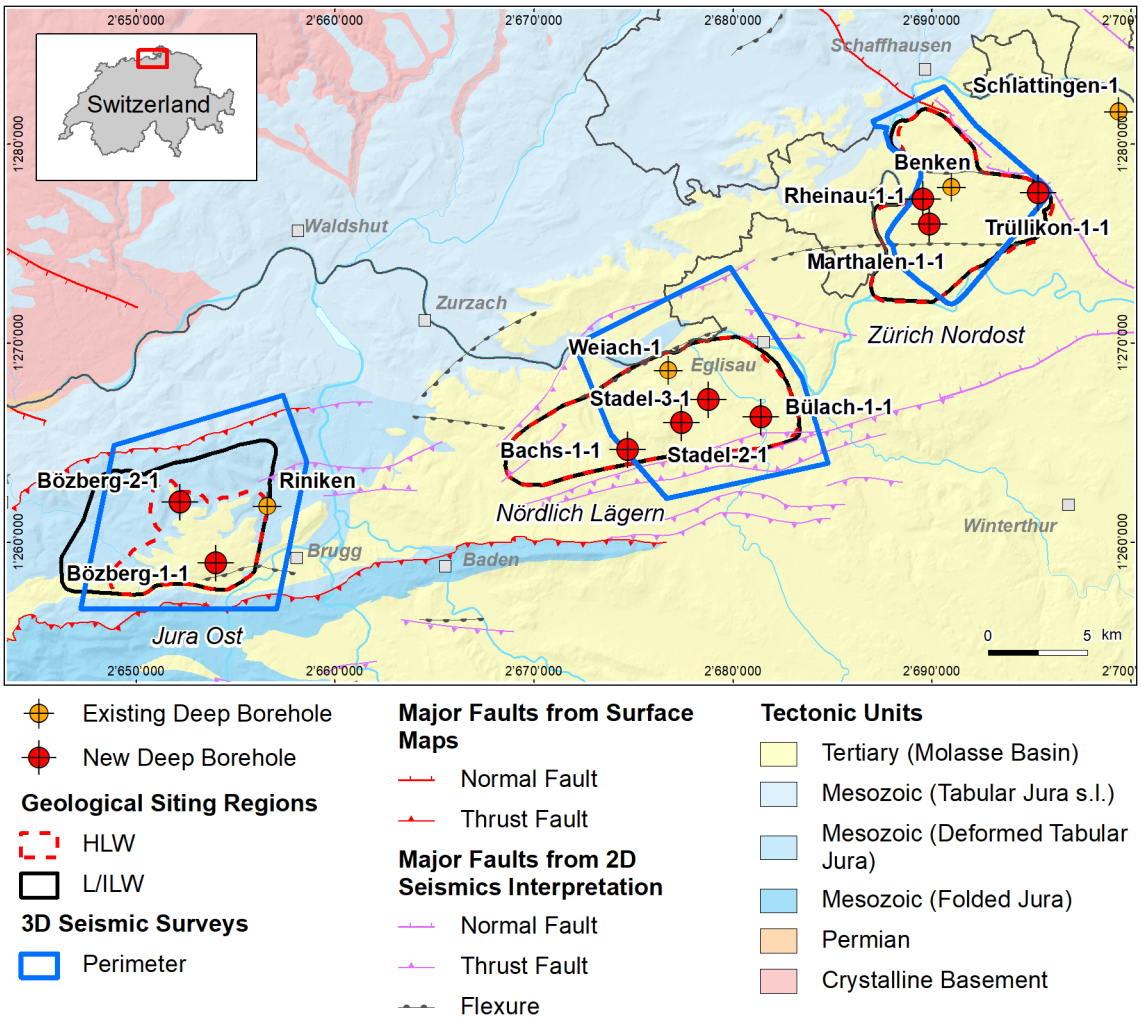


Fig. 1-1: Tectonic overview map with the three siting regions under investigation

1.2 Location and specifications of the borehole

The Stadel-3-1 (STA3-1) exploratory borehole is the sixth borehole drilled within the framework of the TBO project. The drill site is located in the central part of the Nördlich Lägern siting region (Fig. 1-2). The vertical borehole reached a final depth of 1'280.88 m (MD)¹. The borehole specifications are provided in Tab. 1-1.

Tab. 1-1: General information about the STA3-1 borehole

Siting region	Nördlich Lägern
Municipality	Stadel (Canton Zürich / ZH), Switzerland
Drill site	Stadel-3 (STA3)
Borehole	Stadel-3-1 (STA3-1)
Coordinates	LV95: 2'678'792.885 / 1'267'161.988
Elevation	Ground level = top of rig cellar: 408.74 m above sea level (asl)
Borehole depth	1'280.88 m measured depth (MD) below ground level (bgl)
Drilling period	17th December 2020 – 25th June 2021 (spud date to end of rig release)
Drilling company	PR Marriott Drilling Ltd
Drilling rig	Rig-16 Drillmec HH102
Drilling fluid	Water-based mud with various amounts of different components such as ² : 0.0 – 439.0 m: Polymers 439.0 – 640.0 ³ m: Sodium chloride & polymers 640.0 – 1'035.0 m: Potassium silicate & polymers 1'035.0 – 1'101.0 m: Polymers 1'101.0 – 1'280.9 m: Sodium chloride & polymers

The lithostratigraphic profile and the casing scheme are shown in Fig. 1-3. The comparison of the core versus log depth⁴ of the main lithostratigraphic boundaries in the STA3-1 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 Borehole uncased below casing shoe at 437.4 m after drilling fluid exchange.

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.

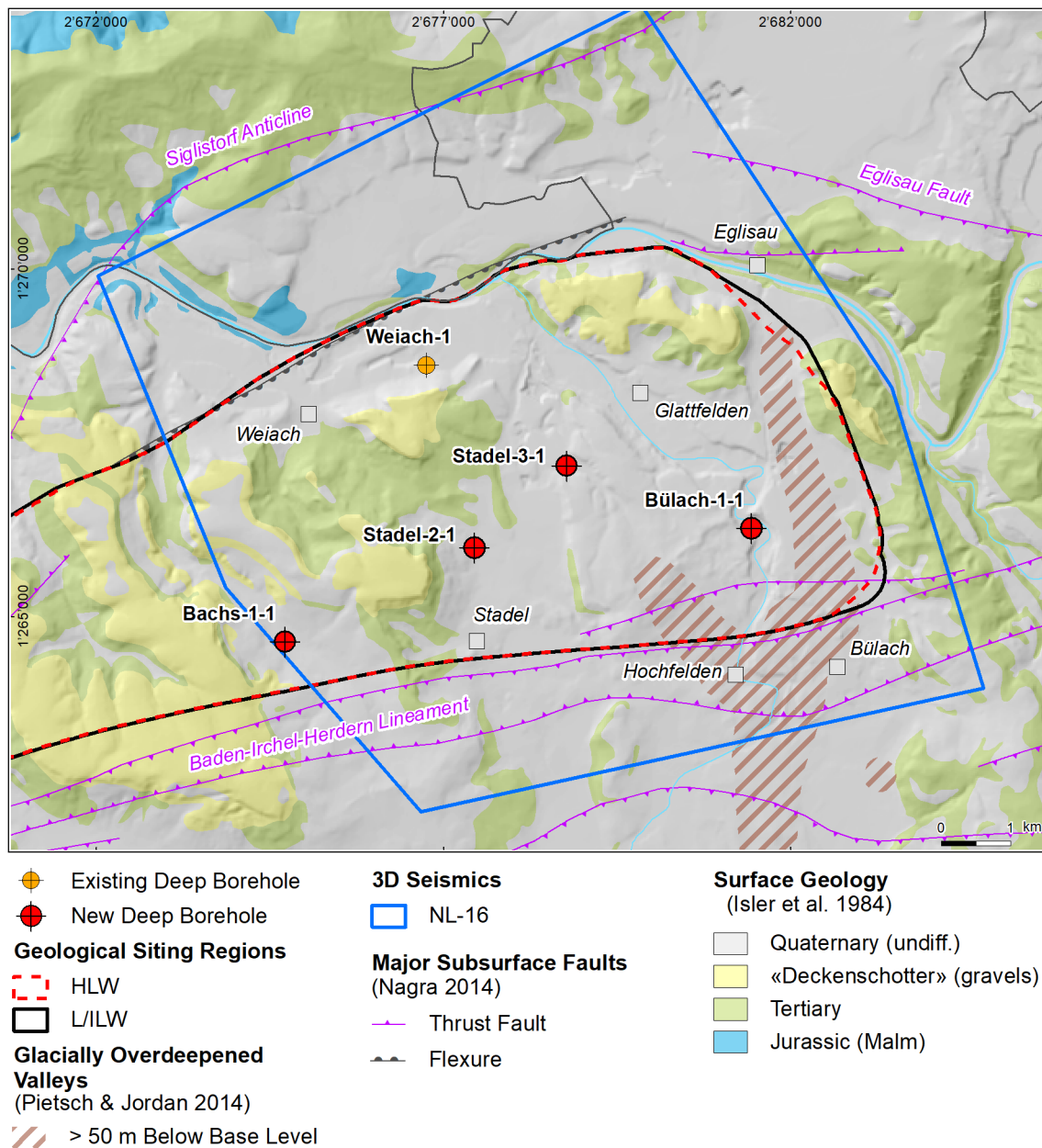
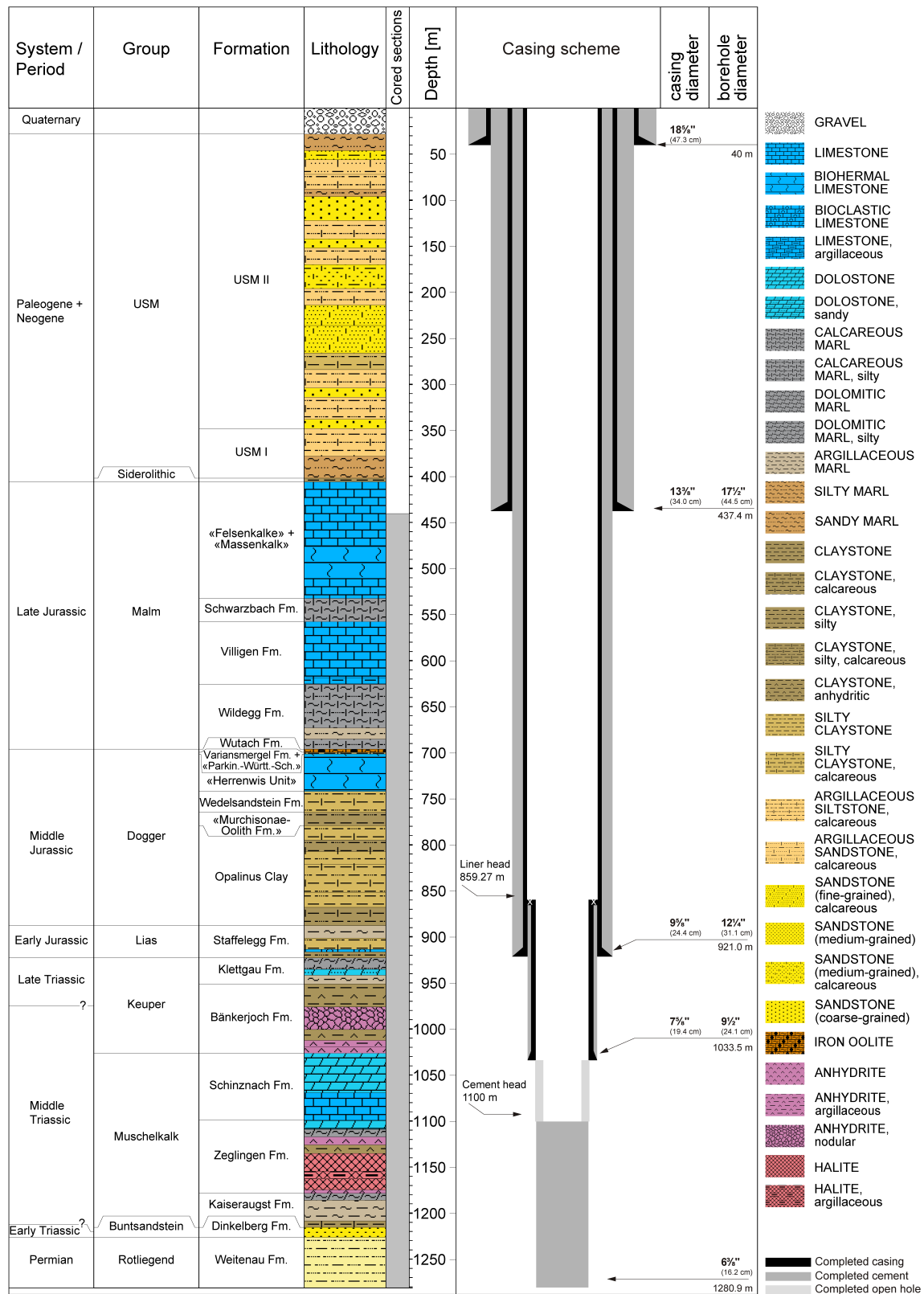


Fig. 1-2: Overview map of the investigation area in the Nördlich Lägern siting region with the location of the STA3-1 borehole in relation to the boreholes Weiach-1, BUL1-1, STA2-1 and BAC1-1

Fig. 1-3: Lithostratigraphic profile and casing scheme for the STA3-1 borehole⁵⁵ For detailed information about the casing scheme see Dossier I.

Tab. 1-2: Core and log depth for the main lithostratigraphic boundaries in the STA3-1 bore-hole⁶

System / Period	Group	Formation	Core depth in m	Log (MD)
Quaternary			28.0	—
Paleogene + Neogene	USM		402.0	—
	Siderolithic		406.0	—
Jurassic	Malm	«Felsenkalke» + «Massenkalk»		
		Schwarzbach Formation	532.55	532.65 —
		Villigen Formation	557.93	558.11 —
		Wildegg Formation	625.58	625.64 —
		Wutach Formation	696.03	696.15 —
	Dogger	Wutach Formation	699.47	699.59 —
		Variansmergel Formation + «Parkinsoni-Württembergica-Schichten»		
		«Herrenwis Unit»	701.65	701.77 —
		Wedelsandstein Formation	742.00	742.03 —
		«Murchisonae-Oolith Formation»	764.97	764.94 —
		Opalinus Clay	779.26	779.16 —
	Lias	Staffelegg Formation	887.94	887.72 —
			922.71	922.44 —
Triassic	Keuper	Klettgau Formation	951.13	951.57 —
		Bänkerjoch Formation	1026.62	1026.96 —
	Muschelkalk	Schinznach Formation	1099.03	1099.64 —
		Zeglingen Formation	1178.43	1178.73 —
		Kaiseraugst Formation	1215.50	1215.74 —
	Buntsandstein	Dinkelberg Formation	1226.38	1226.68 —
Permian	Rotliegend	Weitenau Formation	1280.88	1281.08

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 STA3-1 borehole

NAB 22-01 documents the majority of the investigations carried out in the STA3-1 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 STA3-1 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 22-01

Black indicates the dossier at hand.

Dossier	Title	Authors
I	TBO Stadel-3-1: Drilling	M. Ammen & P.-J. Palten
II	TBO Stadel-3-1: Core Photography	D. Kaehr & M. Gysi
III	TBO Stadel-3-1: Lithostratigraphy	P. Schürch, P. Jordan, M. Schwarz, H. Naef, R. Felber, T. Ibele & M. Gysi
IV	TBO Stadel-3-1: Microfacies, Bio- and Chemostratigraphic Analyses	S. Wohlwend, H.R. Bläsi, S. Feist-Burkhardt, B. Hostettler, U. Menkveld-Gfeller, V. Dietze & G. Deplazes
V	TBO Stadel-3-1: Structural Geology	A. Ebert, S. Cioldi, E. Hägerstedt & M. Gysi
VI	TBO Stadel-3-1: Wireline Logging, Microhydraulic Fracturing and Pressure-meter Testing	J. Gonus, E. Bailey, J. Desroches & R. Garrard
VII	TBO Stadel-3-1: Hydraulic Packer Testing	R. Schwarz, M. Willmann, H. Fisch, L. Schlickenrieder, M. Voß & A. Pechstein
VIII	TBO Stadel-3-1: Rock Properties, Porewater Characterisation and Natural Tracer Profiles	L. Aschwanden, L. Camesi, E. Gaucher, T. Gimmi, A. Jenni, M. Kiczka, U. Mäder, M. Mazurek, D. Rufer, H. N. Waber, P. Wersin, C. Zwahlen & D. Traber
IX	TBO Stadel-3-1: Rock-mechanical and Geomechanical Laboratory Testing	E. Crisci, L. Laloui & S. Giger
X	TBO Stadel-3-1: Petrophysical Log Analysis	S. Marnat & J.K. Becker
	TBO Stadel-3-1: Summary Plot	Nagra

1.4 Scope and objectives of this dossier

The dossier at hand (Dossier III) 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 as documented in 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; *cf.* Dossier VIII), thin sections (*cf.* Dossier IV), biostratigraphy (*cf.* Dossier IV) and borehole geophysics (*cf.* Dossier VI) 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 sections (microfacies) can be found in Dossier IV.

1.5 Petrophysical logs available at data cut-off

The logs listed below were available at data cut-off 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 micro imager (FMI)

1.6 Work undertaken

1.6.1 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 Bülach-1-1 borehole (Jordan et al. 2021b). 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 almost monthly 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 report is based on system / period, group, formation and member boundaries at the data-freeze on 26.08.2021.

All depths in the core descriptions refer to core depth. Depths in the cuttings sections 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. They were then washed, sieved, and roughly described at the drill site by the mud logger for the purpose of operational decisions. The washed and dried cuttings samples were packed in transparent plastic boxes, labelled, and delivered to Nagra's core storage facilities in Würenlingen and Döttingen. The different lithologies of a single sample were identified using a microscope and 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 quicklook 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 how much fine-grained material was lost during the sampling and sample preparation (washing and sieving) at the drill site. Molasse lithologies are often insufficiently lithified and the lost fraction is most likely part of fine-grained, clastic lithologies such as siltstone, claystone or marl. Therefore, the descriptions given in the field logs refer solely to the material in the washed samples and do not consider potentially lost lithologies. As a result, the lithologies presented for the Molasse cuttings sections could be systematically overestimated with respect to coarser-grained lithologies such as sandstone.
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 sandstone.
5. No petrophysical logs were available from 0 m to 438 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 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. 406 m).
6. From 440 m MD onwards, a full suite of petrophysical logs was available. Depths in the text and profile of this section are accurate to two significant digits and refer to measured depth (MD; e.g. 466.45 m MD).

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, orientation, 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 are 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 (e.g. from 696.03 m to 699.47 m MD core depth, Wutach Formation). In 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
- 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. 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 significant digits

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 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 limestone 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.

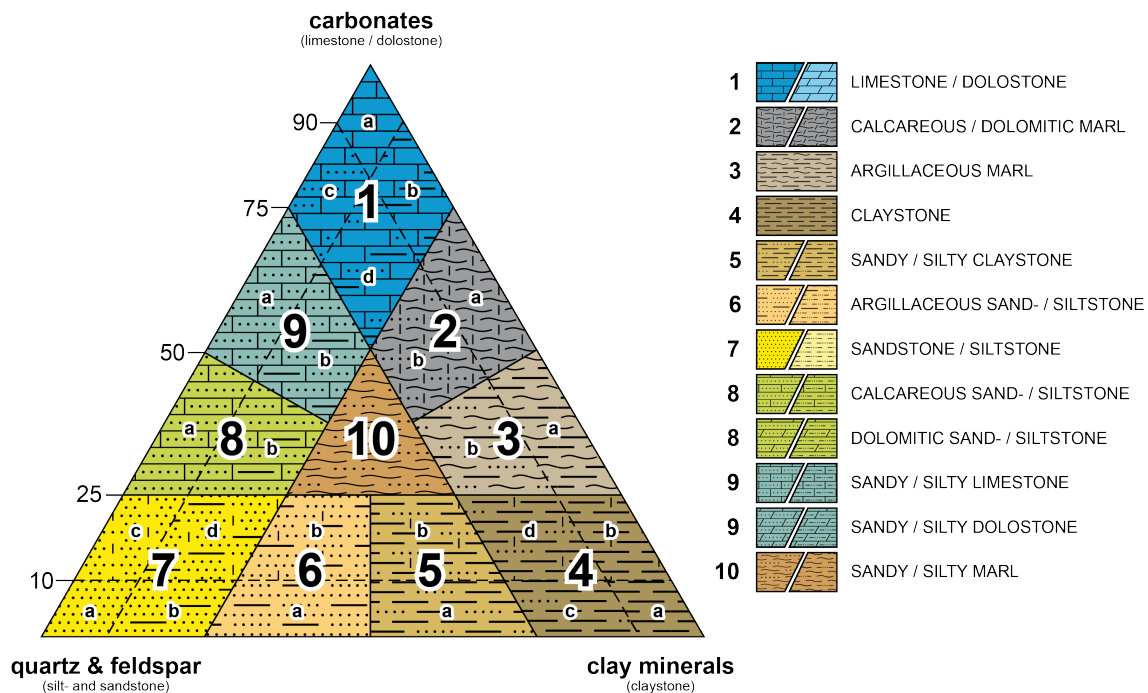
The description of **breccias and conglomerates** requires details on the matrix and components. The breccia / conglomerate pattern distinguishes between monomict and polymict rocks, while the colour represents the mineralogy of the dominant clast fraction. Since this choice could conflict with evidence 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 judgement was necessary.

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 1:100 profile, even if stylolites were diagnostic for a core section. They had to be mentioned in the text instead because stylolites are tectonic features. All symbols used are listed in Appendix D.



profile nomenclature

- 1a LIMESTONE / DOLOSTONE
- 1b LIMESTONE / DOLOSTONE, argillaceous
- 1c LIMESTONE / DOLOSTONE, sandy / silty
- 1d LIMESTONE / DOLOSTONE, sandy / silty, argillaceous
- 2a CALCAREOUS / DOLOMITIC MARL
- 2b CALCAREOUS / DOLOMITIC MARL, sandy / silty
- 3a ARGILLACEOUS MARL
- 3b ARGILLACEOUS MARL, sandy / silty
- 4a CLAYSTONE
- 4b CLAYSTONE, calcareous / dolomitic
- 4c CLAYSTONE, sandy / silty
- 4d CLAYSTONE, sandy / silty, calcareous / dolomitic
- 5a SANDY / SILTY CLAYSTONE
- 5b SANDY / SILTY CLAYSTONE, calcareous / dolomitic
- 6a ARGILLACEOUS SAND- / SILTSTONE
- 6b ARGILLACEOUS SAND- / SILTSTONE, calcareous / dolomitic
- 7a SAND- / SILTSTONE
- 7b SAND- / SILTSTONE, argillaceous
- 7c SAND- / SILTSTONE, calcareous / dolomitic
- 7d SAND- / SILTSTONE, calcareous / dolomitic, argillaceous
- 8a CALCAREOUS / DOLOMITIC SAND- / SILTSTONE
- 8b CALCAREOUS / DOLOMITIC SAND- / SILTSTONE, argillaceous
- 9a SANDY / SILTY LIMESTONE / DOLOSTONE
- 9b SANDY / SILTY LIMESTONE / DOLOSTONE, argillaceous
- 10 SANDY / SILTY MARL

report nomenclature

- 1a limestone / dolostone
- 1b limestone / dolostone (argillaceous)
- 1c limestone / dolostone (sandy / silty)
- 1d limestone / dolostone (sandy / silty, argillaceous)
- 2a calcareous / dolomitic marl
- 2b calcareous / dolomitic marl (sandy / silty)
- 3a argillaceous marl
- 3b argillaceous marl (sandy / silty)
- 4a claystone
- 4b claystone (calcareous / dolomitic)
- 4c claystone (sandy / silty)
- 4d claystone (sandy / silty, calcareous / dolomitic)
- 5a sandy / silty claystone
- 5b sandy / silty claystone (calcareous / dolomitic)
- 6a argillaceous sand- / siltstone
- 6b argillaceous sand- / siltstone (calcareous/dolomitic)
- 7a sand- / siltstone
- 7b sand- / siltstone (argillaceous)
- 7c sand- / siltstone (calcareous / dolomitic)
- 7d sand- / siltstone (calcareous / dolomitic, argillaceous)
- 8a calcareous / dolomitic sand- / siltstone
- 8b calcareous / dolomitic sand- / siltstone (argillaceous)
- 9a sandy / silty limestone / dolostone
- 9b sandy / silty limestone / dolostone (argillaceous)
- 10 sandy / silty marl

Fig. 1-4: Füchtbauer scheme for lithology names in the geological profiles and in this report
Pers. comm. S. Wohlwend modified after Naef et al. (2019)

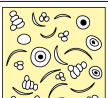
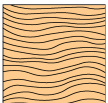
Classification of Carbonate Rocks after Folk (1959, 1962) slightly modified after Flügel (1982) and Lokier & Junaibi (2016)							
		> 10% Allochems (grains): Allochemical Rocks				< 10% Allochems	
		Sparry Allochemical rocks		Microcrystalline Allochemical rocks		Microcrystalline rocks	
		Sparite (cement) > micrite (matrix)		Micrite (matrix) > sparite (cement)		1-10% grains	<1% grains
Volumetric Allochem Compositions	> 25% Intracrasts	Intrasparite (median grains < 2mm) Intrasparrudite (median grains > 2mm)		Intramicroite (median grains < 2mm) Intramicrodite (median grains > 2mm)		Intraclast-bearing micrite (Intraclasts dominate)	
	> 25% Ooids	Oosparite (median grains < 2mm) Oosparrudite (median grains > 2mm)		Oomicroite (median grains < 2mm) Oomicrodite (median grains > 2mm)		Ooid-bearing micrite (Ooids dominate)	
	Volume ratio of Fossils to Pellets 3 : 1 – 1 : 3	Biosparite (median grains < 2mm) Biosparrudite (median grains > 2mm)		Biomicroite (median grains < 2mm) Biomicrodite (median grains > 2mm)		Bioclastic micrite (Bioclasts dominate)	
		Biopelsparite		Biopelmicroite		Peloidal micrite (Peloids dominate)	
		Pelsparite		Pelmicroite		Dismicroite (Disturbed by processes such as bioturbation, soft-sediment deformation or traction currents)	
	Volume ratio of Fossils : Oncoids 1 : 2	Oncosparite (median grains < 2mm) Oncosparrudite (median grains > 2mm)		Oncomicroite (median grains < 2mm) Oncomicrodite (median grains > 2mm)		Ooncooid-bearing micrite (Ooncooids dominate)	
							Biolithite (Undisturbed bioherm rocks such as algal, coral, sponge biolithite, ...)

Fig. 1-5: Folk classification as applied to the description of carbonate rocks in STA3-1
Pers. comm. S. Wohlwend & H.R. Bläsi

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

- "at 542.32 m: belemnites" → several belemnites found at one depth
- "at 795.29 m and at 798.60 m: belemnite" → 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

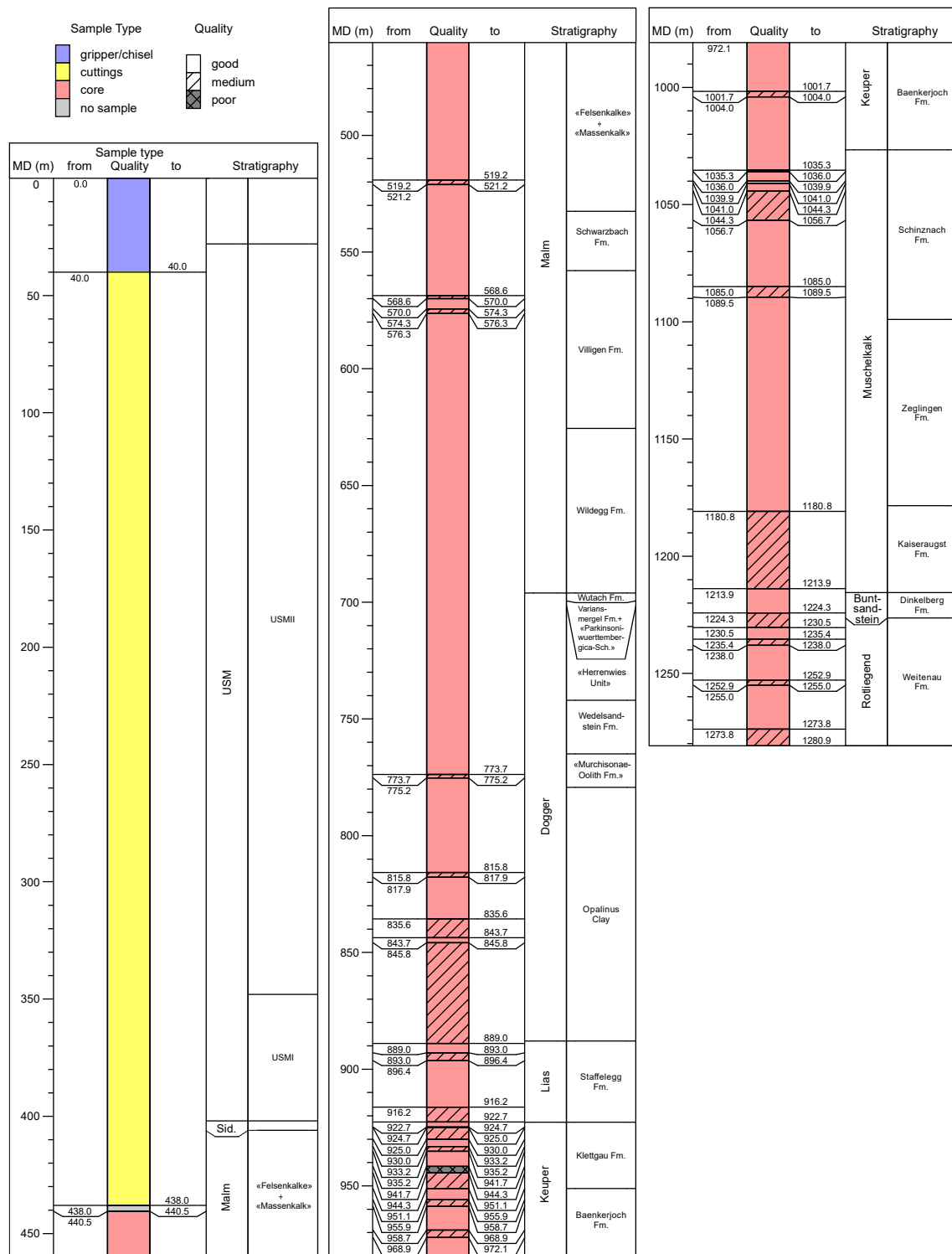


Fig. 2-1: Cuttings and core quality in STA3-1

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 – 28 m (about 28 m)

Unconsolidated rocks were only encountered in the conductor pipe excavation from 0 m to 28 m.

Lithology

0 m – 4 m	Silt (slightly to moderately clayey, slightly sandy, slightly gravelly), very well sorted, gravels subangular to well rounded, with rough to smooth and polished surfaces, gravels of alpine origin including carbonates
4 m – 28 m	Gravel (slightly to moderately clayey to silty, slightly sandy, slightly cobbly), light yellowish and pale brown, poorly to well sorted, cobbles subangular to well rounded, with rough to smooth and polished surfaces, of alpine origin including carbonates

3.2 Lower Freshwater Molasse Group II, 28 m – 348 m (about 320 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 building up variegated sequences of beige, brown, reddish and greenish colours. The sandstone is predominantly of granitic origin (white quartz, reddish feldspar and mica) and represents a period in which mainly crystalline nappes were being eroded in the alpine realm. Therefore, carbonate detritus is generally rare in the USM II. The USM II is mainly of Aquitanian age.

In STA3-1, the destructively drilled section from 28 m to 348 m consists mainly of sand- and siltstone with moderate carbonate content. Typical medium- to mostly coarse-grained granitic sandstone prevails from 66 m to 348 m, indicating that the section corresponds to the USM II down to 348 m. A prominent fine-grained and marl-rich uppermost part which would represent the «Oberaquitane Mergelzone» cannot be defined, although fine-grained and marly lithologies dominate above 96 m.

The *upper boundary* is set at 28 m with the first occurrence of cuttings from the bedrock composed of sandstone (fine- to coarse-grained, calcareous).

The *lower boundary* is set at 348 m. It corresponds to the lower boundary of the first occurrence of coarse-grained, quartz-rich sandstone. Below, sediments with slightly higher carbonate content prevail.

Lithology

Five different lithologies of variable abundance were identified in the section from 28 m to 348 m. All lithologies are micaceous and also pyritic below 242 m.

- sandstone (coarse-grained, about half of it calcareous), angular to subrounded quartz, micaceous, moderately sorted, poorly cemented with calcite. The colour varies between light grey, medium grey, beige and reddish-brown.
- sandstone (fine- to medium-grained, often calcareous, occasionally argillaceous), usually moderately cemented, occasionally poorly or well-cemented with calcite. Fine-grained mica is present throughout, pyrite is present between 182 m and 184 m and below 242 m. The colour varies between light grey, medium grey, beige and occasionally reddish- or ochre-brown.
- argillaceous siltstone to siltstone (argillaceous, calcareous), light grey, beige, ochre-brown, reddish-brown, micaceous
- argillaceous and sandy to silty marl, light grey to variations of brown
- silty claystone (calcareous), beige, ochre brown, reddish orange, occasionally light greenish grey and grey violet, micaceous

3.3 Lower Freshwater Molasse Group I, 348 m – 402 m (about 54 m)

The older formations / members of the Lower Freshwater Molasse (USM I) are found and described mainly in subalpine outcrops and deep boreholes within the Molasse Basin, where they reach a thickness of up to 2 km. Towards the external part of the basin in Northern Switzerland, the basal USM becomes constantly younger, its thickness decreases and it occasionally pinches out in the subcrop.

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, the USM I is also called "Karbonatreiche Molasse". Sandstone is partly present as litharenite with carbonate grains ("Kalksandstein") that reflect the erosion of sedimentary units in the source area. The USM I is roughly of Chattian age.

In STA3-1, the section from 348 m to 402 m is dominated by fine-grained and marl-rich lithologies, while granitic sandstone is absent. Therefore, this lowermost section of Molasse sediments can be correlated with the USM I.

The *upper boundary* is set at 348 m. It corresponds to the lower boundary of the last occurrence of coarse-grained, quartz-rich sandstone. Below, sediments with slightly higher carbonate content prevail.

The *lower boundary* is set at 402 m below a sequence dominated by sandstone (fine- to medium-grained), micaceous and pyritic, overlying a claystone interval.

Lithology

In the section from 348 m to 402 m, four different lithologies of variable abundance were identified. According to their share in decreasing order of abundance:

- sandy to silty marl, beige to ochre-brown, reddish-brown, occasionally grey-violet, micaceous
- argillaceous siltstone (calcareous), light grey, beige, ochre-brown, micaceous
- sandstone (fine- to medium-grained, calcareous), light grey, quartz (angular to subrounded), poorly to moderately sorted, micaceous and pyritic, poorly to moderately cemented (calcite)
- silty claystone (slightly calcareous), beige to ochre-brown, micaceous

3.4 Siderolithic Group, 402 m – 406 m (about 4 m)

Usually, the argument for the delineation of the Siderolithic Group is the presence of non-calcareous claystone, ochre-brown («Boluston»), and of iron-pisoids («Bohnerz»). In STA3-1, iron-pisoids were also found within the top two metres (from 406 m to 408 m) of the Malm Group, possibly due to caving or as karst fillings. The distinct GR signature between 402 m and 406 m, typical for claystone and cuttings samples dominated by claystone in the same interval justified the base of the Siderolithic Group at 406 m.

The *upper boundary* is set at 402 m below a sequence dominated by sandstone (fine- to medium-grained), micaceous and pyritic, overlying a claystone interval.

The *lower boundary* is set at 406 m with the first occurrence of marine limestone (mudstone, micrite) in the cuttings samples and distinct GR log signature. Iron-pisoids, typical for the overlying Siderolithic Group, are also found in the uppermost cuttings sample (from 406 m to 408 m), possibly due to caving or as karst fillings.

Lithology

The Siderolithic Group consists of claystone, dark beige and light ochre-brown.

3.5 Malm Group

3.5.1 «Felsenkalke» + «Massenkalk», 406 m – 532.55 m (about 127 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 supported by Nagra (e.g. Benken, Nagra 2001a, 2001b, or Schlattingen-1, Albert et al. 2012). The «Felsenkalke» represent the mostly well-bedded and sponge-free facies between the bioherms. 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. Thus, the two informal units can also be understood as two facies units replacing each other laterally and vertically.

In STA3-1, the «Felsenkalke» + «Massenkalk» were drilled destructively from 406.0 m to 438.0 m and cored from 440.50 m to 532.55 m. The cuttings section and the upper part of the cored section (down to 457.73 m) are characterised by limestone (mudstone, micrite), locally with pellets and bivalves but virtually no sponges. The middle part (from 457.73 m to 511.57 m) is dominated by sponge bioherms. The lower section (from 511.57 m to 532.55 m) is formed by thick- to medium-bedded limestone (mostly wackestone, pelmicrite and biomicrite), occasionally argillaceous and interbedded with calcareous marl. The section is mostly fossiliferous (crinoids, belemnites). The glauconitic and fossiliferous marly interval from 516.62 m to 520.80 m may be addressed as the informal «Glaukonitbank».

The *upper boundary* is set at 406 m with the first occurrence of marine limestone (mudstone, micrite) in the cuttings samples and distinct GR log signature. Iron-pisoids, typical for the overlying Siderolithic Group, are also found in the uppermost cuttings sample (from 406 m to 408 m), possibly due to caving or as karst fillings.

The *lower boundary* is set at 532.55 m at the top of a thin-bedded nodular alternation of limestone (argillaceous) and calcareous marl, both rich in glauconite, peloids and fossils (including sponges). This alternation is overlain by medium-bedded fossiliferous to bioclastic limestone with sponges and peloids. The transition to a more marl-dominated interval is also supported by a GR-based correlation with BUL1-1 (Jordan et al. 2021a).

Lithology (cuttings section)

406 m – 438 m	Limestone (mudstone, micrite), beige, white, greyish-pink, scattered traces of pyrite From 406 m to 408 m, very few iron-pisoids and down to 418 m abundant caving material from overlying strata From 418 m to the base of the cuttings section (438 m), an increasing but subordinate share of limestone (saccharoidal). Fragments of idiomorphic calcite crystals were identified between 420 m and 426 m
438 m – 440.50 m	Neither cores nor cuttings collected

Lithology (cored section)

440.50 m – 457.73 m	This is a thick-bedded to massive succession of mainly limestone (mudstone, micrite), dark beige, beige, white and subordinate limestone (saccharoidal), beige to white Near the top (at 441.20 m), a layer of breccia, calcareous (monomict), light beige. The upper part down to 446.88 m bioturbated. Peloids were found in most layers between 443.42 m and 453.63 m, pyrite was found down to 441.63 m and towards the base below 455.25 m Single bivalves occur between 448.13 m and 450.34 m and also below 456.96 m Karstic fissures filled with claystone, greyish-green and vugs, partly open, partly filled were documented throughout the section
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	From 453.63 m to 454.44 m, limestone (silty, argillaceous), dark beige to beige-grey with an interlayer of breccia, calcareous (polymict), matrix of argillaceous marl, greenish-grey (from 454.25 m to 454.35 m)
457.73 m – 463.30 m	Biohermal limestone (saccharoidal) and limestone (saccharoidal and wackestone, biomicrite), beige to white, pyritic below 459.75 m, biohermal to fossiliferous down to 460.30 m and from 461.08 m to 461.50 m with sponges, bivalves, brachiopods, elsewhere few disperse fossils (bivalves, brachiopods). The complete interval is thick-bedded to massive with stylolites
463.30 m – 466.45 m	Limestone (mudstone, micrite, locally saccharoidal), breccia-like texture due to abundant stylolites, single chert nodules. A few joints filled with argillaceous marl, greenish-grey and karstic vugs filled with sand-sized limestone debris in claystone matrix, light greenish-grey, were also found
466.45 m – 475.00 m	Limestone (mudstone, micrite), beige, locally grading into limestone (saccharoidal), white. Fossils include scattered sponges and bivalves. A few karstic fissures and vugs are filled with claystone, light grey to light greenish-grey, some pyrite From 467.10 m to 467.30 m, breccia, calcareous (monomict), dark beige
475.00 m – 493.90 m	Biohermal limestone (saccharoidal) and biohermal limestone (wackestone and packstone, biomicrite), beige to white and light grey, with black, pyritic crystals, abundant sponges. The rock is dissected by a fine mesh of calcite-filled veins (mainly a few mm wide). Thicker veins (10 mm and more) are locally filled with argillaceous marl, light greenish-grey. Throughout the interval, vugs of all kinds (karstic, recrystallised fossils [mostly sponges]) were found with an increased abundance from 484.18 m to 484.80 m. One larger karst cavity is situated between 479.22 m and 479.31 m Between 475.80 m and 481.50 m, three interlayers of limestone (wackestone and packstone, biomicrite), light grey to beige, fossiliferous (sponges) but less than in biohermal limestone From 491.57 m to 493.90 m, three interlayers of breccia, calcareous (monomict), beige and medium grey, the lowermost section initially made up of biohermal bioclasts
493.90 m – 504.63 m	Alternation of: • biohermal limestone (mostly saccharoidal), beige and white, pyritic, abundant sponges • bioclastic limestone (packstone, biomicrite), beige to white and medium grey, pyritic, peloids, fossiliferous (sponges, bivalves, bioclasts) • limestone (wackestone and packstone, biomicrite), light grey and pink, pyritic, frequent sponges

All lithologies are dissected by a fine mesh of veins (maximum a few mm in width) filled with calcite

Special features are a sponge bioherm with borings and various infills between sponges (from 499.50 m to 500.70 m), two layers of breccia, calcareous (monomict) between 496.40 m and 497.10 m and occasional fissures filled with argillaceous marl, light greenish-grey. Below 502.39 m some large (maximum 2 cm) vugs partly filled with calcite were found

504.63 m – 511.57 m	Biohermal limestone (mostly saccharoidal), light grey to beige and white, pyritic, fossiliferous (sponges down to 510.79 m), dissected by a fine mesh of calcite veins (maximum a few mm in width). Locally, a variation to limestone (mudstone, biomicrite), beige, pyritic and sparsely fossiliferous (sponges, bioclasts) was observed. Some intervals contain vugs and some are strongly recrystallised. Some vugs are coated with calcite crystals From 506.50 m to 507.22 m, few fissures (> 1 cm) filled with argillaceous marl, light greenish-grey From 508.58 m to 508.60 m, thin layer of argillaceous marl, light greenish-grey
511.57 m – 513.51 m	Limestone (mudstone, biomicrite), beige, pyritic and crinoids down to 512.61 m, bioclastic below 512.62 m, with some cm-thick layers of argillaceous marl, light greenish-grey. A belemnite (at 512.33 m) and an ammonite (at 513.15 m) were found
513.51 m – 516.62 m	Limestone (wackestone, biomicrite), dark beige, partly pyritic, sparsely to moderately fossiliferous (bivalves, sponges, bioclasts, belemnite [at 514.17 m]) is interrupted by some cm-thick layers of argillaceous marl, light greenish-grey From 515.72 m to 515.74 m, layer of argillaceous marl, dark grey, with small lithoclasts of limestone(micrite), beige At the base (from 516.52 m to 516.62 m), small, black sponge nodules
516.62 m – 520.80 m	Alternation of: • bioclastic limestone (wackestone and packstone, pelmicrite and biomicrite), beige to dark beige, peloids, pyritic, very fossiliferous (sponges, bioclasts, echinoderm at 518.12 m) • limestone (wackestone, pelmicrite), peloids, glauconitic below 520.24 m, pyritic, moderately fossiliferous (sponges down to 520.12 m). The microsparitic texture of the thin section STA3-1-520.56 documents a dedolomitisation Subordinately some bioclastic calcareous marl and calcareous marl (silty), pyritic, partly bioclastic occurs. Both lithologies are glauconitic Above an erosional surface (at 518.65 m) within the calcareous marl some limestone lithoclasts were found

	The base of the section (from 520.70 m) is formed by a breccia, calcareous (polymict) as limestone clasts in a matrix of calcareous marl as above
520.80 m – 526.60 m	Limestone (wackestone, pelmicrite and biomicrite), beige-grey, peloids, pyritic below 524.21 m, moderately fossiliferous (sponges, echinoderms down to 522.21 m and below 522.90 m, bioclasts and few single belemnites) From 524.60 m to 524.70 m, interbed of limestone (argillaceous) as above From 524.21 m to the base (526.60 m), one thick (25 cm) and several thin (< 10 cm) interbeds of calcareous marl to limestone (argillaceous). The lowermost bed is silty, dark grey, pyritic and glauconitic
526.60 m – 528.57 m	Alternation of mainly calcareous marl, beige grey with peloids, glauconitic, and nodular interbeds (maximum 33 cm) of limestone (argillaceous) (mudstone and wackestone, pelmicrite), peloids, glauconitic. Both lithologies are fossiliferous with echinoderms, bioclasts, sponges and few belemnites From 528.15 m to 528.43 m, argillaceous marl, medium grey to dark grey, bioturbated
528.57 m – 530.59 m	Limestone (argillaceous) (mudstone and wackestone, pelmicrite and biomicrite), beige and dark grey, peloids, partly glauconitic, bioclastic. Two belemnites were found at 528.85 m and at 529.81 m From 530.39 m to the base (530.59 m), calcareous marl, beige and dark grey, peloids, glauconitic, fossiliferous (echinoderms, bioclastic)
530.59 m – 532.55 m	Bioclastic limestone (wackestone and packstone, biopelmicrite), beige and dark grey, peloids, very fossiliferous (sponges, bioclasts). A belemnite (at 530.64 m) and an ammonite (at 530.66 m) were found From 531.89 m to 532.00 m, bioclastic calcareous marl, dark grey, peloids, as fossiliferous as bioclastic limestone

3.5.2 Schwarzbach Formation 532.55 m – 557.93 m (25.38 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, making a demarcation difficult. In STA3-1, the Schwarzbach Formation is consistently glauconitic and very fossiliferous (ammonites, belemnites, bivalves, crinoids, echinoids and, occasionally, sponges).

The *upper boundary* is set at 532.55 m at the top of a thin-bedded nodular alternation of limestone (argillaceous) and calcareous marl, both rich in glauconite, peloids and fossils (including sponges). This alternation is overlain by medium-bedded fossiliferous to bioclastic limestone with sponges and peloids. The transition to a marl-dominated interval is also supported by a GR-based correlation with BUL1-1 (Jordan et al. 2021a).

The *lower boundary* is set at 557.93 m at an erosional surface at the base of a succession of thin calcareous marl beds (alternating with thin limestone [argillaceous] beds) showing a downward increase in clay minerals content (well visible in the FMI).

Lithology

532.55 m – 534.68 m	Nodular, thin-bedded limestone (argillaceous) (mudstone and wackestone, biopelmicrite and biomicrite), dark beige. It contains peloids, glauconite and fossils (sponges, foraminifera [thin section STA3-1-532.80], bivalves, the lowermost bed with echinoderms) Four nodular interbeds (max. 25 cm) of calcareous marl, dark grey, interrupt the above main lithology. These beds contain limestone nodules (argillaceous), medium grey, with peloids, glauconite and fossils (sponges, the upper three beds also with bioclasts)
534.68 m – 536.82 m	Calcareous marl, dark grey, glauconitic, pyritic, bioturbated From the top (534.68 m) to 534.83 m and from 536.27 m to the base (536.82 m), two beds of argillaceous marl, dark grey, glauconitic and pyritic, sparsely fossiliferous with crinoids in the upper interval and a belemnite at 536.81 m, bioturbated. The lower interval is divided by a thin bed of calcareous marl
536.82 m – 537.94 m	Limestone (argillaceous) (mudstone, locally wackestone, pelmicrite), beige-grey with peloids and scattered fossils (sponges, bioclasts). It is bioturbated from 536.97 m to the base (537.94 m) From the top (536.82 m) to 536.97 m and from 537.33 m to 537.44 m, two interbeds of calcareous marl, dark grey, glauconitic
537.94 m – 540.09 m	Thin-bedded alternation of argillaceous marl and calcareous marl. Both lithologies are dark grey, glauconitic and pyritic, moderately fossiliferous (sponges), bioturbated from 539.66 m to the base (540.09 m). A belemnite (at 538.16 m) and an ammonite (at 539.14 m) were found
540.09 m – 542.82 m	Bioclastic calcareous marl, mainly dark grey, less often medium grey, peloids, glauconitic, fossiliferous (bioclastic, echinoderms near the top, bivalves, scattered belemnites), intensely bioturbated From 540.29 m to 540.70 m, nodular interbed of limestone (argillaceous) (mudstone and wackestone, biomicrite), medium light grey, peloids, glauconitic, bioclastic, bioturbated Two interbeds of argillaceous marl, dark grey, with peloids and glauconite, bioclastic, from 541.34 m to 541.46 m and from 542.20 m to 542.36 m
542.82 m – 549.16 m	Thin-bedded alternation (with abundant firmgrounds) of calcareous marl and bioclastic calcareous marl, dark grey, with peloids and glauconite. Both lithologies are bioturbated. The main lithology is frequently interrupted by nodular interbeds of limestone (argillaceous) (mudstone and wackestone, biomicrite), medium light grey,

	with peloids and glauconite, bioturbated. The section is fossiliferous with sponges, crinoids, bivalves (548.10 m), belemnites (543.40 m and 545.63 m) and single ammonites between 544.77 m and 547.05 m
549.16 m – 551.51 m	Section with a thin-bedded alternation of mainly limestone (argillaceous) (mudstone and wackestone, micrite and biomicrite), beige-grey, and calcareous marl to bioclastic calcareous marl, dark grey, bioturbated. Both lithologies are mostly glauconitic and pyritic, at 550.48 m a single pyrite nodule was found. Crinoids and bioclasts were found down to 549.97 m, belemnites between 549.02 m and 549.38 m and a single bivalve at 549.57 m
551.51 m – 557.00 m	Section with two massive beds of argillaceous marl, dark grey to black, pyritic at the top and at the base, ending in an erosional boundary From 552.20 m to 555.93 m, thin- to medium-bedded alternation of limestone (argillaceous) (mudstone and wackestone, biomicrite), beige-grey, and calcareous marl, dark grey, glauconitic. Both lithologies are pyritic and bioturbated Macrofossils include belemnites, crinoids and sponges. A few peloids were found between 554.56 m and 554.76 m
557.00 m – 557.93 m	Thin-bedded alternation of calcareous marl, dark grey, and limestone (argillaceous) (mudstone and wackestone, biomicrite), beige-grey, bioturbated. Both lithologies are glauconitic and pyritic. Macrofossils include sponges, crinoids and a single belemnite at 557.50 m. Near the erosional base some lithoclasts were found

3.5.3 Villigen Formation 557.93 m – 625.58 m (67.65 m)

The 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 deeper marine environment characterised by the abundance of sponges. The Stadel – Bülach area is part of a transitional domain delimited by the rivers Rhine and Töss (Rhine – Töss-Line; Jordan & Deplazes 2019). At present, a conclusive subdivision of the section found in STA3-1 following one of the two subdivisions of Jordan & Deplazes (2019) is not possible.

Only the basal 6.91 m can be clearly assigned to the Hornbuck Member of the north-eastern realm (see below). The overlying ca. 60 m are characterised by a mostly medium-bedded, occasionally thin-bedded and, from 568.82 m to 578.97 m and from 585.12 m to 592.34 m, thick-bedded alternation of limestone (mostly mudstone, micrite) with mostly thin intervals of calcareous and, rarely, argillaceous marl. The succession is quite fossiliferous (mainly crinoids and bioclasts, occasionally belemnites and ammonites).

The *upper boundary* is set at 557.93 m at an erosional surface at the base of a succession of thin calcareous marl beds (alternating with thin limestone [argillaceous] beds) showing a downward increase in clay mineral content (well visible in the FMI).

The *lower boundary* is set at 625.58 m at a firmground at the top of a bed of limestone (argillaceous) without sponges (in contrast to the hanging succession characterised by abundant sponges). Below this ca. 45 cm thick bed, the typical calcareous (locally argillaceous) marl (silty) of the Effingen Member is found. Therefore, the boundary coincides with the change in colour from brighter grey and beige (above) to dark grey.

Lithology (of the section not assigned to a member)

557.93 m – 559.48 m	Calcareous marl with a bed (28 cm) of bioclastic calcareous marl at the base, both lithologies medium light grey, glauconitic and pyritic, moderately to very fossiliferous (crinoids, bioclasts) From the top (557.93 m) to 558.10 m, limestone (argillaceous) (mudstone, micrite), beige grey, glauconitic and pyritic, bioturbated
559.48 m – 578.97 m	Limestone (mudstone, micrite), medium light grey and beige-grey, glauconitic towards the base, bioturbated throughout, medium- to thick-bedded The main lithology is interrupted by thin (maximum 10 cm) interlayers of: • bioclastic calcareous marl, dark grey and beige-grey, locally glauconitic • calcareous marl, dark grey and beige-grey, locally glauconitic. This lithology often contains sand-sized carbonate components and silt • argillaceous marl, dark grey, locally glauconitic Two interbeds (between 564.44 m and 565.01 m) differ slightly from the main lithology as described above. They consist of limestone (wackestone, pelmicrite), beige-grey, with peloids, sponges and echinoderms The section contains several erosional surfaces with fissures and burrows filled with material from the overlying lithology, often marl. Additionally, single vugs and a pyrite nodule were found. Macrofossils found in the section include several belemnites, several beds with abundant crinoids and sponges
578.97 m – 585.12 m	This inhomogeneous section consists mainly of limestone (argillaceous) (mudstone, micrite), medium grey to beige-grey with patches of dark grey, sparsely glauconitic down to 583.01 m, crinoids below 583.01 m, intensely bioturbated. A few interbeds interrupt the main lithology: • three beds of calcareous marl, dark grey, bioturbated, the bed from 582.89 m to 583.01 m with lithoclasts above erosional base, the lowermost bed with crinoids • single bed of argillaceous marl, dark grey, crinoids

585.12 m – 592.45 m	This monotonous section consists mainly of limestone (mudstone, micrite), beige-grey with patches of dark grey, intensely bioturbated, medium-bedded, with thin (a few cm thick) interbeds of calcareous marl to argillaceous marl, dark grey. Crinoids occur in all lithologies but are more abundant below 588.66 m
592.45 m – 612.03 m	Beneath follows an alternation of mainly two lithologies: • limestone (mudstone, micrite), medium light grey and beige-grey, partly pyritic, moderately to intensely bioturbated, medium-bedded, as dominant lithology • calcareous marl, medium grey to dark grey, occasionally with crinoids, as usually thin (< 10 cm) interbeds. Some are flaser-bedded Towards the base, one thick (27 cm) and a few thin interbeds of argillaceous marl (partly silty), dark grey, interrupt this uniform section At 594.35 m and at 611.95 m, aggregates of pyrite nodules were found
612.03 m – 613.96 m	This heterogeneous succession consists of: From the top (612.03 m) to 612.60 m, argillaceous marl (silty), medium grey, top and base show inclined tectonic boundaries. An open vug was found at 612.11 m From 612.60 m to 613.05 m, limestone (mudstone, micrite), medium light grey and beige-grey, pyritic, intensely bioturbated From 613.05 m to 613.41 m and from 613.61 m to the base (613.96 m), calcareous marl (silty), dark beige, pyritic and glauconitic. In between a thin bed of limestone (silty, argillaceous) (mudstone, micrite), beige-grey, pyritic and glauconitic with a belemnite at 613.10 m
613.96 m – 616.19 m	Limestone (mudstone, micrite), beige-grey and medium light grey, bioturbated. This main lithology is interrupted by a bed of calcareous marl (silty), dark beige, glauconitic, bioturbated (from 614.95 m to 615.09 m)
616.19 m – 618.67 m	Limestone (silty, argillaceous) (mudstone, micrite), dark beige and medium grey, bioturbated. Some sponges were found near the top From 618.41 m to the base (618.67 m), sandy marl, dark beige and medium grey. The hardground at the base shows fissures and burrows and is covered with dark grey sponge remains and a few chert nodules

3.5.3.1 Hornbuck Member 618.67 m – 625.58 m (6.91 m)

In STA3-1, the Hornbuck Member consists of a fossiliferous (crinoids, sponges) and mostly thin- to medium-bedded alternation of limestone (occasionally silty) and calcareous (rarely argillaceous) marl.

The *upper boundary* is set at 618.67 m at a hardground at the top of a 1.2 m thick bed (the only m-thick bed in the member) of limestone (wackestone, biomicrite).

The *lower boundary* is set at 625.58 m at a firmground at the top of a bed of limestone (argillaceous) without sponges (in contrast to the hanging succession characterised by abundant sponges). Below this ca. 45 cm thick bed, the typical calcareous (locally argillaceous) marl (silty) of the Effingen Member is found. Therefore, the boundary coincides with the change in colour from brighter grey and beige (above) to dark grey.

Lithology

618.67 m – 625.58 m	Limestone (partly silty and argillaceous) and calcareous marl (silty). In the lower part (from 623.07 m to 623.27 m) and near the base, there are also two layers of argillaceous marl (silty). The section is fossiliferous throughout with sponges, occasional peloids and crinoids within the limestone and belemnites within the calcareous marl The limestone is either wackestone / biomicrite or mudstone / micrite. All lithotypes are pyritic below 623.07 m. At 622.38 m a belemnite and at 624.56 m a chert nodule were found. At 624.80 m a large vug or druse was found. At the base, a firmground is covered with dark grey sponge remains
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3.5.4 Wildegg Formation, 625.58 m – 696.03 m (70.45 m)

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

The *upper boundary* is set at 625.58 m at a firmground at the top of a bed of limestone (argillaceous) without sponges (in contrast to the hanging succession characterised by abundant sponges). Below this ca. 45 cm thick bed, the typical calcareous (locally argillaceous) marl (silty) of the Effingen Member is found. Therefore, the boundary coincides with the change in colour from brighter grey and beige (above) to dark grey.

The *lower boundary* is set at 696.03 m at an erosional surface which separates an overlying bioclastic argillaceous marl with abundant glauconite from a fossiliferous limestone and marl (both iron-oolitic).

3.5.4.1 Effingen Member, 625.58 m – 695.71 m (70.13 m)

The Effingen Member is predominantly a succession of calcareous (and subordinately argillaceous) marl. It is repeatedly interbedded with micritic limestone (mostly argillaceous) beds. The most prominent of these limestone successions is the Gerstenhübel Bed (Gygi 2000). In STA3-1 the latter or at least its most calcareous part can be localised from 649.07 m to 653.42 m. A poor fossil content, a continuous occurrence of silt- to sand-sized quartz as well as a repeated occurrence of pyrite are characteristic for most of the unit (Deplazes et al. 2013).

The *upper boundary* is set at 625.58 m at a firmground at the top of a bed of limestone (argillaceous) without sponges (in contrast to the hanging succession characterised by abundant sponges). Below this ca. 45 cm thick bed, the typical calcareous (locally argillaceous) marl (silty) of the Effingen Member is found. Therefore, the boundary coincides with the change in colour from brighter grey and beige (above) to dark grey.

The *lower boundary* is set at 695.71 m at the transition from the typical medium to dark grey calcareous marl (silty and glauconitic) of the Effingen Member to the dark grey silty marl (glauconitic) with encrusted clasts of the Birmenstorf Member and «Glaukonitsandmergel Bed».

Lithology

625.58 m – 641.67 m	This section is dominated by a medium to dark grey calcareous marl (mostly silty). Some larger intervals are argillaceous marl (silty), dark grey (from 631.70 m to 634.49 m, and from 640.36 m to 641.67 m). Both lithologies are bioturbated, micaceous and pyritic. Scattered pyrite nodules were also found. Down to 631.70 m glauconite is abundant. Below 631.70 m many burrows were found From the top (625.58 m) to 631.70 m, the main lithology is interrupted by interbeds (maximum 45 cm thick) of limestone (silty, argillaceous), medium light grey From 631.70 m to 634.49 m, the main lithology is interrupted by some thin (< 10 cm) layers of limestone (sandy), calcareous marl (silty) and two thin (maximum 3 cm) beds of calcareous sandstone. The upper bed of calcareous sandstone is pyritic Between 638.26 m and 640.36 m, the main lithology is interrupted by three thin (maximum 4 cm) beds of calcareous sandstone (fine-grained), glauconitic, sparsely pyritic
641.67 m – 649.07 m	Calcareous marl (silty in the upper half), medium grey, and interrupted by beds (maximum 47 cm thick) of limestone (argillaceous) (mudstone, micrite), medium light grey Near the top, the calcareous marl is pyritic and shows burrows. In the lower half, occasional crinoids were found. Most layers are bioturbated. The limestone is slightly bioclastic
649.07 m – 653.42 m	Limestone (partly argillaceous) (mudstone, micrite), medium light grey, a few crinoids, bioturbated. The main lithology is interrupted by several interbeds (maximum 32 cm thick) of calcareous marl, medium grey with black pyritic peloids (thin section STA3-1-652.83), echinoderms and crinoids in the lower interbeds, mostly bioturbated

653.42 m – 656.88 m	Calcareous marl (silty), medium grey, with pyrite aggregates and pyritised burrows, micaceous in the middle part, sparsely bioclastic Three interbeds interrupt this main lithology. They consist of limestone (argillaceous) (mudstone, micrite), medium light grey, sparsely bioclastic, bioturbated. The layers are partly nodular
656.88 m – 660.36 m	Argillaceous marl (silty) in transition to calcareous marl (silty), medium grey to dark grey, with pyrite aggregates and pyritised burrows. The section is sparsely bioclastic and bioturbated throughout. Some thin (maximum 7 cm) layers of calcareous marl, medium light grey, pyritic, interrupt the main lithology
660.36 m – 662.96 m	Calcareous marl (silty below 662.37 m), medium grey to dark grey, with increasing carbonate content, transitions to limestone (argillaceous) (mudstone, micrite), medium light grey. At the base, calcareous marl as above but with limestone lithoclasts and burrows. The base is formed by an erosional surface. Both lithologies are sparsely bioclastic and bioturbated
662.96 m – 664.29 m	Limestone (mudstone, micrite), medium light grey, bioturbated below 663.24 m, with erosional top surfaces. These are partly bored and filled with overlying sediment of thin interbeds. These interbeds consist of calcareous marl, dark grey (663.16 m to 663.24 m) and argillaceous marl, dark grey (663.93 m to 664.12 m), both with bioclasts (e.g. belemnites)
664.29 m – 672.94 m	Uniform section with calcareous marl (silty) in transition to argillaceous marl (silty), dark grey, slightly pyritic below 669.00 m, sparsely bioclastic, with pyritised burrows. The section is bioturbated down to 666.33 m and laminated below
672.94 m – 675.70 m	This almost uniform section is formed by argillaceous marl (silty, except for the interval from 673.57 m to 673.88 m), medium grey to dark grey, slightly pyritic, sparsely bioclastic, bioturbated. Pyritised burrows are found only in the uppermost part From 673.16 m to 673.27 m, an interbed of calcareous marl, silty, medium light grey, sparsely bioclastic, with pyritised burrows and a belemnite at 674.39 m, bioturbated
675.70 m – 680.80 m	Calcareous marl (silty), medium grey, in sections sparsely bioclastic and slightly bioturbated. Argillaceous marl (silty), dark grey, is present in two beds from 676.59 m to 677.75 m and from 679.20 m to 679.40 m. Both main lithologies are laminated From 679.98 m to 680.12 m, a layer of limestone (argillaceous), medium light grey, slightly bioturbated

680.80 m – 685.06 m	This is a three-part succession starting with the dominant lithology at the top: argillaceous marl, medium grey to dark grey with pyritised burrows From 682.30 m to 684.27 m, calcareous marl, dark grey, pyritised burrows, alternately laminated or slightly bioturbated. This is followed by argillaceous marl (silty), as above, with an erosional surface at the base (685.06 m)
685.06 m – 690.17 m	Calcareous marl (silty), medium grey to dark grey, slightly pyritic, laminated, with three beds of limestone (argillaceous) (mudstone, micrite), medium light grey (685.06 m to 685.16 m, 686.27 m to 686.74 m, 689.90 m to 690.17 m), except for the uppermost bed with burrows and bioturbated. In the lower half thin (< 10 cm) nodular layers of limestone (argillaceous) (mudstone, micrite), medium light grey, with burrows From 686.74 m to 687.36 m, argillaceous marl (silty), medium grey to dark grey, laminated, with burrows at 687.30 m
690.17 m – 695.71 m	Calcareous marl (silty), medium grey to dark grey, slightly glauconitic, slightly pyritic, laminated, burrows, erosional surface at 691.80 m with cracks. Between 692.35 m and 692.52 m, limestone (argillaceous) (mudstone, micrite), medium light grey. Below 692.58 m a horizon with subangular to angular, encrusted limestone lithoclasts was found. Within these lithoclasts and down to the base of the section (695.71 m), several belemnites and ammonites (693.49 m and 694.82 m) and a few crinoids were found; the interval is fossiliferous

3.5.4.2 Birmenstorf Member and «Glaukonitsandmergel Bed», 695.71 m – 696.03 m (0.32 m)

In STA3-1, there is no fossiliferous limestone or calcareous marl such as typical for the Birmenstorf Member. The thin interval from 695.71 m to 696.03 m, consisting of silty marl and argillaceous marl (silty), both glauconitic and fossiliferous and with encrusted bioclasts and lithoclasts, shows affinities with the «Mumienmergel Bed» (informally regarded as part of the Birmenstorf Member by Jordan & Deplazes 2019) and the «Glaukonitsandmergel Bed» of Gygi (1977, 2000, 2012) found at other locations.

The *upper boundary* is set at 695.71 m at the transition from the typical medium to dark grey calcareous marl (silty and glauconitic) of the Effingen Member to the dark grey silty marl (glauconitic) with encrusted clasts of the Birmenstorf Member and «Glaukonitsandmergel Bed».

The *lower boundary* is set at 696.03 m at an erosional surface which separates an overlying bioclastic argillaceous marl with abundant glauconite from a fossiliferous limestone and marl (both iron-oolitic).

Lithology

695.71 m – 695.81 m	Silty to sandy (fine-grained) marl, dark grey, glauconitic. This layer also contains many partly encrusted, subangular to rounded limestone lithoclasts (so-called "mummies"), moderate grey to grey-green, bioturbated, partly iron-oolitic. Fossils include belemnites and a single ammonite at 695.75 m
695.81 m – 996.03 m	Argillaceous marl (silty), dark grey, glauconitic with limonitic intraclasts, bioturbated. In the lowermost 5 cm belemnites are very abundant (belemnite horizon)

3.6 Dogger Group

3.6.1 Wutach Formation, 696.03 m – 699.47 m (3.44 m)

In STA3-1, the Wutach Formation is characterised by iron-oolite dominating in the upper part, and marl (iron-oolitic) dominating in the lower part, with few thin beds of limestone (iron-oolitic). Hardgrounds are found in the uppermost part. Below, the boundaries are rather gradual. The succession is fossiliferous (mainly belemnites and ammonites).

The *upper boundary* is set at 696.03 m at an erosional surface which separates an overlying bioclastic argillaceous marl with abundant glauconite from a fossiliferous limestone and marl (both iron-oolitic).

The *lower boundary* is set at 699.47 m at an erosional surface separating the overlying iron-oolitic and mostly marly sediments from the underlying claystone (silty, calcareous).

Lithology

696.03 m – 699.47 m	Succession of: From the top (696.03 m) to 696.27 m, several hardgrounds with nodular limestone (iron-oolitic), medium light grey to beige-grey, limonitic and glauconitic, with iron-oolids and encrusted lithoclasts of iron-oolite, fossiliferous with bivalves and belemnites; some of the iron-oolids are calcitic and limonitic (thin section STA3-1-696.05 and STA3-1-696.10) From 696.27 m to 697.77 m, alternation of iron-oolite, limestone (iron-oolitic) and marl (iron-oolitic) with preponderance of the iron-oolite. All lithologies are variegated (medium light grey to dark grey, reddish-brown, dark greyish-brown and ochre-brown). They contain bored, encrusted intraclasts and are fossiliferous (bivalves, belemnites, ammonites: e.g. at 696.29 m and 696.35 m). A hardground occurs at 696.65 m From 697.77 m to 699.47 m, alternation as above but with preponderance of marl (iron-oolitic) over iron-oolite and limestone (iron-oolitic). The interval is still fossiliferous (e.g. ammonite at 698.35 m)
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3.6.2 Variansmergel Formation and «Parkinsoni-Württembergica-Schichten», 699.47 m – 701.65 m (2.18 m)

In STA3-1, the section from 699.47 m to 701.55 m is formed by claystone (silty, calcareous), locally trending to argillaceous marl (silty), with pyritised burrows and few bioclasts. It is underlain by an 8 cm thick bed of fossiliferous, argillaceous to bioclastic limestone with iron-oolids. This bed is suggested to represent the «Parkinsoni-Oolith». Therefore, the section from 699.47 m to 701.55 m would probably represent the Variansmergel Formation and the upper part of the «Parkinsoni-Württembergica-Schichten» («Württembergica-Schichten» *sensu stricto*).

The *upper boundary* is set at 699.47 m at an erosional surface separating the overlying iron-oolitic and mostly marly sediments from the underlying claystone (silty, calcareous).

The *lower boundary* is set at 701.65 m at the top of a hardground separating the overlying fossiliferous argillaceous to bioclastic limestone with iron-oolids from the underlying biohermal (coral) limestone.

Lithology

699.47 m – 701.65 m	Succession of:
	From the top (699.47 m) to 701.55 m, claystone (silty, calcareous), in the upper part in transition to argillaceous marl (silty), mainly dark grey, bioclastic, with burrows and bioturbated
	From 701.55 m to 701.63 m, limestone (argillaceous) (wackestone, biomicrite), medium light grey, scattered calcitic and limonitic iron-oolids (thin section STA3-1-701.59), fossiliferous (bivalves, crinoids). This bed could correspond to the «Parkinsoni-Oolith»
	From 701.63 m to the base (701.65 m), above a hardground, a layer of claystone (silty, calcareous), dark grey, with an ammonite at 701.64 m

3.6.3 «Herrenwis Unit», 701.65 m – 742.00 m (40.35 m)

The «Herrenwis Unit» was introduced (as an informal stratigraphic unit of undefined rank) to describe the findings in the BUL1-1 borehole (Jordan et al. 2021a). There, the unit comprises two sections. The upper one consists of coralligenous sediments, probably autochthonous coral bioherm and minor redeposited reef debris. The lower section is formed by encrinite.

In STA3-1, three sections can be distinguished:

701.65 m – 723.36 m	Biohermal limestone (platestone), which is considered a predominantly autochthonous reef body, with pale green marl found as cavity fills and as thin beds down to 722.10 m
723.36 m – 729.83 m	Bioclastic limestone (floatstone, biomicrite to biosparite), very fossiliferous and with coral clasts throughout.

729.83 m – 742.00 m Biohermal (coral) limestone (platestone) with thin (up to 30 cm) inter-layers of argillaceous marl (silty) to claystone (silty, calcareous). This section probably represents an autochthonous reef body whose growth was periodically interrupted by terrigenous inputs

The *upper boundary* is set at 701.65 m at the top of a hardground separating the overlying fossiliferous argillaceous to bioclastic limestone with iron-ooids from the underlying coral limestone.

The *lower boundary* is set at 742.00 m at the base of an argillaceous siltstone with the lowermost occurrence of coral fragments and clasts of bioclastic limestone, itself containing coral debris.

Lithology

701.65 m – 704.60 m	Biohermal limestone (platestone), overall medium grey to beige-grey, peloids, very fossiliferous (abundant corals, bivalves, crinoids), corals mainly platy, all fossil types mainly < 2 mm, massive and featureless texture. The interval contains a distinct horizon at its top: From the top (701.65 m) to 701.80 m, intensely bored hardground with a thin (few mm) cover of iron-stromatolites (thin section STA3-1-701.67), crinoids and bioclasts
704.60 m – 723.36 m	Biohermal limestone (platestone) as above but with: • a nodular texture due to flaser bedding and thin layers of argillaceous marl to claystone (calcareous), dark grey, pale green to greyish-green from 713.16 m to 722.10 m • intraclasts below 718.67 m (thin section STA3-1-719.48) • vugs and druses partly filled with calcite
723.36 m – 726.76 m	Bioclastic limestone (floatstone, biomicrite and biosparite), light grey, peloids, very fossiliferous (bioclasts, subordinately corals, crinoids and bivalves [thin section STA3-1-723.46]). The fossils are found concentrated in mm-thick layers. The upper part is porous due to open vugs
726.76 m – 728.56 m	Bioclastic limestone (floatstone, biomicrite), overall medium grey, very fossiliferous (bioclasts, corals, crinoids, bivalves), both corals and thin layers of argillaceous marl (silty) to claystone (silty, calcareous), dark grey. The fossils are concentrated in dm-thick, nodular sections resulting in a medium-bedded alternation
728.56 m – 729.83 m	Bioclastic limestone (floatstone, biomicrite and biosparite) as from 723.36 m to 726.76 m but the fossils (fragments of crinoids, bivalves and corals: thin section STA3-1-729.39) are found concentrated in dm-thick layers

729.83 m – 736.47 m	Coral limestone (platestone), overall medium grey, peloids, very fossiliferous (abundant corals, crinoids, bivalves), corals in situ and in growth position, platy to tabular and mostly < 1 cm, with a matrix and some interbeds consisting of argillaceous marl (silty) to claystone (silty, calcareous), dark grey. The marl contains the same fossil types as the coral limestone, but they are less abundant and smaller
736.47 m – 742.00 m	Coral limestone (platestone) as described above with microsparitic to sparitic cement (thin sections STA3-1-737.04 and STA3-1-741.84). The interval contains a distinct horizon at its base: From 741.90 m to the base (742.00 m), argillaceous siltstone (sandy), calcareous, dark grey, with bored, encrusted lithoclasts and reworked bioclasts of corals and bivalves

3.6.4 Wedelsandstein Formation, 742.00 m – 764.97 m (22.97 m)

In STA3-1, the Wedelsandstein Formation is formed predominantly by argillaceous siltstone grading in general downward into silty claystone and claystone (silty). All lithologies are micaceous and contain some fine-grained sand. However, the quartz content decreases with depth. The rather monotonous sequence is framed and interrupted by four intervals:

742.00 m – 742.21 m	Bed with oysters and echinoderm clasts
760.73 m – 760.86 m	Bed with iron-oids, oysters and serpulides, among others
762.38 m – 762.65 m	Bed of sandy and marly limestone with bivalves and crinoids
762.82 m – 764.97 m	Bed of sandy marl with iron-oids and large oysters in the lower part

The *upper boundary* is set at 742.00 m at the base of an argillaceous siltstone with the lowermost occurrence of coral fragments and clasts of bioclastic limestone, itself containing coral debris.

The *lower boundary* is set at 764.97 m at the base of the "Austernbank" succession, i.e. at the base of the lowermost bed (a bioclastic sandy marl) with abundant iron-oids and oysters.

Lithology

742.00 m – 747.78 m	From the top (742.00 m) to 742.21 m, calcareous marl (sandy) and bioclastic limestone (sandy, thin section STA3-1-742.04), medium light grey. The bed is characterised by oysters and three beds of calcareous marl and sandy limestone (argillaceous), the uppermost with a hardground at its top, separated by silty marl Below 742.21 m, argillaceous siltstone (sandy, calcareous), with gradually decreasing quartz content downwards, medium grey to dark grey, micaceous, with burrows and bioturbated
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747.78 m – 756.40 m	Silty claystone (sandy, calcareous), medium grey to dark grey, downwards decreasing quartz content, micaceous, bioturbated, siderite nodules scattered in the upper part and abundant in the lower part
756.40 m – 760.73 m	Claystone (silty to sandy, calcareous), dark grey, micaceous, with pyritised burrows, abundant siderite nodules
760.73 m – 762.38 m	From the top (760.73 m) to 760.86 m, above a hardground, a conglomerate, calcareous (polymict), with bored clasts of bioclastic limestone (limonitic) and of iron-oolite. The matrix is a bioclastic marl (sandy [thin section STA3-1-760.80]), medium grey to dark grey, fossiliferous (oysters, belemnites, serpulids), pyritic, bioturbated. This bed may be correlated with the "Schwamm- und Serpuliden-Kalk mit Austern" of Weiach (from 536.70 m to 536.90 m; Matter et al. 1988). From 760.86 m to 762.38 m, silty marl, medium grey to dark grey, micaceous, fossiliferous (mainly bivalves), some siderite nodules, with three distinct horizons, with, from 760.86 m to 760.98 m and from 761.76 m to 761.92 m, two beds of calcareous marl (silty), medium light grey, bioclastic, sparitic, lower bed pyritic, bioturbated
762.38 m – 764.97 m	From the top (762.38 m) to 762.65 m, bioclastic sandy limestone (argillaceous [thin section STA3-1-762.44]), medium light grey, micaceous, fossiliferous (bivalves, crinoids) bioturbated, siderite nodules From 762.65 m to 764.82 m, silty claystone (sandy), dark grey, micaceous, pyritic, scattered small bioclasts, bivalves in two thin layers, bioturbated, with two distinct horizons with larger bivalves From 764.82 m to the base (764.97 m), bioclastic sandy marl, dark grey to dark greyish-brown, scattered iron-oolids (thin section STA3-1-764.86), micaceous, very fossiliferous (large, bored oyster shells, crinoids), siderite nodules. This bed may correspond, although much sandier, to the lowermost of the "Austernpflaster" of Weiach (from 538.10 m to 539.17 m; Matter et al. 1988)

3.6.5 «Murchisonae-Oolith Formation», 764.97 m – 779.26 m (14.29 m)

In STA3-1, the «Murchisonae-Oolith Formation» is a very heterogeneous succession, which can be divided into three distinct parts:

The upper part from the top (764.97 m) to 767.86 m is a heterogeneous, mostly fossiliferous and occasionally iron-oolitic succession of (from top) argillaceous marl to claystone (silty, calcareous), followed by an interbed of limestone (silty, argillaceous), to silty marl with several horizons with intraclasts.

The middle part from 767.86 m to 775.50 m is a rather monotonous succession of argillaceous siltstone grading downwards into silty claystone and claystone (silty to sandy).

The lower part from 775.50 m to the base (779.26 m) is a heterogeneous, fossiliferous and occasionally iron-oolitic succession dominated by beds of limestone (argillaceous), bioclastic calcareous marl, limestone with claystone (silty, calcareous) and silty marl interbeds.

The *upper boundary* is set at 764.97 m, at the base of the "Austernbank" succession, i.e. at the base of the lowermost bed (a bioclastic sandy marl) with abundant iron-oolids and oysters.

The *lower boundary* is set at 779.26 m, at the base of a light to medium grey bioclastic limestone overlying a thick succession of dark grey and micaceous silty claystone (calcareous). The delimitation is also supported by the analysis of FMI and GR logs and by palaeontological evidence.

Lithology

764.97 m – 767.86 m	Heterogeneous succession of: From 764.97 m to 765.85 m, argillaceous marl (silty), dark grey, micaceous, fossiliferous (belemnites, bivalves), bioturbated, some dolomitic concretions From 765.85 m to 766.88 m, two beds of claystone (silty, calcareous), mainly dark grey, bioclastic limestone intraclasts with iron-oolids (thin section STA3-1-765.94). The upper bed contains large limestone nodules. The lower bed is micaceous and fossiliferous (bivalves, crinoids) and contains some siderite nodules. The beds are separated in the middle by a ca. 20 cm thick bed of limestone (silty, argillaceous) (packstone, biosparite), medium light grey, micaceous, scattered iron-oolids, many bivalves, with burrows and bioturbated From 766.88 m to 767.86 m, silty marl, mainly medium light grey, micaceous, fossiliferous (many bivalves, crinoids [thin section STA3-1-767.44]) some limonitic and iron-oolitic intraclasts (thin section STA3-1-767.76), iron-oolids and peloids, with burrows and bioturbated Close to the base, the interval contains a ca. 18 cm thick bed of claystone (silty, calcareous), dark grey, some iron-oolids and peloids at the base (767.75 m), limonitic and micaceous, bioclastic
767.86 m – 775.50 m	Monotonous succession of: From 767.86 m to 769.50 m, argillaceous siltstone, medium light grey to dark grey, peloids, micaceous, bioclastic, bioturbated From 769.50 m to 769.98 m, silty claystone (sandy), dark grey, micaceous, moderately bioclastic, with burrows and bioturbated From 769.98 m to 775.50 m, claystone (silty to sandy), dark grey, micaceous and pyrite aggregates, with many pyritised burrows, bioturbated, abundant siderite nodules

775.50 m – 779.26 m

Heterogeneous succession of:

From 775.50 m to 776.19 m, silty claystone (calcareous), dark grey, in the upper part scattered iron-ooids, fossiliferous (crinoids, bivalves), some siderite nodules and two layers of calcareous nodules. In between (from 775.50 m to 775.86 m) a 36 cm thick bed of limestone (silty, argillaceous) (packstone and grainstone, biomicrite and biosparite), medium light grey to medium grey, with intraclasts, peloids and scattered iron-ooids, fossiliferous (echinoderms, bivalves), bioturbated

From 776.19 m to 776.78 m, claystone (silty, calcareous), dark grey, with an ammonite at 776.34 m, with pyritised burrows and bioturbated

From 776.78 m to 778.19 m, bioclastic calcareous marl (limonitic), medium light grey to reddish-brown, with peloids, encrusted intraclasts with iron-ooids (iron-oolitic bioclastic limestone, thin section STA3-1-777.00), fossiliferous (bioclasts, bivalves, belemnites), bioturbated. Some of the fossils are limonitised (thin section STA3-1-777.83). Two ammonites were found at 776.94 m and 777.72 m

From 778.19 m to the base (at 779.26 m), some beds of sandy marl, dark grey to dark greyish brown, peloids, limonitic, fossiliferous (bioclasts, bivalves). Close to the top and at the base the interval contains two beds (10 cm and 24 cm thick, respectively) of bioclastic limestone (packstone, biomicrite), sandy, light grey, with peloids. The upper bed is limonitic and contains some iron-ooids (thin section STA3-1-778.66). The lower bed contains intraclasts, bioclasts and bivalves. Two ammonites were found at 778.55 m and 779.24 m

3.6.6 Opalinus Clay, 779.26 m – 887.94 m (108.68 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 except in a few limestone beds and enriched intervals, the latter mainly in the lowermost section.

The findings in STA3-1 generally confirm the uniform lithology known from the adjacent BUL1-1 borehole (Jordan et al. 2021a).

The *upper boundary* is set at 779.26 m at the base of a light to medium grey bioclastic limestone overlying a thick succession of dark grey and micaceous silty claystone (calcareous). The delimitation is also supported by the analysis of FMI and GR logs and by palaeontological evidence.

The *lower boundary* is set at 887.94 m at the base of the last occurrence of claystone (silty, micaceous) and thus at the top of a calcareous marl interval. The distinct change in carbonate content is clearly visible in the FMI and GR logs.

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:

779.26 m – 807.34 m	«Sub-unit with silty calcareous beds» (28.08 m)
807.34 m – 821.09 m	«Upper silty sub-unit» (13.75 m)
821.09 m – 868.06 m	«Mixed clay-silt-carbonate sub-unit» (46.97 m)
868.06 m – 887.94 m	«Clay-rich sub-unit» (19.88 m)

Lithology

«Sub-unit with silty calcareous beds», 779.26 m – 807.34 m (28.08 m)

This sub-unit is defined by the presence of discrete heterogeneities, particularly silty and calcareous beds and nodules which are also well expressed as excursions in petrophysical logs (Mazurek & Aschwanden 2020). It is noteworthy that in STA3-1 some of the beds also contain iron-oooids or larger fossils.

779.26 m – 794.98 m	Massive succession of silty claystone (calcareous), medium grey to dark grey, micaceous with pyrite aggregates and pyritised burrows, some thin (< 1 cm) lenses of siltstone and sandstone decreasing in abundance towards the base and a few larger lenses of siltstone (max. 3 cm). Siderite nodules (> 2 cm) occur from 783.81 m downwards
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The middle part of the section between 785.61 m and 788.35 m shows a somewhat different succession. The interval consists of silty marl to silty claystone (sandy), dark grey, and contains three calcareous beds and a 7 cm thick layer of encrusted and bored lithoclasts of limestone (mudstone and wackestone, biomicrite, from 786.30 m to 786.37 m). The thin section from the 7 cm thick layer (STA3-1-786.32) documents that some lithoclasts contain iron-oooids (replaced by calcite) or can be described as iron-oolites. Additionally, the thin section shows that the layer contains biogenic components as echinoderms, bivalves and one fragment of a coral

The upper calcareous bed (from 787.12 m to 787.28 m) is a silty limestone (argillaceous), medium light grey to medium grey, pyritic and bioturbated. The middle and lower beds (from 787.52 m to 787.74 m and from 788.22 m to 788.35 m) are calcareous marl (silty), medium grey, also bioturbated

The lowermost 12 cm of the section (from 794.86 m to 794.98 m) is a calcareous marl (silty to sandy), bioclastic, in the lower part in transition to bioclastic calcareous marl (silty), medium grey to dark grey, phosphoritic, sideritic, with bored and encrusted lithoclasts of limestone, fossil fragments with crinoids, iron-oooids (calcitic and chamositic: thin section STA3-1-794.95), bioturbated

- 794.98 m – 803.75 m Claystone (silty, calcareous [from 794.98 m to 799.06 m]), dark grey, micaceous, with a few pyrite nodules and pyritised burrows. The section is also bioturbated and contains belemnites (at 795.29 m and at 798.60 m) and is dotted with occasional siderite and calcareous nodules, as well as several septarian nodules (795.03 m, 795.78 m and 796.03 m) with a thickness of up to 10 cm (uppermost one)
- In the middle part (between 799.06 m to 800.70 m), a more calcareous succession is found:
- From 799.06 m to 799.30 m, calcareous marl (silty, dolomitic), medium grey to dark grey, with, mostly in the topmost 4 cm, bored lithoclasts of limestone (iron-oolitic), beige-grey, with iron-oolids partly recrystallised as calcite, and some bivalves. The section is intensely bioturbated
- From 799.30 m to 799.46 m, limestone (iron-oolitic, dolomitic), iron-oolids partly recrystallised with calcite (thin section STA3-1-799.36). Here, the same lithoclasts as above occur but they are more frequent and larger. The sparse matrix consists of argillaceous marl to calcareous marl, medium grey to dark grey, dolomitic, with bivalves and crinoids
- From 799.46 m to 800.70 m, silty claystone (calcareous), dark grey, micaceous, with some pyrite nodules. This part is lenticularly bedded with frequent thin (< 1 cm) lenses of siltstone to sandstone (fine-grained), medium light grey
- 803.75 m – 807.34 m The lowermost part of this sub-unit consists predominantly of silty claystone (calcareous), dark grey, micaceous with a few pyrite nodules and a 3 cm thick dolostone nodule (806.53 m); the succession is lenticularly bedded down to 805.20 m with frequent thin (< 1 cm) lenses of siltstone to sandstone (fine-grained), medium light grey, rare below 805.20 m, pyritised burrows, whole interval intensely bioturbated, at the base from 807.25 m to 807.34 m a bioclastic interval
- The topmost 13 cm of this interval consist of a bioclastic limestone (silty [quartz], argillaceous), sideritic, beige-grey, as encrusted, bored limestone lithoclasts in a matrix of silty marl, dark grey, pyritic, fossiliferous (bivalves and crinoids), bioturbated, at the base (803.88 m) with oncoids (thin section STA3-1-803.85)

«Upper silty sub-unit», 807.34 m – 821.09 m (13.75 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 STA3-1, these siltstone lenses are present as expected but a distinct decrease in the frequency of the lenses towards the base of the unit is evident.

807.34 m – 821.09 m Silty claystone (calcareous), dark grey, micaceous, with occasional pyrite nodules and partly pyritised burrows. The section is bioturbated and lenticularly bedded with abundant siltstone lenses, medium light grey down to 817.00 m. Beneath, the lenses are rare. A few solitary siderite nodules were found (e.g. at 816.31 m and from 816.48 m to 817.00 m)

In the lower part between 813.31 m and 813.41 m, an argillaceous siltstone (calcareous), medium light grey with up to 2 mm large bioclasts is present

«Mixed clay-silt-carbonate sub-unit», 821.09 m – 868.06 m (46.97 m)

This sub-unit represents the section of the Opalinus Clay which is devoid of characteristics typical of the other sub-units (Mazurek & Aschwanden 2020). In STA3-1, it shows a distinct decrease (top to bottom) in carbonate and silt content from silty claystone (calcareous) to claystone (silty).

In STA3-1, a broad subdivision of this generally monotonous succession of silty claystone into two bioturbated and two non-bioturbated sections is obvious:

821.09 m – 830.27 m Silty claystone (calcareous), dark grey, micaceous, with burrows, rare lenses of siltstone, medium light grey, and frequent siderite nodules. The layers are inclined with some angular discordances due to soft sediment deformation from 823.50 m to 826.00 m with a sedimentary dyke in the upper part of this interval. The section is bioturbated

830.27 m – 840.88 m Silty claystone (calcareous), dark grey, micaceous, slightly to moderately pyritic, frequent siderite nodules, laminated, with rare thin (< 1 cm) siltstone lenses, medium light grey. The section is non-bioturbated

840.88 m – 851.40 m Silty claystone (calcareous), dark grey, micaceous with abundant siderite nodules, pyrite nodules and thin (< 1 cm) siltstone lenses, medium light grey. The section is bioturbated

The interval additionally contains a thin (< 1 cm) bioclastic layer at 842.62 m and two sideritic layers at 849.71 m and at 851.38 m. The layer from 848.22 m to 848.43 m is more obvious; it is a calcareous marl (silty), dark grey, pyritic, with two bioclastic layers with crinoids (thin section STA3-1-848.30), both bioturbated. The base (at 848.43 m) is erosional and is covered by bored lithoclasts of limestone (mudstone, micrite), medium light grey, and fragments of ammonites

851.40 m – 868.06 m Silty claystone, dark grey, micaceous, with abundant siderite nodules, and some pyrite nodules. Burrows were found alongside laminated parts throughout the section. From 862.81 m to 862.87 m, a septarian nodule was found, medium light grey, with cone-in-cone calcite. The section is non-bioturbated

«Clay-rich sub-unit», 868.06 m – 887.94 m (19.88 m)

As the name suggests, this dark homogeneous sub-unit has a high content of clay minerals (mostly more than 60%). The «Clay-rich sub-unit» marks the base of the Opalinus Clay (Mazurek & Aschwanden 2020). It also contains several ammonites and sections with bivalves or bioclasts.

868.06 m – 881.20 m Claystone (silty, calcareous [down to 870.45 m]), dark grey, micaceous, with pyrite nodules and pyritised burrows (frequent below 874.19 m). The section is mostly bioturbated but increasingly laminated towards the base. This part is fossiliferous compared to the rest of the Opalinus Clay, with many bivalves (*Bositra* sp.) on bedding planes (below 872.83 m) and ammonites at 871.56 m, 874.91 m, 875.00 m, 876.05 m and at 880.12 m

In the monotonous succession, several calcareous lenses or concretions can be found: one calcareous lens with cone-in-cone-calcite (from 872.89 m to 872.91 m) and three calcareous nodules and concretions, medium light grey, the lowermost in the form of a septaria with ammonite fragments (at 874.22 m, from 874.67 m to 874.83 m and at 875.15 m)

881.20 m – 887.94 m Claystone (silty), dark grey, with sparse, small pyrite nodules and frequent pyritised burrows. It is bioclastic and bioturbated and in parts also homogeneous to laminated. Ammonites were found at 884.15 m, at 886.02 m and at 887.61 m, and an unidentified fossil fragment was detected at 887.31 m

3.7 Lias Group

3.7.1 Staffelegg Formation, 887.94 m – 922.71 m (34.77 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 887.94 m, at the base of the last occurrence of claystone (silty, micaceous) and thus at the top of a calcareous marl interval. The distinct change in carbonate content is clearly visible in the FMI and GR logs.

The *lower boundary* is set at 922.71 m at an erosional surface with overlying reworked clasts. It coincides with a significant change in colour and lithology, i.e. from claystone (silty, calcareous), dark grey (top) to dolomitic marl (silty), greyish-green to pale green.

3.7.1.1 Gross Wolf Member, 887.94 m – 892.79 m (4.85 m)

In STA3-1, the Gross Wolf Member (Reisdorf et al. 2011) can be divided into two very fossiliferous parts. The upper part (from 887.94 m to 889.19 m) consists predominantly of argillaceous marl with thin, and at the top thicker, beds of calcareous marl. The lower part (from 889.19 m to 892.79 m) represents the typical "Jurensismergel" facies with nodular beds of limestone separated by thicker beds of calcareous marl. A thin bed at the base (see below) may correlate to the Gipf Bed of Reisdorf et al. (2011).

The *upper boundary* is set at 887.94 m at the base of the last occurrence of claystone (silty, micaceous) and thus at the top of a calcareous marl interval. The distinct change in carbonate content is clearly visible in the FMI and GR logs.

The *lower boundary* is set at 892.79 m at the base of a thin bed with bored limonitic clasts. The boundary coincides with the onset of a bituminous facies.

Lithology

887.94 m – 889.19 m	Argillaceous marl, dark grey, fossiliferous (belemnites, ammonites e.g. at 888.02 m, 888.36 m and 889.12 m, bioclasts). The interval contains frequent nodules and thin nodular beds of limestone (argillaceous) (wackestone, biomicrite), light grey, and at the top a thicker bed of calcareous marl, medium grey. They are as fossiliferous as the argillaceous marl. The whole interval is bioturbated
889.19 m – 892.79 m	Calcareous marl, medium grey to dark grey, slightly glauconitic, and slightly phosphoritic, fossiliferous (belemnites, bioclasts), a few siderite nodules. The interval contains both abundant nodules and thin, nodular beds of limestone (argillaceous) (mudstone, micrite) and in sections fossils (bivalves, belemnites) From 892.70 m to the base (892.79 m), a bed with bored clasts with limonitic crusts and an ammonite at 892.74 m were found

3.7.1.2 Rietheim Member, 892.79 m – 899.30 m (6.51 m)

In STA3-1, the Rietheim Member is distinctive due to its bituminous content which increases with depth. The upper part (from 892.79 m to 895.00 m) is an argillaceous marl, slightly bituminous with two ca. 10 cm thick normally graded phosphoritised coquinas. The middle part is a bituminous and argillaceous marl interrupted by a ca. 20 cm thick bed of limestone (argillaceous). The lower part (from 897.82 m to 899.30 m) consists of an alternation of laminated bituminous shale and laminated limestone (mudstone, micrite), slightly bituminous.

The *upper boundary* is set at 892.79 m, at the base of a thin bed with bored limonitic clasts. The boundary coincides with the onset of a bituminous facies.

The *lower boundary* is set at 899.30 m, at the top of the uppermost calcareous marl with glauconite which is overlain by laminated bituminous shale without glauconite.

Lithology

892.79 m – 895.00 m	Argillaceous marl, dark grey, slightly bituminous, pyrite nodules and aggregates, fossiliferous (belemnites [some phosphoritised and encrusted with pyrite], bioclasts), bioturbated. Between 893.20 m and 893.74 m the interval contains some thin (< 10 cm) and two thicker (11 cm) beds of calcareous marl, medium grey to dark grey and beige-grey, laminated to fine-bedded with abundant shells. The shells are phosphoritised and normally graded
895.00 m – 897.82 m	Argillaceous marl, slightly silty, dark grey to beige-grey, bituminous, pyrite nodules. Close to the top, the interval contains solitary belemnites (some phosphoritised). Close to the base, the interval contains a ca. 20 cm thick bed (896.90 m to 897.11 m) of limestone (argillaceous) (mudstone, micrite), medium grey to beige-grey. The whole interval is laminated
897.82 m – 899.30 m	Bituminous shale, dark grey to black and dark greyish-brown, pyrite nodules, laminated. The lowermost 10 cm (899.20 m to 899.30 m) with abundant bioclasts. The interval contains two distinct beds of limestone (argillaceous) (mudstone, micrite), medium light grey to beige-grey, bituminous, laminated (897.82 m to 897.97 m and 898.28 m to 898.52 m). The lower bed is the marker horizon «Unterer Stein»

3.7.1.3 Grünschholz Member, Breitenmatt Member and Rickenbach Member, 899.30 m – 901.53 m (2.23 m)

Throughout Northern Switzerland, the Grünschholz Member, the Breitenmatt Member and the Rickenbach Member represent a strongly condensed succession (Reisdorf et al. 2011). Jordan & Deplazes (2019) recommend describing the three members as one informal stratigraphic unit, because 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 STA3-1, the section is characterised by a thin- to medium-bedded, fossiliferous (predominantly belemnites) succession of limestone and calcareous marl, both glauconitic. Reworked and partially encrusted lithoclasts and phosphoritised fossils are typical for this section. The distinct peak in the GR log, which is generally associated with the Breitenmatt Member, is observed in the uppermost part of the section. Gryphid oysters are found in the lowermost beds.

The *upper boundary* is set at 899.30 m at the top of the uppermost calcareous marl with glauconite which is overlain by laminated bituminous shale without glauconite.

The *lower boundary* is set at 901.53 m at the base of a thin limestone (argillaceous) bed overlying an interval of argillaceous siltstone with mica and pyrite.

Lithology

- 899.30 m – 901.53 m A thin-bedded alternation (with frequent erosional surfaces) of:
- limestone (argillaceous) (mainly wackestone and packstone, mainly biomicrite), in the upper part variegated, in the lower part medium light grey, layer of phosphorite nodules from 899.99 m to 900.16 m
 - calcareous marl, medium grey to dark grey
- The common features of both lithologies are bored lithoclasts with phosphoritic crusts, glauconite and, in the lower part, frequent pyrite nodules and abundant fossils (belemnites, crinoids, bivalves, gryphaea at 901.43 m). The whole interval is moderately to intensely bioturbated

3.7.1.4 Frick Member, 901.53 m – 913.47 m (11.94 m)

In STA3-1, the Frick Member is a uniform succession of argillaceous siltstone (calcareous) with thin beds of siltstone (calcareous) grading downward into silty claystone (calcareous). The whole interval is micaceous and, as is commonly the case, almost devoid of macrofossils.

The *upper boundary* is set at 901.53 m at the base of a thin limestone (argillaceous) bed overlying an interval of argillaceous siltstone with mica and pyrite.

The *lower boundary* is set at 913.47 m at the base of a thick succession of silty claystone (calcareous, micaceous). It corresponds to the top of a thin (11 cm) layer of glauconitic and fossiliferous argillaceous marl overlying a medium-bedded succession of fossiliferous limestone.

Lithology

- 901.53 m – 907.09 m Argillaceous siltstone (sandy), medium grey to dark grey, micaceous and with frequent pyrite nodules. Close to the top the interval contains three beds (10 cm) of argillaceous marl (silty), medium light grey, micaceous. An ammonite fragment was recognised at 903.27 m
- 907.09 m – 913.47 m Silty claystone (sandy, calcareous), medium grey to dark grey, micaceous and some large pyrite nodules, laminated, with partly abundant lenses of siltstone to sandstone, light grey to medium light grey

3.7.1.5 Beggingen Member, 913.47 m – 916.23 m (2.76 m)

In STA3-1, the Beggingen Member can be divided in three sections: the upper, most prominent section (913.47 m to 915.30 m) is a middle- to thin-bedded succession of limestone, limestone (argillaceous), bioclastic limestone and bioclastic marl (with oncoids) separated by claystone to argillaceous marl drapes. This part is glauconitic and very fossiliferous, including *Gryphaea arcuata*, other bivalves, ammonites and crinoids. Fossils are partly phosphoritised. Iron-oids are found in the lower part of the upper section, from 914.73 m to 915.30 m.

The middle section (from 915.30 m to 915.73 m) consists of claystone with iron-oids and oncoids.

The lower section (915.73 m to 916.23 m) is a limestone (iron-oolitic) with glauconite and abundant, partly bored, bivalves of the *Cardinia* genus.

The *upper boundary* is set at 913.47 m at the base of a thick succession of silty claystone (calcareous, micaceous). It corresponds to the top of a thin (11 cm) layer of glauconitic and fossiliferous argillaceous marl overlying a medium-bedded succession of fossiliferous limestone.

The *lower boundary* is set at 916.23 m at an erosional surface separating the overlying limestone (iron-oolitic) from a thick succession of claystone (silty, calcareous) without iron-oids.

Lithology

913.47 m – 915.30 m	Heterogeneous succession which can be subdivided into four sections: From the top (913.47 m) to 913.58 m, argillaceous marl, medium grey to dark grey, with frequent small bioclasts increasing in amount towards the base (913.58 m) From 913.58 m to 914.73 m, an interval with several erosional surfaces in limestone (argillaceous below 913.93 m) (mainly wackestone and packstone, biomicrite), glauconitic, towards the top pyritic, moderately fossiliferous (frequent small bioclasts, gryphaea in the argillaceous section) and an ammonite at 914.00 m The section from 914.73 m to 915.17 m consists of a bioclastic limestone (packstone and grainstone, biomicrite and biosparite), with frequent iron-oids (thin section STA3-1-914.77), glauconitic, very fossiliferous (gryphaea, crinoids, bioclasts). Fossils occur as a core of oncoids with a limonitic crust at the base (915.17 m) The base (from 915.17 m to 915.30 m) is formed by a bioclastic calcareous marl, with iron-oids, glauconite and abundant fossils (gryphaea, bioclasts)
915.30 m – 916.23 m	This section is divided into two parts; from the top (915.30 m) to 915.73 m, a claystone, dark grey, micaceous, with sparse iron-oids, and a thin oncoloid layer prevails, followed by a bioclastic limestone (iron-oolitic), with iron-oolites (thin section STA3-1-915.83) and abundant fossils (bored large bivalves, crinoids) (from 915.73 m to the base at 916.23 m). Both lithologies are glauconitic and the lower part also limonitic This bed of bioclastic limestone may be equivalent to the Schleithem Bed

3.7.1.6 Schambelen Member, 916.23 m – 922.71 m (6.48 m)

In STA3-1, the Schambelen Member consists mainly of a monotonous succession of claystone (silty, calcareous) with mica and pyrite. From 919.53 m to 920.43 m, it is divided into two by a fossiliferous interval (crinoids and bivalves) formed by an alternating bedding of limestone (argillaceous) and argillaceous marl (silty). Below this interval, the claystone (silty, calcareous) is slightly fossiliferous (mainly bivalves), including some thin bioclastic intervals with the interval at the base also including lithoclasts.

The *upper boundary* is set at 916.23 m at an erosional surface separating the overlying limestone (iron-oolitic) from a thick succession of claystone (silty, calcareous) without iron-oolids.

The *lower boundary* is set at 922.71 m at an erosional surface with overlying reworked clasts. It coincides with a significant change in colour and lithology, i.e. from claystone (silty, calcareous), dark grey (top) to dolomitic marl (silty), greyish-green to pale green.

Lithology

916.23 m – 922.71 m	Claystone (silty, calcareous), dark grey, micaceous, some small pyrite nodules, laminated. The claystone succession is separated in the middle by three beds of limestone (see description below). The upper interval contains thin (maximum 2 cm) siltstone lenses. The lower bed shows siltstone lenses only in its uppermost part. It additionally contains some maximum 2 cm thick bioclastic layers From 919.53 m to 920.43 m, three beds of limestone (silty, argillaceous), light grey, fossiliferous (crinoids, bioclasts, bivalves), bioturbated. In between and at the base, argillaceous marl (silty), dark grey, sparsely fossiliferous (bioclasts, crinoids), bioturbated
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3.8 Keuper Group

3.8.1 Klettgau Formation, 922.71 m – 951.13 m (28.42 m)

The Klettgau Formation is a heterogeneous succession dominated by variegated playa (coastal, sabkha and continental) sediments with mostly silty claystone and dolocretes. Interstratified therein are dolostone intervals and fine-grained siliciclastic sediments representing marine to coastal and fluvial intercalations. In STA3-1, the Belchen Member was not encountered.

The *upper boundary* is set at 922.71 m at an erosional surface with overlying reworked clasts. It coincides with a significant change in colour and lithology, i.e. from claystone (silty, calcareous), dark grey (top) to dolomitic marl (silty), greyish-green to pale green.

The *lower boundary* is set at 951.13 m at the top of a dolostone to dolostone (argillaceous) bed overlying the uppermost deposit of massive anhydrite which is itself overlain by an argillaceous marl (dolomitic).

3.8.1.1 Gruhalde Member above Seebi Member, 922.71 m – 935.22 m (12.51 m)

In STA3-1, the upper part of the Gruhalde Member (above the Seebi Member) is characterised by variegated dolomitic marl (silty) with frequent root structures documenting palaeosoils.

The *upper boundary* is set at 922.71 m at an erosional surface with overlying reworked clasts. It coincides with a significant change in colour and lithology, i.e. from claystone (silty, calcareous), dark grey (top) to dolomitic marl (silty), greyish-green to pale green.

The *lower boundary* is set at 935.22 m where a dolomitic marl (silty) overlays a dolostone (sandy) with some nodules of dolomitic marl.

Lithology

922.71 m – 935.22 m	Dolomitic marl (silty almost throughout). The colour changes from greyish-green to pale green to grey-violet. The succession contains several horizons with plant root tubes (e.g. from 926.67 m to 927.29 m and from 928.09 m to 928.09 m), reduction spots and slightly brecciated to nodular texture, sometimes due to desiccation cracks and fractures
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3.8.1.2 Seebi Member, 935.22 m – 941.66 m (6.44 m)

In STA3-1, the Seebi Member is characterised by a three-part division into dolostone (silty, locally sandy) dominating the upper and lower part of the succession and sandy dolostone (locally argillaceous), prevalent in the central part. In the lower part of the interval, the dolostone is brecciated in a dolomitic marl matrix.

The *upper boundary* is set at 935.22 m where a dolomitic marl (silty) overlays a dolostone (sandy) with some nodules of dolomitic marl.

The *lower boundary* is set at 941.66 m at an irregular surface separating the overlying sandy dolostone (argillaceous) from the underlying argillaceous marl (dolomitic).

Lithology

935.22 m – 937.37 m	Dolostone (silty, argillaceous), towards the base (937.37 m) in transition to dolomitic marl (silty), variegated (ochre-brown to reddish-brown, with beige and pale green patches), (sub)vertical microfissures, frequently occurring in the lower part resulting in a breccia-like texture with angular intraclasts. At the top (935.22 m to 935.51 m), the interval consists of a dolostone (sandy), beige to ochre-brown, with some nodules of dolomitic marl (thin section STA3-1-935.27), pale green
937.37 m – 939.02 m	Sandy dolostone (thin section STA3-1-938.02), light grey and pale green, quartz (angular to subrounded, medium- to coarse-grained and a few granules), intraclasts of dolomitic marl, pale green, matrix-supported

- 939.02 m – 941.66 m Two-fold repetition of two lithologies:
- breccia, dolomitic (monomict), silty to sandy, in the lower part platy, elsewhere angular to nodular clasts of sandy dolostone, light grey to pale green, in a matrix of dolomitic marl (silty to sandy), grey-violet; transitioning downwards from matrix- to clast-supported
 - sandy dolostone (the lower bed argillaceous), light grey to pale green, grey-violet in patches

3.8.1.3 Gruhalde Member below Seebi Member, 941.66 m – 943.46 m (1.80 m)

In STA3-1, the lower part of the Gruhalde Member (below the Seebi Member) is characterised by an argillaceous marl (dolomitic) with two beds of dolostone (argillaceous) and frequent root structures indicating palaeosoils.

The *upper boundary* is set at 941.66 m at an irregular surface separating the overlying sandy dolostone (argillaceous) from the underlying argillaceous marl (dolomitic).

The *lower boundary* is set at 943.46 m at an erosional surface at the top of a massive bed of dolostone (argillaceous) which is overlain by argillaceous marl (dolomitic).

Lithology

- 941.66 m – 943.46 m Argillaceous marl (dolomitic), with plant root tubes and some thin (< 10 cm) and two thicker nodular beds of dolostone (argillaceous). Above the erosional base at 943.46 m, reworked clasts from the underlying dolostone (argillaceous) are embedded in the sediment

3.8.1.4 Gansingen Member, 943.46 m – 945.28 m (1.82 m)

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

In STA3-1, the Gansingen Member consists of a succession of dolostone (argillaceous), dolomitic marl and dolostone, locally with relicts of ooids, with microbial mats, desiccation cracks and brecciated intervals.

The *upper boundary* is set at 943.46 m at an erosional surface at the top of a massive bed of dolostone (argillaceous) which is overlain by argillaceous marl (dolomitic).

The *lower boundary* is set at 945.28 m at the base of a massive dolostone bed documenting the first marine ingressions over argillaceous marl (silty, dolomitic).

Lithology

943.46 m – 945.28 m	This succession is dominated by dolomitic lithologies which can be subdivided into four intervals: The uppermost part from the top (943.46 m) to 943.95 m, is a dolostone (argillaceous), irregularly wavy laminated by microbial mats and cm-thick layers of dolomitic marl, pale green to light brown From 943.95 m to 944.15 m, dolomitic marl (silty), grey-violet to dark reddish-brown, brecciated texture with clasts of dolostone (argillaceous), light grey From 944.15 m to 944.29 m, dolomitic marl, pale green to light grey and slightly brecciated The lowermost part from 944.29 m to the base (945.28 m), is a dolostone (thin section STA3-1-944.45), beige to dark beige, with a brecciated texture with desiccation cracks
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3.8.1.5 Ergolz Member, 945.28 m – 951.13 m (5.85 m)

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

In STA3-1, argillaceous marl (mostly silty and micaceous) with occasional root structures dominates and can be interpreted as a distal overspill facies. The nodular anhydrite and dolostone beds found in the upper part, represent palaeosoils. Several intervals composed of argillaceous sandstone, siltstone (dolomitic, argillaceous) and dolomitic marl (silty), all micaceous, mostly with flaser bedding and occasionally with an erosional base represent a more proximal facies with respect to the channels.

The *upper boundary* is set at 945.28 m at the base of a massive dolostone bed documenting the first marine ingress over argillaceous marl (silty, dolomitic).

The *lower boundary* is set at 951.13 m at the top of a dolostone to dolostone (argillaceous) bed overlying the uppermost deposit of massive anhydrite, which is itself overlain by an argillaceous marl (dolomitic).

Lithology

945.28 m – 949.15 m	Argillaceous marl (dolomitic, silty), pale green and grey-violet, with nodules and thin nodular layers of dolostone. The middle part (from 946.76 m to 947.03 m) consists of an argillaceous sandstone (fine-grained), dark reddish-brown, micaceous, with clasts of argillaceous marl (dolomitic) and a lower erosional boundary Below the erosional boundary (from 947.03 m to 947.74 m), a micaceous siltstone (sandy, dolomitic, argillaceous), light grey to light greenish-grey is present. Argillaceous marl (dolomitic, silty to sandy), similar to the one above but of different colour (dark pink and pale green), micaceous and interspersed with plant root tubes in the upper part is located below the siltstone
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949.15 m – 950.54 m	Thin-bedded alternation of two lithologies: • dolomitic marl (silty), dark pink, with plant root tubes in the upper part • siltstone (dolomitic, argillaceous), light greenish-grey, micaceous The piecewise preponderance of dolomitic marl over siltstone and vice versa results in a double repetition of the two lithologies. The whole interval is flaser-bedded
950.54 m – 951.13 m	Argillaceous marl (dolomitic), greyish-green to grey-violet, with a distinct horizon near the top (from 950.54 m to 950.67 m). This horizon is a 13 cm thick argillaceous sandstone (fine-grained [thin section STA3-1-950.65]) (calcareous) with an erosional surface at the base. Near the base (950.67 m), clasts of argillaceous marl from below the erosional boundary were found

3.8.2 Bänkerjoch Formation, 951.13 m – 1'026.62 m (75.49 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 951.13 m at the top of a dolostone to dolostone (argillaceous) bed overlying the uppermost deposit of massive anhydrite, which is itself overlain by an argillaceous marl (dolomitic).

The *lower boundary* is set at 1'026.62 m at the base of the lowermost massive anhydrite bed of the overlying Bänkerjoch Formation and at the top of the dolostone succession of the Asp Member.

Lithostratigraphic subdivision

There is still no formal subdivision of the Bänkerjoch Formation. For this drilling campaign Jordan & Deplazes (2019) proposed to use the informal subdivision based on earlier core records of Nagra (e.g. Matter et al. 1987, Dronkert et al. 1990, Nagra 2001a, 2001b). All five sub-units could be recognised in STA3-1:

951.13 m – 976.08 m	«Claystone with anhydrite nodules» (24.95 m)
976.08 m – 1'000.71 m	«Cyclic sequence» (24.63 m)
1'000.71 m – 1'019.81 m	«Thin-layered anhydrite and claystone sequence» (19.10 m)
1'019.81 m – 1'023.45 m	«Banded massive anhydrite» (3.64 m)
1'023.45 m – 1'026.62 m	«Dolomite and anhydrite» (3.17 m)

Lithology

«Claystone with anhydrite nodules», 951.13 m – 976.08 m (24.95 m)

The sub-unit consists of three heterogeneous intervals with a wide variety of lithologies and three units with rather uniform lithologies, two of them dominated by claystone and one dominated by anhydrite. From 973.55 m to 974.44 m, an interval of sandy dolostone stands out and is identified as marker bed 1 of Jordan et al. (2016). Anhydrite nodules only prevail down to about 958 m. Beneath, anhydrite is concentrated in veins, except in a few beds with chickenwire texture.

951.13 m – 958.72 m Upper heterogeneous succession dominated by various types of claystone. Claystone (silty) and claystone (anhydritic and silty), both dark grey to black are present. In both claystone intervals the white anhydrite can be found in nodules and veins embedded in a claystone matrix

The claystone succession is interrupted by some lithologies that occur less frequently:

- anhydrite, mostly as abundant white nodules embedded in a sparse claystone matrix, black. The nodules are partly arranged in a chickenwire texture
- anhydrite (argillaceous) as abundant white nodules with a higher share of claystone matrix, darker than in the anhydrite
- dolomitic marl (in sections silty), medium grey to dark grey and greyish-green, in sections with some anhydrite nodules

The uppermost part (from 951.13 m to 951.60 m) of the succession shows a distinct sequence of several thin (< 10 cm) beds of dolostone (below 951.25 m argillaceous), medium light grey. They are inter-layered by argillaceous marl (dolomitic), pale green

958.72 m – 963.26 m Claystone-anhydrite alternation of:

- claystone (mainly anhydritic), consisting of sparse white anhydrite veins embedded in a claystone matrix. The claystone is mainly black but additionally dark reddish-brown to pale pink towards the base
- anhydrite (mostly argillaceous, partly dolomitic), as frequent white anhydrite veins and few nodular layers embedded in claystone matrix, black and medium grey

At the top and at the base, the interval is enclosed by thick (28 cm and 87 cm, respectively) sections of small, white anhydrite nodules arranged in a chickenwire texture with sparse claystone matrix, black

963.26 m – 965.68 m Claystone (anhydritic) and scarce dolomitic marl, few white anhydrite nodules and veins embedded in a claystone matrix. The colour of the matrix transitions downwards from medium grey and black to dark grey and black and to dark reddish-brown towards the base

The claystone succession is divided in half by a 13 cm thick breccia, anhydritic (polymict), with matrix-supported, small (few mm) anhydrite and dolostone nodules

965.68 m – 969.65 m	Succession of mostly white anhydrite and anhydrite (argillaceous) as veins within a sparse claystone matrix. In two layers (14 cm and 20 cm in thickness, respectively) the anhydrite is concentrated in nodules forming a chickenwire texture The succession is divided by three layers (14 cm to 35 cm thick) of claystone, black, towards the base dark reddish-brown. Apart from the central claystone with some anhydrite veins, anhydrite is almost absent
969.65 m – 973.55 m	Heterogeneous succession dominated by various types of claystone, such as claystone (dolomitic), claystone (anhydritic), with some white anhydrite nodules and claystone (silty to sandy), with fine laminae to lenticular bedding and bioturbation All claystone intervals are medium grey to black and dark reddish-brown. The claystone succession is interrupted by a minor occurrence of dolomitic marl, medium light grey and subordinately dark reddish-brown (mud cracks at the respective tops, some cracks filled with anhydrite), anhydrite, white, arranged in bands, and anhydrite (argillaceous), as frequent white nodules embedded in claystone matrix, black
973.55 m – 974.77 m	Sandy dolostone (silty) to dolostone (silty to sandy), medium light grey, with mm-thick seams and lenses of siltstone to sandstone (fine-grained), (dolomitic), laminae mostly disrupted by bioturbation and mud cracks at the top (973.55 m). This bed probably corresponds to the marker bed 1
974.77 m – 976.08 m	Heterogeneous succession (similar to above) also dominated by various types of claystone, such as claystone (silty, dolomitic), with just a few white anhydrite veins, and claystone (silty, anhydritic), with white anhydrite nodules. The claystone succession is interrupted by some lithologies with a minor occurrence of anhydrite, as abundant white bands and nodules with a sparse claystone matrix, dark grey and dolomitic marl, medium light grey

«Cyclic sequence», 976.08 m – 1'000.71 m (24.63 m)

Anhydrite is dominant in this sub-unit. The claystone is restricted to a few beds or forms the sparse matrix. It is dominantly dark grey to black. In sections, the claystone is dolomitic or anhydritic, the latter due the occurrence of sparse anhydrite veins. Anhydrite is found in veins, beds with chickenwire structure and in sulpharenitic laminae and thin layers.

976.08 m – 981.20 m	Alternation of (in order of decreasing abundance): • anhydrite, dominated by mm-sized white anhydrite nodules, arranged in a chickenwire texture. The matrix is claystone, mainly black, rarely dark grey and dark reddish-brown and contains laminae of sulpharenite • claystone (anhydritic), consisting of rare white anhydrite veins in claystone matrix, black • anhydrite (argillaceous), as white horizontal anhydrite veins and thin (max. 3 cm) sulpharenitic layers in claystone matrix, black The interval terminates at the base with a distinct bed of claystone (dolomitic), black, with a few anhydrite nodules and veins
981.20 m – 986.65 m	Cyclic alternation (with many incomplete cycles) of: • anhydrite (argillaceous, partly dolomitic), consisting of abundant white sulpharenitic laminae and claystone seams, black and medium grey • anhydrite, consisting of mm-sized, white anhydrite nodules arranged in a chickenwire texture and sparse sulpharenitic laminae • three beds (14 cm to 21 cm thick) of claystone, black, with thin sulpharenitic layers. All beds contain sparse white anhydrite veins
986.65 m – 991.14 m	Medium-bedded alternation of anhydrite, as abundant white anhydrite veins and sulpharenitic laminae in sparse matrix of claystone (dolomitic), and anhydrite (argillaceous, partly dolomitic), as described above but showing fewer veins and laminae and with more claystone matrix. In addition, the section contains four intervals (26 cm to 48 cm thick) of claystone, black, with some thin sulpharenitic layers. The two central intervals are anhydritic due to rare white anhydrite veins
991.14 m – 997.23 m	This section is similar to the one above but it consists mainly of a thin- to medium-bedded alternation of anhydrite, white, as abundant sulpharenitic laminae and mm-sized anhydrite nodules, dominating some intervals with a chickenwire texture, and anhydrite (argillaceous) as frequent thin sulpharenitic layers and anhydrite veins, both white, in a matrix of claystone (silty), black and medium grey. The claystone intervals are missing
997.23 m – 1'000.71 m	Thin- to medium-bedded alternation of anhydrite and anhydrite (argillaceous) as above but, in contrast, the claystone matrix is partly dolomitic and black. In addition, four beds (15 cm to 35 cm thick) of claystone, black, containing some thin white sulpharenitic layers were found. The two upper beds are anhydritic due to rare white anhydrite veins

«Thin-layered anhydrite and claystone sequence», 1'000.71 m – 1'019.81 m (19.10 m)

Generally, the sub-unit shows a thin-layered alternation of claystone and anhydrite. However, there is a clear dominance of claystone over anhydrite down to 1'008.91 m. Below 1'012.66 m, anhydrite dominates. In between, a very heterogeneous interval with a wide variety of lithologies occurs. Down to 1'012.66 m, the anhydrite is concentrated in layers and less frequently in veins, while beneath it is exclusively in layers. In contrast to the sub-unit above, the claystone is additionally greyish-green to grey-violet and more dolomitic. From 1'006.35 m to 1'006.55 m, an interval made up of dolostone (argillaceous) is identified as the marker bed 2 of Jordan et al. (2016).

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|-------------------------|---|
| 1'000.71 m – 1'006.55 m | <p>Thin- to medium-bedded alternation of (in order of decreasing abundance):</p> <ul style="list-style-type: none"> • claystone (anhydritic), consisting of rare white anhydrite laminae embedded in claystone (partly dolomitic), black, at the base (1'006.55 m) greyish-green • anhydrite (argillaceous, partly dolomitic), as in claystone (anhydritic) but considerably more anhydrite laminae • anhydrite, consisting largely of anhydrite laminae. The claystone matrix is almost absent <p>The rare anhydrite veins and nodules are partly arranged in a chicken-wire texture. The interval concludes close to the base with a massive bed (80 cm) of white anhydrite bands and just a few black claystone seams</p> |
| 1'006.55 m – 1'008.91 m | <p>Heterogeneous succession dominated by claystone (silty), with plant root tubes in the lower half and with rare white anhydrite veins. Additionally, anhydrite (argillaceous) occurs as frequent white bands with sparse claystone matrix, and anhydrite as abundant white anhydrite nodules arranged in a chickenwire texture</p> <p>From the top (1'006.55 m) to 1'006.82 m, below an erosional surface, the section is capped by a dolostone (argillaceous), pale green to greyish-green, brecciated with cracks filled by bioturbated claystone. The bed could correspond to the marker bed 2</p> |
| 1'008.91 m – 1'012.66 m | <p>Very heterogeneous, thin- to medium-bedded alternation of many different lithologies:</p> <ul style="list-style-type: none"> • dolomitic marl (in sections silty), pale green to grey-violet, towards the base (1'012.66 m) additionally light greenish-grey, some beds bioturbated. Rare anhydrite veins and nodules occur • argillaceous marl (dolomitic), silty, pale green • claystone (silty, dolomitic), greyish-blue green to dark grey. Rare anhydrite veins and nodules occur • claystone, grey-violet, greyish-blue-green, partly with plant root tubes • anhydrite, as white anhydrite laminae and thin bands, alternating with sparse claystone seams, alternating with claystone, pale green |

From the top (1'008.91 m) to 1'009.11 m, the section starts with a breccia, dolomitic marl (polymict), pale green to grey-violet, with mud cracks in dolomitic marl. Cracks are filled by argillaceous sandstone (fine-grained)

1'012.66 m – 1'016.07 m Thin- to medium-bedded alternation, but clearly dominated by anhydrite:

Anhydrite and anhydrite (argillaceous), as sulpharenitic laminae and layers (mm-thick to a maximum of 10 cm in thickness) of nodular anhydrite, both white and greyish-pink and in varying degrees of abundance, alternating with claystone (silty to sandy), pale green to grey-violet and dark grey. The mm-sized anhydrite nodules are partly arranged in a chickenwire texture

A distinct bed occurs from 1'012.82 m to 1'013.16 m, summarised as anhydrite (argillaceous, dolomitic). It is an alternation of thin sulpharenite layers and dolostone, pale green to grey-violet

1'016.07 m – 1'017.32 m Prominent and massive bed of white anhydrite, laminated to featureless, with some thin layers of claystone (silty to sandy), medium light grey to beige-grey and dark grey

1'017.32 m – 1'019.81 m Thin- to medium-bedded alternation of anhydrite, white, laminated to featureless, silty to sandy marl, and calcareous marl (silty). The marly lithologies are medium grey to beige-grey or dark grey and contain some white sulpharenitic laminae

«Banded massive anhydrite», 1'019.81 m – 1'023.45 m (3.64 m)

This sub-unit consists of massive to banded anhydrite with a few claystone seams. The central part of the sub-unit contains somewhat more of the claystone seams resulting in anhydrite (argillaceous).

1'019.81 m – 1'023.45 m Anhydrite, white, partly interlayered by claystone seams (dolomitic), dark grey to black. The central part of the interval is an anhydrite (argillaceous), due to the higher amount of claystone seams. At 1'021.72 m a breccia, anhydritic (polymict), occurs with angular anhydrite clasts and pyrite aggregates

«Dolomite and anhydrite», 1'023.45– 1'026.62 m (3.17 m)

The upper half of the sub-unit consists of dolomitic marl and dolostone. The lower half consists of rather massive anhydrite with just two dolostone beds.

- | | |
|-------------------------|--|
| 1'023.45 m – 1'024.83 m | Dolomitic marl, beige-grey to dark grey. The dolomitic marl is interrupted by two beds (13 cm and 41 cm thick, respectively) of dolostone (argillaceous), beige-grey. Both lithologies contain small white anhydrite nodules, solitary or clustered in thin layers |
| 1'024.83 m – 1'026.62 m | Anhydrite, white, partly interlayered by thin dolostone layers, beige-grey. The anhydrite is interrupted by two beds (12 cm and 18 cm thick, respectively) of dolostone, beige-grey. The upper bed is interspersed with mm-sized black and white anhydrite nodules |

3.9 Muschelkalk Group

3.9.1 Schinznach Formation, 1'026.62 m – 1'099.03 m (72.41 m)

The Schinznach Formation and its members are not consistently congruent with the stratigraphic units «Lettenkohle», «Trigonodus-Dolomit» 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 litho-stratigraphic concepts.

The *upper boundary* is set at 1'026.62 m at the base of the lowermost massive anhydrite bed of the overlying Bänkerjoch Formation and the top of the dolostone succession of the Asp Member.

The *lower boundary* is set at 1'099.03 m where an oncolitic limestone (dolomitic) overlays the uppermost occurrence of dolostone.

3.9.1.1 Asp Member, 1'026.62 m – 1'030.65 m (4.03 m)

The Asp Member generally shows a two-part composition. The upper part of the member is dominated by dolostone which is, in outcrops, 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).

The STA3-1 borehole drilled through both the dolostone in the upper part and the claystone in the lower part. The dolostone succession contains small anhydrite nodules. The bituminous shale in the lower part is quite fossiliferous (thin coquinas, few bivalves).

The *upper boundary* is set at 1'026.62 m at the base of the lowermost massive anhydrite bed of the overlying Bänkerjoch Formation and the top of the dolostone succession of the Asp Member.

The lower boundary is set at 1'030.65 m at the erosional top of a thick succession of dolostone overlain by bituminous shale of the Asp Member.

Lithology

- 1'026.62 m – 1'029.76 m Dolostone, beige-grey. Below 1'029.05 m dolostone (argillaceous), beige-grey to medium grey. Almost throughout both lithologies white anhydrite nodules occur. They are mm-sized, abundant above 1'026.89 m and rather scattered but large beneath
- From 1'027.35 m to 1'027.42 m, the main lithology is interrupted by a claystone (silty), dark grey. This thin bed is divided by an erosional surface at 1'027.37 m, below which it is additionally laminated by siltstone, medium light grey. Above the erosional surface bivalves were found
- From 1'027.99 m to 1'028.30 m, a network of micro-fissures filled with anhydrite dissects the main lithotype described above
- 1'029.76 m – 1'030.65 m Bituminous shale, dark grey, micaceous, sparsely pyritic, laminated by brighter coquina layers and few bivalves

3.9.1.2 Stamberg Member, 1'030.65 m – 1'069.18 m (38.53 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 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 STA3-1, the Stamberg Member can be divided into three parts based on lithology and fossil content.

The thin upper part from 1'030.65 m to 1'032.23 m is formed by a fossiliferous dolostone.

The middle part from 1'032.23 m to 1'046.87 m is a rather monotonous succession of dolostone with thin anhydrite nodules and few fossils. Remarkable is an occurrence of ooids at 1'039.79 m, possibly to be correlated with the Kaisten Bed (Pietsch et al. 2016).

The lower part from 1'046.87 m to 1'069.18 m, a succession of dolostone and, locally, dolostone (argillaceous), is again more fossiliferous (bivalves and bioclasts mostly concentrated in coquinas). An interval of oolitic dolostone from 1'053.26 m to 1'056.54 m is possibly correlated with the Eptingen Bed (Pietsch et al. 2016).

The *upper boundary* is set at 1'030.65 m at the erosional top of a thick succession of dolostone overlain by bituminous shale of the Asp Member.

The *lower boundary* is set at 1'069.18 m at the lower boundary of the persistent and complete dolomitisation. This coincides with a colour change from dark greyish-brown to beige of the Stamberg Member above to the very light grey of the upper part of the Liedertswil Member below. Additionally, it is accompanied by a pronounced downwards increase of the apparent resistivity (FMI).

Lithology

- 1'030.65 m – 1'033.14 m Dolostone, near the top medium grey and homogeneous, then in transition to alternating patches of medium grey and beige-grey. The dolostone is formed by a dolomitised bioclastic limestone and is porous throughout. In the upper half of the section scattered, large (maximum 4 cm) anhydrite nodules, white, and abundant vugs (max. a few mm) with a "Rauhwacke"-like texture occur. Below 1'031.57 m vugs are sparse and smaller
- 1'033.14 m – 1'039.91 m Dolostone, with a sample gap between 1'035.29 m and 1'036.00 m and below the base (at 1'039.91 m):
- Dolostone, beige-grey, subordinately dark greyish-brown, down to 1'035.29 m the dolostone is partly formed by a dolomitised bioclastic limestone due to abundant shells. Close to the top, some lamination was found, elsewhere the section is homogeneous. Some open, mostly mm-sized vugs were found alongside some cm-sized anhydrite nodules, white
- The transition to a dolostone with fewer bioclasts is obscured by a lack of core or cuttings between 1'035.29 m and 1'036.00 m
- From 1'036.00 m to the base (1'039.91 m), dolostone, beige-grey and subordinately dark greyish-brown in patches and in the lower half mainly dark greyish-brown with subordinate patches of beige-grey, beige and medium grey. The dolostone is mostly formed by grains (< 2 mm) and is only sparsely fossiliferous (large shells of bivalves) and porous. According to thin section STA3-1-1039.78, the dolostone here is formed by a dolomitised oomicrite containing pellets and ooids. Small (maximum 1 cm) anhydrite nodules, white to light grey, occur throughout, mostly concentrated in clusters
- At 1'039.30 m and at 1'039.50 m, open vugs, a few mm in size, were found and at 1'039.79 m, close to the base, also ooids
- 1'039.91 m – 1'041.00 m Neither core nor cuttings sampled
- 1'041.00 m – 1'046.87 m Succession of dolostone mainly differing in colour:
- From the top (1'041.00 m) to 1'043.66 m, dolostone, dark greyish-brown with subordinate patches of beige-grey, beige and medium grey, porous. Throughout the section large (maximum 7 cm) solitary anhydrite nodules occur, white to light grey
- From 1'043.66 m to 1'046.87 m, alternation of dolostone, beige-grey, and dolostone, dark greyish-brown, in transition to dolostone (argillaceous), dark beige, thin-bedded but partly dispersed by intense bioturbation. Near the base large (maximum 5 cm) anhydrite nodules, white, were found
- 1'046.87 m – 1'053.26 m Dolostone, alternating medium light grey and medium grey, partly also dark grey. The dolostone is mostly formed by grains (< 2 mm) and frequent black peloids resulting in a foamy texture and is generally bioclastic and porous. Some open vugs (a few mm) are due to dissolution of bioclasts. At the top of the interval, the dolostone is

formed by a dolomitised oomicrite containing pellets, ooids and bivalves (thin section STA3-1-1047.76). Anhydrite nodules, white, are located at 1'048.75 m, 1'048.84 m and at 1'049.16 m

- 1'053.26 m – 1'056.54 m Oolitic dolostone, medium light grey to medium grey, as densely packed ooids within a sparse micritic matrix, with four prominent coquina layers and open vugs. The section probably corresponds to the Eptingen Bed
- From 1'054.39 m to 1'055.34 m, interbed of dolostone, light grey to medium light grey with black peloids
- From 1'056.10 m to 1'056.54 m, the base of the section is formed by a thin-bedded alternation of dolostone, beige-grey to dark beige, and dolostone, bioclastic, consisting of abundant coquina layers and ooids, riddled with vugs, partly filled with calcite. A single large anhydrite nodule was found near the top. Top and base are erosional surfaces
- 1'056.54 m – 1'059.43 m Dolostone (argillaceous), in the upper part medium light grey to medium grey, in the lower part transitioning to beige-grey to dark greyish-brown, slightly to moderately bioturbated
- From 1'059.22 m to the base (1'059.43 m), dolostone, very light grey, as dolomitised bioclastic limestone. Coquinas and cm-sized vugs partly filled with dolomite are abundant
- 1'059.43 m – 1'062.18 m Alternation of dolostone, dark greyish-brown and thin (1 cm to 3 cm) beds of dolostone (argillaceous), dark grey. Dolostone dominates the upper part down to 1'061.02 m, and transitions there to dolostone (argillaceous). The whole interval is slightly to moderately bioturbated. A single layer of bioclasts < 0.2 mm, very light grey is located at 1'060.43 m
- 1'062.18 m – 1'066.19 m Dolostone, dark greyish-brown, as abundant patches in dolostone (argillaceous), dark grey, with black, elongated peloids. Peloids are concentrated mainly in two distinct zones, elsewhere peloids are sparse. Towards the base the dolostone is formed by grains < 2 mm. The whole section shows open vugs with an overall porous and bioturbated appearance
- From 1'063.74 m to 1'063.94 m, dolostone, as coquina, dark greyish-brown, in micritic dolostone, dark beige
- 1'066.19 m – 1'069.18 m From the top (1'066.19 m) to 1'066.34 m bed of dolostone (argillaceous), dark grey, as interbedding of dolostone and thin (1 cm to 3 cm) layers of dolomitic marl. Beneath the dolostone, dark greyish-brown, subordinately beige-grey with sparse peloids. The section is moderately to intensely bioturbated. Several coquinas with many open vugs and some cm-thick bioclastic layers in a matrix of dolomitic marl, dark grey, interrupt the main lithology. A large (7 cm x 2 cm) vug filled with calcite is located at 1'069.14 m

3.9.1.3 Liedertswil Member, 1'069.18 m – 1'071.02 m (1.84 m)

Because of the deep penetration of post-sedimentary, persistent and complete dolomitisation in STA3-1, the Liedertswil Member is very thin. It is formed by a medium-bedded succession of bioturbated limestone (dolomitic in the lower part).

The *upper boundary* is set at 1'069.18 m at the lower boundary of the persistent and complete dolomitisation. This coincides with a colour change from dark greyish-brown to beige of the Stamberg Member above to the very light grey of the upper part of the Liedertswil Member below. Additionally, it is accompanied by a pronounced downwards increase of the apparent resistivity (FMI).

The *lower boundary* is set at 1'071.02 m at the top of the uppermost bioclastic bed which is thicker than 10 cm and contains more than 10% crinoids.

Lithology

- | | |
|-------------------------|--|
| 1'069.18 m – 1'070.23 m | Limestone (mudstone, micrite), very light grey to medium light grey, sparse peloids and bioturbated. From 1'070.09 m to the base (1'070.23 m), limestone as above but argillaceous |
| 1'070.23 m – 1'071.02 m | Limestone (dolomitic) (mudstone, micrite), beige-grey down to 1'070.66 m, beneath medium grey and with laminae of calcareous marl, dark grey. The section contains sparse peloids and is bioturbated |

3.9.1.4 Leutschenberg Member and Kienberg Member, 1'071.02 m – 1'099.03 m (28.01 m)

For the present purpose, the Leutschenberg Member and the overlying Kienberg Member should be combined because a separation may not be possible at all locations in question according to Jordan & Deplazes (2019). 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 and often partly dolomitised (Merki 1961).

In STA3-1, this threefold division can be well observed with the non-fossiliferous section extending from 1'084.61 m (an erosional surface) to 1'090.81 m. However, the Saalhof Bed (Pietsch et al. 2016), formally separating the Leutschenberg Member from the Kienberg Member, could not be identified. The bioclastic limestone from 1'084.30 m to 1'084.16 m above the non-fossiliferous section contains crinoids (and the Saalhof Bed should not). The erosional surface, on the other hand, supports the thesis of a demarcation (Merki 1961, Pietsch et al. 2016).

The *upper boundary* is set at 1'071.02 m at the top of the uppermost bioclastic which is thicker than 10 cm and contains more than 10% crinoids.

The *lower boundary* is set at 1'099.03 m where an oncolitic limestone (dolomitic) overlies the uppermost occurrence of dolostone.

Lithology

1'071.02 m – 1'075.29 m Limestone (partly argillaceous) (mudstone, micrite), dark greyish-brown, beige-grey to medium grey, slightly to moderately bioturbated. The boundaries between the lithologies are mostly stylolitic with up to cm-thick, nodular coatings of claystone

The limestone interval is interrupted by two types of thin beds:

- dm-thick beds of limestone (wackestone, biomicrite), beige-grey and medium grey, from 1'073.23 m to 1'073.68 m with scattered lithoclasts (< 2 mm) of claystone, black, moderately fossiliferous (crinoids, bivalves, bioclasts, rarely brachiopods)
- rare, maximum 14 cm thick beds of bioclastic limestone (wackestone and packstone, biomicrite), beige-grey and medium grey, very fossiliferous (abundant ruditic crinoids and bivalves, subordinate bioclasts and brachiopods < 2 mm), partly with open vugs

From 1'071.26 m to 1'074.41 m, several cm-thick, bioclastic layers with bivalves and many open vugs

1'075.29 m – 1'084.61 m Alternation of:

- limestone (mudstone, micrite), beige-grey to medium grey, and dark greyish-brown, slightly to moderately bioturbated, occasionally with burrows
- limestone (wackestone, biomicrite), dark greyish-brown to medium grey and beige-grey and medium grey but speckled by calcareous intraclasts < 2 mm, moderately fossiliferous (whitish fossils of crinoids, bivalves and bioclasts), burrows
- subordinate bioclastic limestone (packstone, biomicrite) as thicker (maximum 48 cm) beds than above, beige-grey and medium grey, very fossiliferous (crinoids, bivalves, bioclasts), occasionally with open vugs in the lower part of the section

The boundaries are mostly stylolitic, and sometimes also erosional, with up to cm-thick claystone coatings, black. Often a rapid transition was noticed downwards from mudstone at the top to wackestone above a stylolitic base

From 1'080.00 m to 1'080.37 m and from 1'082.04 m to 1'082.35 m, some large (maximum 3 cm) limestone intraclasts, medium grey

1'084.61 m – 1'089.48 m Limestone (mudstone, micrite), light grey to medium light grey, moderately to intensely bioturbated. Stylolites exhibit abundant coatings of claystone. The coating thickness increases downwards from a few mm to 1 cm

- 1'089.48 m – 1'094.50 m Limestone (slightly dolomitic) (mudstone, micrite), dark greyish-brown and medium light grey to beige-grey, moderately bioturbated. Vugs occur almost throughout the section and are either open or filled with calcite. The section contains crinoids and bioclasts along with few oncoids below 1'090.81 m and is almost continually bioturbated and burrowed in sections
- From 1'094.28 m to 1'094.50 m, both lithologies exhibit frequent limestone clasts (wackestone, biomicrite), light grey, with crinoids
- 1'094.50 m – 1'096.00 m Oncolitic limestone (slightly dolomitic), beige-grey to dark greyish-brown, with peloids and densely packed oncoids (maximum a few cm). The bioclastic matrix with crinoids and echinoderms is of brighter colour than the oncoids (thin section STA3-1-1095.82). The section is intensely bioturbated and open vugs (maximum 1 cm) occur near top and base
- 1'096.00 m – 1'099.03 m Limestone (dolomitic) (mudstone, micrite), dark greyish-brown, towards the base beige-grey, sparse oncoids gradually vanishing downwards. A bored surface is located at the top (1'096.00 m). Fossils below 1'096.92 m include scattered bivalves and crinoids
- From 1'096.85 m to 1'096.92 m, cm-thick intervals of mm-sized anhydrite nodules, black
- At 1'097.94 m, microbial mat followed by a coquina layer (at 1'098.31 m) and some limestone lithoclasts (wackestone, biomicrite), beige-grey to medium light grey, with crinoids (at 1'098.60 m)
- From 1'098.91 m to the base (1'099.03 m), oncolitic limestone (dolomitic) (packstone, oncomicrite), beige-grey to greyish-brown. The oncoids (maximum 3 cm) are densely packed

3.9.2 Zeglingen Formation, 1'099.03 m – 1'178.43 m (79.40 m)

The Zeglingen Formation (Jordan et al. 2016) is an evaporitic sequence with anhydrite, rock salt and dolostone.

The *upper boundary* is set at 1'099.03 m where an oncolitic limestone (dolomitic) overlies the uppermost occurrence of dolostone.

The *lower boundary* is set at 1'178.43 m at the topmost bed of dolostone. Anhydrite is found down to 1'180.64 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 STA3-1 as follows:

- 1'099.03 m – 1'109.13 m «Dolomitzone» (10.10 m)
- 1'109.13 m – 1'135.31 m «Obere Sulfatzone» (26.18 m)

1'135.31 m – 1'174.87 m «Salzlager» (39.56 m)

1'174.87 m – 1'178.43 m «Untere Sulfatzone» (3.56 m)

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

The considerable thickness of the «Salzlager» (delimited by the uppermost and lowermost occurrence of rock salt) was surprising and unexpected compared to the findings of the nearby boreholes BUL1-1B (Jordan et al. 2021a), TRU1-1 (Schwarz et al. 2021) and MAR1-1 (Jordan et al. 2021b).

Lithology

«Dolomitzone», 1'099.03 m – 1'109.13 m (10.10 m)

1'099.03 m – 1'102.67 m Section consists entirely of dolostone, beige-grey, subordinately dark beige and greyish-brown. Near top and base the section is strongly laminated by microbial mats, some layers are disrupted into fragments of nodular layers, others are intensely bioturbated. Scattered chert nodules, black, and two anhydrite nodules (at 1'102.60 m) were found

From 1'099.90 m to 1'100.02 m, breccia, dolomitic (monomict), as flat pebbles of dolostone

1'102.67 m – 1'108.15 m Homogeneous section of dolostone, beige-grey in the upper part, beneath medium light grey, in the laminated sections dark beige to dark greyish-brown. A lamination due to microbial mats was identified

Throughout the section anhydrite, white, as mm-sized nodules mostly concentrated in cm-thick layers, interrupts the dolostone. Three prominent nodules are located at 1'104.13 m, 1'104.58 m and 1'106.07 m. Chert nodules, dark grey, and layers of silicified dolostone (maximum 6 cm) occur across the whole section. From 1'103.64 m to 1'103.93 m, intraclasts, dark grey, silicified with angular shape were found

From 1'107.24 m to 1'107.40 m, breccia, anhydritic (polymict), consisting of bands and clasts of anhydrite, light grey, of large clasts of chert nodules, and of dolostone, oolitic, all embedded in a matrix of dolostone, dark greyish-brown (thin section STA3-1-1107.37)

From 1'107.40 m to 1'107.51 m, anhydrite, white, layered, with platy to rounded clasts of dolostone (maximum 1 cm), beige-grey

1'108.15 m – 1'109.13 m Dolostone (argillaceous), medium light grey, homogeneous with a thin layer of dolomitic marl, medium light grey to medium grey at the top (from 1'108.15 m to 1'108.32 m)

«Obere Sulfatzone», 1'109.13 m – 1'135.31 m (26.18 m)

- 1'109.13 m – 1'110.20 m Anhydrite, dark beige to medium light grey, homogeneous to laminated
- 1'110.20 m – 1'111.29 m Succession of dolostone, beige-grey, (laminated with a chert layer, dark grey to black, and one single large white anhydrite nodule), and argillaceous marl (dolomitic), medium grey, bedded by serrate dolostone nodules, medium light grey
- 1'111.29 m – 1'112.77 m Dolostone, beige-grey, with maximum 1 cm-thick layers of claystone, black. Anhydrite nodules, chert layers and a single chert nodule
- 1'112.77 m – 1'113.86 m Anhydrite (argillaceous), as thin (maximum 3 cm) anhydrite layers and bands, white to light grey, within a claystone, medium grey. This main lithology is interrupted by an interval of claystone (anhydritic), as sparse anhydrite layers in claystone, medium grey (from 1'113.18 m to 1'113.46 m). One prominent anhydrite nodule is located at 1'113.46 m
- 1'113.86 m – 1'117.34 m Two-fold succession of dolomitic marl, beige-grey and medium grey, and dolostone (argillaceous), beige-grey. The dolomitic marl contains sparse anhydrite bands, veins and layers and occasionally nodules in layers, white to light grey. The dolostone (argillaceous) is laminated by microbial mats and contains some chert layers (at 1'115.21 m and at 1'115.27 m). Within the lower bed of dolostone (argillaceous) microbial mats are absent
- This succession is interrupted at 1'115.56 m and from 1'115.70 m to 1'115.85 m by clusters and thin layers of small, white anhydrite nodules
- 1'117.34 m – 1'120.80 m Anhydrite (argillaceous), and subordinately anhydrite, both lithologies consist of cm-thick bands of anhydrite, white to very light grey, embedded in a matrix of claystone (anhydritic), dark grey to medium grey. The layers are subhorizontal and partly irregularly wavy
- From 1'119.39 m to 1'119.72 m, anhydrite (argillaceous), as layers of densely packed, small anhydrite nodules in a claystone matrix
- 1'120.80 m – 1'126.03 m This section is dominated by the same lithologies as above but in reverse abundance:
- Anhydrite, and subordinately anhydrite (argillaceous), in both lithologies as bands of anhydrite, white to very light grey, with gradual transition to rare thin (max. 1 cm) beds of dolomitic marl, medium light grey to medium grey
- From 1'124.14 m to 1'124.21 m, argillaceous marl (dolomitic), medium light grey to medium grey, at the base (1'124.21 m) with frequent, elongated anhydrite nodules and nodular anhydrite layer

- 1'126.03 m – 1'128.55 m Alternation of mainly claystone (anhydritic), subordinately with claystone, and anhydrite (argillaceous). All lithologies are formed by crenulated bands of anhydrite, white to very light grey, in strongly varying abundance within claystone, dark grey. The separation between anhydrite and claystone is more distinct than above. Near the base the bands are disintegrated into either serrated or frazzled nodules
- At 1'128.39 m, anhydrite, white, both as a nodule and as a vein
- 1'128.55 m – 1'130.20 m From the top (1'128.55 m) to 1'129.12 m, the section starts with a conglomerate, anhydritic (polymict) formed by anhydrite bands disintegrated into both platy fragments and rounded clasts within claystone matrix. This is followed by anhydrite, and anhydrite (argillaceous). Both lithologies are formed by bands of anhydrite, white to very light grey, in varying abundance, embedded within a claystone matrix, dark grey
- From 1'129.12 m to 1'129.26 m, claystone, dark grey, with a single anhydrite nodule
- 1'130.20 m – 1'132.64 m Claystone (mostly anhydritic), as cm-thick bands of anhydrite, white to very light grey, in claystone, dark grey and dark beige. Anhydrite nodules were also found from 1'130.39 m to 1'131.12 m
- 1'132.64 m – 1'135.31 m From the top (1'132.64 m) to 1'132.81 m anhydrite as nodules. This is followed by a succession of anhydrite (argillaceous), with frequent interbeds of claystone, dark grey and dark beige, and anhydrite, white, banded, with sparse interbeds of claystone, dark grey and dark beige
- From 1'134.48 m to 1'134.62 m, breccia, anhydritic (polymict), bands completely disintegrated into platy, directionless fragments
- «Salzlager», 1'135.31 m – 1'174.87 m (39.56 m)**
- 1'135.31 m – 1'136.03 m Halite, translucent, coarse-grained as large, xenomorphic crystals, at intervals of 10 cm, thin (1 cm), frazzled layers of claystone, dark grey
- 1'136.03 m – 1'141.32 m Anhydrite, in alternation with and in transition to anhydrite (argillaceous), in both lithologies as gently dipping, slightly crenulated bands and nodular layers of anhydrite, white to light grey, and with varying abundance of a claystone matrix, dark grey. Some teepee structures were found below 1'139.31 m
- Halite-filled vugs are found from the top (1'136.03 m) to 1'136.22 m and from 1'140.08 m to 1'140.40 m
- From 1'140.67 m to 1'140.78 m, a thin interbedding of claystone (anhydritic), as a contorted anhydrite layer, white, in claystone, dark grey interrupts the main lithology

- 1'141.32 m – 1'154.50 m Pure halite with scattered clasts of claystone, occasionally in clusters:
From the top (1'141.32 m) to 1'144.32 m, halite, translucent, coarse-grained as large, xenomorphic crystals
From 1'144.32 m to 1'146.30 m, halite, medium grey to dark grey, rarely light brown to translucent, fine-grained
From 1'146.30 m to the base (1'154.50 m), halite, speckled appearance of colours from white and medium grey to dark grey, subordinately translucent and light brown, fine-grained. Throughout this part scattered clasts of claystone, subordinately of anhydrite and of laminated alternations of claystone and anhydrite were found
- 1'154.50 m – 1'162.58 m Succession dominated by massive or brecciated halite (argillaceous), scattered with lithoclasts:
From the top (1'154.50 m) to 1'157.75 m, halite (argillaceous), speckled colours as above but claystone clasts are more frequent here than above. Near the base additionally clusters of large clasts of laminated anhydrite, white, with claystone seams, dark grey. Clasts make up 30% of the rock volume with halite as matrix. The halite is more translucent than above
From 1'157.75 m to 1'160.00 m, breccia, halite (polymict), as a frazzled mesh of subvertical to vertical layer fragments formed by alternating bands of claystone, dark grey. Additionally, anhydrite, white, embedded in a halite matrix, translucent, was found
From 1'160.00 m to 1'160.81 m, halite (argillaceous), medium grey to dark grey, fine-grained, with scattered, large (a few cm) claystone clasts, dark grey. A prominent feature is a cobble (at 1'160.30 m) (size 15 cm) of a folded lamination of claystone, and claystone (anhedritic)
From 1'160.81 m to 1'161.85 m, anhydrite (argillaceous), as a mm- to cm-thick alternation of anhydrite, white and claystone, dark grey, with a recumbent fold
From 1'161.85 m to the base (1'162.58 m), halite (argillaceous), medium grey to dark grey, fine-grained, with mm-thick claystone layers, dark grey. At 1'162.58 m a layer fragment, the size of a coarse pebble of alternating anhydrite, claystone, and dolostone, riddled with vugs, was found
- 1'162.58 m – 1'165.41 m Halite, medium grey to dark grey, fine-grained down to 1'164.30 m, beneath more translucent, coarse-grained with large xenomorphic crystals, with sparse claystone clasts, dark grey. Near the base, the lithology trends towards halite (argillaceous), with mm-thick, crenulated to disrupted claystone layers, dark grey
- 1'165.41 m – 1'167.61 m Claystone (anhedritic), as a thin-bedded alternation of claystone, dark grey and claystone (anhedritic), medium grey, subordinately also anhydrite, white, with halite veins, reddish-brown to dark reddish-brown
From 1'166.90 m to 1'167.16 m, halite, translucent, coarse-grained with large xenomorphic crystals and claystone clasts

From 1'167.16 m to 1'167.61 m, breccia, claystone (polymict), thin-bedded alternation as above but fragmented and with a higher number of halite veins

1'167.61 m – 1'173.18 m Halite, mainly translucent, subordinately medium grey, rarely dark grey, coarse-grained with large xenomorphic crystals. Throughout the section scattered clasts (a few cm) of anhydrite, white to light grey were found (e.g. at 1'168.60 m large [16 cm × 5 cm], cluster of anhydrite clasts). In the lower half additionally clasts of claystone, dark grey, and of claystone, anhydritic, medium grey

1'173.18 m – 1'174.87 m Breccia, halite (polymict), as a frazzled mesh of both crenulated and folded layer fragments in halite matrix, translucent to reddish-brown, formed by:

- alternating bands of claystone, dark grey
- claystone (anhydritic), medium grey
- anhydrite, white
- dolostone, dark beige to dark greyish-brown

«Untere Sulfatzone», 1'174.87 m – 1'178.43 m (3.56 m)

1'174.87 m – 1'178.43 m This section is dominated by anhydrite in different varieties:

- as anhydrite bands, white, alternating with mm- to cm-thick layers of claystone, dark grey or dolostone, dark beige, in the lower part
- as anhydrite (argillaceous), as an alternation of anhydrite bands, white, with cm-thick claystone layers, dark grey. Additionally, anhydrite nodules, white (from 1'175.62 m to 1'176.63 m). Below 1'175.87 m the bands and layers are crenulated or disrupted
- as anhydrite, white, as irregularly wavy anhydrite bands, white, and with small claystone clasts

From 1'176.38 m to the base (1'176.63 m), claystone (anhydritic), crosscut by fractures and small vugs filled with anhydrite

3.9.3 Kaiseraugst Formation, 1'178.43 m – 1'215.50 m (37.07 m)

The Kaiseraugst Formation is usually a succession of claystone (calcareous, silty) to argillaceous marl (silty), partly bituminous in the upper part and with 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 the interbeds are lithostratigraphic marker horizons. To date, there is no formal subdivision of the Kaiseraugst Formation. 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 STA3-1 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 STA3-1 the upper part consists of claystone (calcareous) to calcareous marl and the lower part consists of sandstone (calcareous, argillaceous) and argillaceous sandstone (calcareous) with few thin interbeds of limestone (argillaceous) and a thicker bed of bioclastic limestone at the top.

The *upper boundary* is set at 1'178.43 m at the top of the uppermost bed of dolostone. Anhydrite is found down to 1'180.64 m.

The *lower boundary* is set at 1'215.50 m at the top of the thick sandstone interval starting with a 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 STA3-1 as follows:

1'178.43 m – 1'185.81 m «Orbicularismergel» (7.38 m) including the «Geislingen-Bank» from 1'184.52 m to 1'185.18 m

1'185.81 m – 1'208.52 m «Wellenmergel» (22.71 m) including the «Spiriferina-Bank» from 1'192.69 m to 1'193.34 m and the «Terebratula-Bank» from 1'199.58 m to 1'199.66 m

1'208.52 m – 1'215.50 m «Wellendolomit» (6.98 m) including the «Bleiglanz-Bank» from 1'208.52 m to 1'208.67 m

The boundary between the «Orbicularismergel» and the «Wellenmergel» is set at the base of the thin bioclastic limestone interval from 1'185.73 m to 1'185.81 m. This interval is correlated with the «Orbicularis-Bank» traditionally marking the base of the «Orbicularismergel» (Becker et al. 1997, Nagra 2001a, Jordan et al. 2021a).

The boundary between the «Wellenmergel» and the «Wellendolomit» is set at 1'208.52 m. It is the top of the «Bleiglanz-Bank», a regional marker horizon consisting of various beds of bioclastic limestone, dolostone (argillaceous), calcareous and argillaceous marl, most of them with conspicuous crystals of galena.

Lithology

«Orbicularismergel», 1'178.43 m – 1'185.81 m (7.38 m)

1'178.43 m – 1'180.64 m Succession of dolostone, dark beige to dark greyish-brown, homogeneous, with some thin (maximum 10 cm) layers of anhydrite and numerous fractures and vugs filled with white anhydrite and anhydrite, white to light grey, as bands in mm-thick alternation with subordinate dolostone, dark beige and dark greyish-brown, homogeneous with some anhydrite veins reaching into the dolostone beds

1'180.64 m – 1'182.50 m Gradual downwards transition from dolostone (argillaceous), dark greyish-brown, homogeneous, to dolomitic marl, dark grey and ultimately calcareous marl, dark grey (below 1'181.61 m)

The complete interval is interspersed with wide fractures and vugs mostly filled with anhydrite, white and pink, enclosing large (several cm) lithoclasts of calcareous marl (below 1'181.61 m)

1'182.50 m – 1'185.81 m Argillaceous marl, dark grey, slightly laminated, sparse fractures filled with anhydrite, white. A few bioclasts were found (from 1'184.42 m to 1'184.52 m)

From 1'184.52 m to 1'185.18 m, anhydrite, white to light grey, banded, in the upper part with claystone seams, dark grey, disintegrated to clasts

The section ends with a limestone (mudstone, micrite), medium grey to dark grey, bituminous, porous, sharp base and gradual top (from 1'185.73 m to the base [1'185.81 m])

«Wellenmergel», 1'185.81 m – 1'208.52 m (22.71 m)

1'185.81 m – 1'191.68 m Argillaceous marl, dark grey, in sections slightly laminated, with thin (maximum a few cm-thick) beds and lenses of calcareous sandstone, medium light grey, normally graded with bioclasts (< 2 mm) at the base. The base is sharp and the top gradual. Ripples occur in the thicker beds and lenses. Thin beds are clustered from 1'185.81 m to 1'186.02 m and from 1'186.68 m to 1'187.15 m. The upper interval shows flaser bedding

At 1'189.45 m, nodular, bioclastic layer, very light grey, with sharp top and base

From 1'190.23 m to 1'190.29 m, bioclastic limestone (packstone and grainstone, biomicrite and biosparite), very light grey, abundant large bivalves, sharp top and base

From 1'191.06 m to 1'191.18 m, in the upper part bioclastic limestone (packstone, biomicrite), medium light grey, abundant bioclasts, sharp top and base, very porous; in the lower part limestone (wackestone to packstone, biomicrite), medium grey, bioclastic, nodular

1'191.68 m – 1'192.61 m Claystone (calcareous), dark grey; with thin (maximum a few cm-thick) beds of limestone, medium light grey, sharp base and gradual top

1'192.61 m – 1'193.34 m Succession of a 6 cm thick limestone (mudstone, biomicrite) bed, medium grey, with bioclasts at the top and a sharp lower boundary, and from 1'192.69 m to 1'193.06 m, calcareous marl, as clasts of calcareous marl, bioclastic limestone and of limestone, in a matrix of argillaceous marl, dark grey, bioturbated. At the base a 28 cm thin-bedded alternation of limestone (mudstone, micrite) and three layers of bioclastic limestone (packstone, grainstone, biomicrite, biosparite), very light grey. The bioclastic layers are located from 1'193.06 m to 1'193.10 m, from 1'193.17 m to 1'193.24 m and from 1'193.31 m to the base (1'193.34 m). Pyrite nodules (< 5 mm) were found within all bioclastic layers and, within the lowermost, also galena

1'193.34 m – 1'200.44 m This section is dominated by argillaceous marl (slightly silty), from 1'193.56 m to 1'195.00 m and from 1'195.77 m to 1'197.60 m in transition to claystone (calcareous), dark grey. A few thin (maximum a few cm) beds and lenses of calcareous sandstone, medium light grey, with a sharp base and a gradual top were identified. These are often laminated and with ripples

This main lithology is interrupted by nodular, bioclastic layers, with sharp top and base (at 1'198.23 m and 1'199.50 m) and from 1'199.58 m to 1'199.66 m by a bioclastic limestone, light grey to medium light grey, with bivalves and brachiopods in a matrix of argillaceous marl, dark grey

1'200.44 m – 1'208.52 m Succession of argillaceous marl (slightly silty) and claystone (calcareous), with gradual transitions between the two lithologies. Both lithologies are dark grey. Bedding surfaces are sparsely with bivalves. A few single pyrite nodules and from 1'205.28 m to 1'206.52 m a slightly irregularly wavy bedded layer with scattered bioclasts (< 2 mm) were found. In addition, at 1'207.79 m and at 1'208.16 m, thin (maximum 3 cm) coquina layers, with nodular appearance and sharp top and base were identified

Subordinate thin beds and lenses of calcareous sandstone, medium light grey, with sharp base and gradual top, often laminated and with ripples

From 1'205.54 m to 1'205.55 m, sandy limestone (bioclastic), consisting of four cm-thick coquina layers, sandy, medium light grey, with argillaceous marl, dark grey, in between

«Wellendolomit», 1'208.52 m – 1'215.50 m (6.98 m)

1'208.52 m – 1'209.25 m Succession of (from top to base): bioclastic limestone, light grey (from 1'208.52 m to 1'208.67 m), with bivalves, brachiopods, bioclasts, galena («Bleiglanz-Bank»); calcareous marl, with beds and lenses of limestone (sandy), medium light grey, bioclastic, rippled; argillaceous marl, dark grey and dolostone (argillaceous), medium grey, homogeneous

1'209.25 m – 1'212.12 m Claystone (calcareous), dark grey, with thin beds and lenses of nodular limestone, medium light grey, consisting of rounded limestone clasts and bioclasts. Five thin coquina layers in the lower half were identified

From 1'211.41 m to 1'211.52 m and from 1'211.60 m to 1'211.73 m, calcareous marl, as densely stacked, thin limestone beds and lenses in claystone (calcareous)

1'212.12 m – 1'212.59 m Bioclastic limestone (sandy [fine-grained], dolomitic) (alternating packstone and grainstone, biomicrite and biosparite), white to medium grey with a matrix of micrite and quartz (angular, fine-grained). The quartz grains exhibit a calcite coating. Also, galena and small, black, lithic fragments (possibly claystone) were found. The bioclastic limestone is well-cemented (calcite). Fossils include abundant bivalves, crinoids, echinoderms and shell fragments (thin section STA3-1-1212.35)

From 1'212.59 m to 1'214.00 m Sandstone (fine-grained) (calcareous), very light grey to light grey, partly argillaceous and medium light grey to medium grey, quartz (angular), well sorted, moderately cemented (calcite) and below 1'213.60 m alternating silty and sandy marl, white to medium grey, quartz (angular, fine-grained), irregularly wavy-bedded, well-cemented (calcite)

1'214.00 m – 1'215.50 m Succession dominated by argillaceous sandstone (fine-grained), the upper bed dolomitic, medium grey to dark grey and dark greyish-brown, quartz (angular), moderately to well sorted, towards the base moderately cemented, flaser-bedded, elsewhere well-cemented (dolomite, calcite)

From the top (1'214.00 m) to 1'214.07 m, bioclastic limestone (sandy [fine-grained]), white to medium grey, abundant bioclasts, frequent bivalves, matrix is mainly micrite and subordinate quartz (angular, fine-grained), well-cemented (calcite)

From 1'214.70 m to 1'215.17 m, sandstone (fine- to medium-grained) (dolomitic, argillaceous), medium grey to dark grey, angular quartz, moderately to well sorted, well-cemented (dolomite and calcite)

3.10 Buntsandstein Group

3.10.1 Dinkelberg Formation, 1'215.50 m – 1'226.38 m (10.88 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 1'215.50 m at the top of the thick sandstone interval starting with a sandstone (fine-grained, argillaceous).

The *lower boundary* is set at 1'226.38 m at the base of the sandstone interval and the top of the siltstone (argillaceous) interval. This boundary, although not associated with an obvious change in colour, coincides with a sharp rise in GR readings and a distinct signature of the porosity-density-log, both indicating a change from quartz cement to an argillaceous matrix when moving into the Weitenau Formation. The argillaceous matrix is a result of feldspar dissolution as observed in the core. Hence, the boundary was set where the change in composition of the primary sediment presumably occurs (i.e. disappearance of feldspar and emergence of quartz grains).

Lithostratigraphic subdivision

There is as yet 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 STA3-1, this subdivision is not clearly recognisable. The «Rötton» seems to be missing as in other adjacent boreholes (e.g. Bülach-1-1 borehole; Jordan et al. 2021a). If the chalcedony nodules and calcareous concretions found from 1'218.81 m to 1'219.47 m are a relict of the «Karneol-Dolomit-Horizont», the interval from 1'219.47 m or, more obviously, from 1'220.00 m to the base (at 1'226.38 m) can be equated with the «Vogesensandstein». Consequently, the interval from the top (at 1'215.50 m) to 1'220.00 m would be the «Plattensandstein» including the «Karneol-Dolomit-Horizont».

Lithology

1'215.50 m – 1'216.87 m Sandstone (fine-grained) (down to 1'216.10 m argillaceous), beige-grey to dark greyish-brown, white to very light grey below 1'216.10 m, quartz (subrounded to rounded), irregularly wavy-bedded, well sorted, well-cemented (quartz)

From 1'215.96 m to 1'216.10 m, argillaceous sandstone, beige-grey to medium grey, as thin layers of siltstone (argillaceous), alternating with layers of sandstone, irregularly wavy-bedded

1'216.87 m – 1'217.90 m Sandstone (mainly fine-grained, subordinately medium-grained) (argillaceous), white, quartz (subrounded to rounded) and sparsely black, sand-sized lithic fragments, moderately to well sorted, well-cemented (quartz). The main lithology is interrupted by mm- to cm-thick layers of claystone, greyish-blue-green

From the top (1'216.87 m) to 1'217.77 m, strongly contorted bedding with large (maximum 4 cm x 3 cm) chalcedony nodules

1'217.90 m – 1'220.00 m Section starting with a sandstone, normal graded from medium- to fine-grained, white, quartz (subangular to subrounded), well sorted, well-cemented (quartz) down to 1'218.37 m, followed by a sandstone (fine- to medium-grained), mainly light greenish-grey and pale green, quartz (angular to rounded) and lithic fragments (< 2 mm), moderately to well sorted, cross-bedded from 1'218.37 m to 1'218.81 m, poorly to moderately cemented (quartz). This lithology contains a sparse claystone matrix with a large amount of grey-violet patches

From 1'218.81 m to 1'219.47 m, scattered chalcedony nodules (a few cm maximum), reddish-brown to dark reddish-brown and medium light grey

From 1'218.81 m to 1'219.02 m, at 1'219.40 m and 1'219.47 m, calcareous concretions as caliche layers and white pedogenic nodules

- 1'220.00 m – 1'222.36 m Sandstone (alternating fine- and medium-grained), mainly pale green, quartz (angular to subrounded), with sparse matrix of claystone as frayed, grey-violet patches, moderately to well sorted, moderately consolidated in the fine-grained sections, poorly consolidated and porous in the medium-grained sections. The whole section contains scattered chalcedony nodules (a few cm maximum), dark reddish-brown and medium grey
- 1'222.36 m – 1'223.79 m Sandstone (fine- to coarse-grained), mainly light greenish-grey, quartz (subangular to subrounded), the size of medium pebbles, from 1'223.43 m to the base (1'223.79 m) as conglomerate, sandstone (monomict). A matrix of claystone is partly present as frayed, grey-violet patches, normal graded from fine- to very coarse-grained from the top (1'222.36 m) to 1'222.81 m, elsewhere poorly sorted. The finer grained sections are moderately consolidated, the coarser sections are moderately to poorly consolidated. Below 1'222.81 m the sandstone is porous. Throughout the section sparse chalcedony nodules were found
- 1'223.79 m – 1'225.51 m This section starts with sparse chalcedony clasts (as above) down to 1'224.11 m, within a sandstone (coarse-grained with fine pebbles), very light grey and pale green, quartz (subrounded), normal graded from 1'225.28 m to the base (1'225.51 m) from fine- to very coarse-grained, sparse claystone matrix, poorly to moderately sorted, very poorly consolidated (loose sand)
- 1'225.51 m – 1'226.38 m Sandstone (medium-grained), very light grey, quartz (subangular to subrounded), well sorted, with mm-thick layers of claystone, greyish-blue-green, becoming more numerous and cm-thick towards the base, cross-bedded, well-cemented (quartz)
- At the base (1'226.38 m), thin layer of conglomerate, sandstone (monomict) with quartz up to the size of 2 cm

3.11 Permo-Carboniferous sediments

3.11.1 Weitenau Formation, 1'226.38 m – 1'280.88 m (> 54.50 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).

In STA3-1, the section from the top of the formation (at 1'226.38 m) to the final depth of the borehole at 1'280.88 m consists of siltstone (argillaceous) with few beds of sandstone (mostly fine-grained and argillaceous). Only from 1'243.47 m to 1'251.93 m, the abundance and thickness of (partly cross-bedded) sandstone beds increase slightly. Fanglomerates, as found in all nearby boreholes, are completely missing. Therefore, the whole drilled section probably corresponds to the informal «Playa-Serie».

The *upper boundary* is set at 1'226.38 m at the base of the sandstone interval and the top of the siltstone (argillaceous) interval. This boundary, although not associated with an obvious change in colour, coincides with a sharp rise in GR readings and a distinct signature of the porosity-density-log, both indicating a change from quartz cement to an argillaceous matrix when moving into the Weitenau Formation. The argillaceous matrix is a result of feldspar dissolution as observed in the core. Hence, the boundary was set where the change in composition of the primary sediment presumably occurs (i.e. disappearance of feldspar and emergence of quartz grains).

The *lower boundary* was not encountered before the final depth of the borehole at 1'280.88 m.

Lithology

- 1'226.38 m – 1'243.17 m Siltstone (argillaceous), reddish-brown to dark reddish-brown, micaceous. Greyish-green, irregular reduction spots probably stem from feldspar dissolution. They are a few cm in diameter. This main lithology is interrupted by only a few interbeds (< 30 cm) of:
- Siltstone (one bed) (sandy [fine-grained], argillaceous), reddish-brown to dark reddish-brown, irregularly wavy-bedded (from 1'229.24 m to 1'229.42 m)
- Sandstone (three beds) (fine-grained) (silty, argillaceous), quartz (angular), poorly sorted (from 1'233.15 m to 1'233.30 m, from 1'234.00 m to 1'234.30 m and from 1'239.91 m to 1'240.13 m). The uppermost interval is cross-bedded. All intervals are well-consolidated and tight
- Sandstone (a solitary lens) (fine-grained) (argillaceous), reddish-brown
- 1'243.17 m – 1'251.93 m This interval is similar to the one above but contains considerably more sandstone beds. All lithologies are micaceous. A dominant siltstone (argillaceous), reddish-brown to dark reddish-brown, is interrupted by intervals of three lithologies:
- siltstone (sandy [fine-grained], argillaceous), reddish-brown to dark reddish-brown
 - sandstone (fine-grained) (argillaceous), reddish-brown to dark reddish-brown, micaceous, with claystone matrix. The quartz grains are angular and poorly to moderately sorted. Cross-bedding was found from 1'243.52 m to 1'243.77 m and flaser-bedding with greenish claystone from 1'248.20 m to 1'248.40 m. The sandstone is very well-consolidated and tight
 - sandstone (fine- to medium-grained) (calcareous, argillaceous), medium light grey to medium grey in a patchy pattern, quartz, rare feldspar and rare black lithic fragments, all angular to subangular, claystone matrix, poorly to moderately sorted, micaceous, cross-bedded from 1'246.90 m to 1'247.20 m, well-cemented (quartz) and tight

The base of the section (from 1'251.20 m to 1'251.93 m) is formed by a sandstone (medium-grained, subordinatedly fine-grained) (calcareous, argillaceous), beige-grey to medium light grey, angular to subangular quartz and feldspar, moderately sorted, micaceous, well-cemented (calcite), with a few laminae of claystone, greyish-green

- 1'251.93 m – 1'257.50 m Siltstone (argillaceous), reddish-brown to dark reddish-brown, with greyish-green circular reduction spots some cm in diameter, micaceous. A 2 cm thick sandstone lens (fine-grained) (argillaceous), medium light grey to medium grey, laminated, was found at 1'256.00 m
- 1'257.50 m – 1'260.42 m This section stands out slightly due to a main lithology of siltstone (sandy [fine-grained], argillaceous), reddish-brown to dark reddish-brown, with greyish-green circular reduction spots, micaceous. Some idiomorphic feldspar crystals were found and, at 1'259.88 m, a cloudy cluster (8 cm wide) of small calcareous concretions was noticed. In addition, from 1'260.27 m to 1'260.34 m a sandstone layer (fine- to medium-grained) (calcareous, argillaceous), medium light grey, quartz (angular to subangular), subordinatedly feldspar and mica, was identified
- 1'260.42 m – 1'280.88 m Siltstone (argillaceous), reddish-brown to dark reddish-brown, with greyish-green circular reduction spots some cm in diameter. Throughout the section, many calcareous concretions were found, up to 8 cm in diameter, white and pink, in solitary occurrence and in cm-thick layers, as cloudy clusters or sparsely as veins. The most prominent ones were found at 1'261.13 m, 1'264.03 m, 1'264.93 m and at 1'266.40 m. From 1'272.84 m to 1'273.06 m, calcareous concretions were identified, increasing upwards in abundance, and coalescing into a continuous caliche bed at the top (1'273.06 m)
- From 1'260.86 m to 1'260.96 m, a slight variation of the main lithology (as described above) occurs in the form of a siltstone (sandy [fine-grained], argillaceous), dark reddish-brown and grey-violet, and from 1'267.14 m to 1'267.22 m a sandstone (fine-grained) (argillaceous), greyish-green to greyish-blue-green, partly rippled, interrupts the siltstone (argillaceous)
- From 1'268.69 m to 1'268.84 m, thin layers and lenses of sandstone are represented in the profile as a bed of sandstone (fine- to medium-grained) (calcareous, argillaceous), medium light grey, quartz (angular to subangular), subordinatedly feldspar and mica with a matrix of claystone. The sandstone is poorly sorted, cross-bedded, well-cemented (calcite) and shows laminae of claystone, greyish-green. Further below (from 1'276.42 m to 1'276.52 m) another bed of sandstone (fine-grained) (silty, argillaceous), greyish-green

4 Comparison with the forecast profile

The results of the STA3-1 borehole deviate considerably from the forecast. This mainly concerns the thicknesses but also the facies in some sections. Due to the lack of outcrops in the surroundings, especially of the Mesozoic units, only the findings of the Weiach borehole (Matter et al. 1988, Bläsi et al. 2013), located about 3.5 km to the west-northwest, as well as seismic models were available for the prognosis. A comparison with the BUL1-1/1B boreholes (Jordan et al. 2021a), which were drilled previously about 1.8 km east-southeast, shows good agreement in many sections but also considerable deviations in others.

The Molasse bedrock was encountered at the expected depth of 28 m (forecast was rounded to 30 m, Fig. 4-1). The Molasse Group proved to be thicker (374 m) than expected (335 m). The Siderolithic Group (2 m) is within the expected uncertainty (0 m to 10 m). As a result, the depth of the top of the Malm Group (406 m) was encountered some 21 m deeper than expected (385 m).

The «Felsenkalke» + «Massenkalk» are significantly thicker (127 m) than expected. Due to the erosive nature of the top of this formation, a thickness comparison with other boreholes, namely BUL1-1, is not meaningful. On the other hand, the encountered thicknesses of the Schwarzbach Formation (25 m) and the Villigen Formation (68 m) almost exactly match the expectation (BUL1-1: 23 m and 75 m). The marly Wildeggen Formation proved to be thinner (70 m) than expected (80 m) but significantly thicker than in BUL1-1 (54 m).

In STA3-1, the thickness of the upper part of the Dogger Group, the so-called «Brauner Dogger», is 83 m. The forecast was 100 m. As expected from the findings of BUL1-1, almost half of this sequence is constituted by the «Herrenwis Unit», the existence of which was still unknown at the time the forecast for STA3-1 was prepared (seismic analysis pointed to a sedimentary body of unknown nature). The «Herrenwis Unit» in STA3-1 (40 m) is practically as thick as in BUL1-1 (42 m). However, there are considerable differences in facies. The facies of the Opalinus Clay corresponds to expectations. However, instead of the forecasted 120 m, only 109 m were encountered (in BUL1-1 the thickness is 104 m).

The following formations, although encountered in the expected facies, proved to be thinner as predicted: the Staffelegg Formation (35 m instead of 40 m), the Klettgau Formation (29 m instead of 35 m) and the Bänkerjoch Formation (75 m instead of 80 m). It is remarkable that the thickness of the Staffelegg Formation corresponds exactly with the findings of BUL1-1. This also more or less applies to the thickness of the Keuper Group (104 m in STA3-1, 102 m in BUL1-1), which includes the Klettgau Formation and the Bänkerjoch Formation.

For the seismically clearly recognisable top of the Muschelkalk Group, the deviation between the findings and the forecast is only 12 m (1'026.62 m instead of 1'015 m). The thickness of the Schinznach Formation is constant over a wide area (Jordan 2016). Accordingly, it is not surprising that the encountered thickness of 72 m corresponds to the forecast rounded to 70 m.

While the presence of rock salt («Salzlager») in the Zeglingen Formation was not ruled out in the forecast, the thickness of the actual salt deposit (35 m, which also includes a few sections without halite) and, therefore, the significantly greater thickness of the Zeglingen Formation (79 m instead of the predicted 60 m) were surprising. In contrast, the thickness and facies of the underlying Kaiseraugst Formation (37 m instead of 40 m) and Dinkelberg Formation (11 m instead of 10 m) were in line with expectations. The base of the Mesozoic succession (1'226.38 m) was found about 21 m lower than expected (1'195 m).

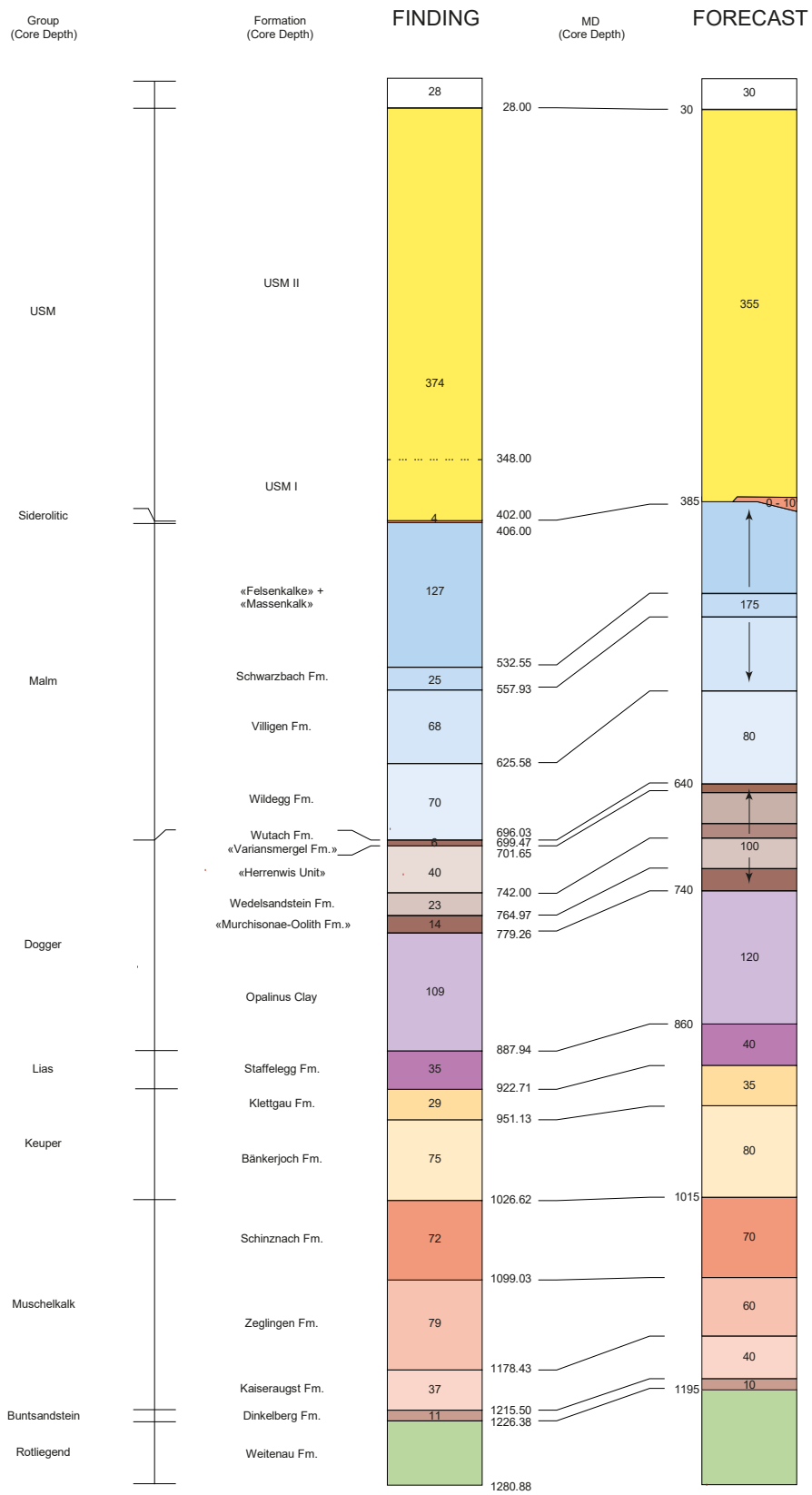


Fig. 4-1: Comparison of the forecast with the actual findings of STA3-1

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