

Arbeitsbericht NAB 21-22

**TBO Bözberg-2-1:
Data Report**

**Dossier III
Lithostratigraphy**

April 2022

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

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Lithostratigraphy**

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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 Dossier was prepared by a project team consisting of:

P. Jordan (core description, profile compilation, writing and QC)

M. Schwarz (cuttings and core description and QC)

R. Felber (cuttings and core description)

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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. C-2: Lithostratigraphy profile Bözberg-2-1, 1:100, 280.00 m to 570.00 m MD core depth
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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 Bözberg-2-1 borehole.

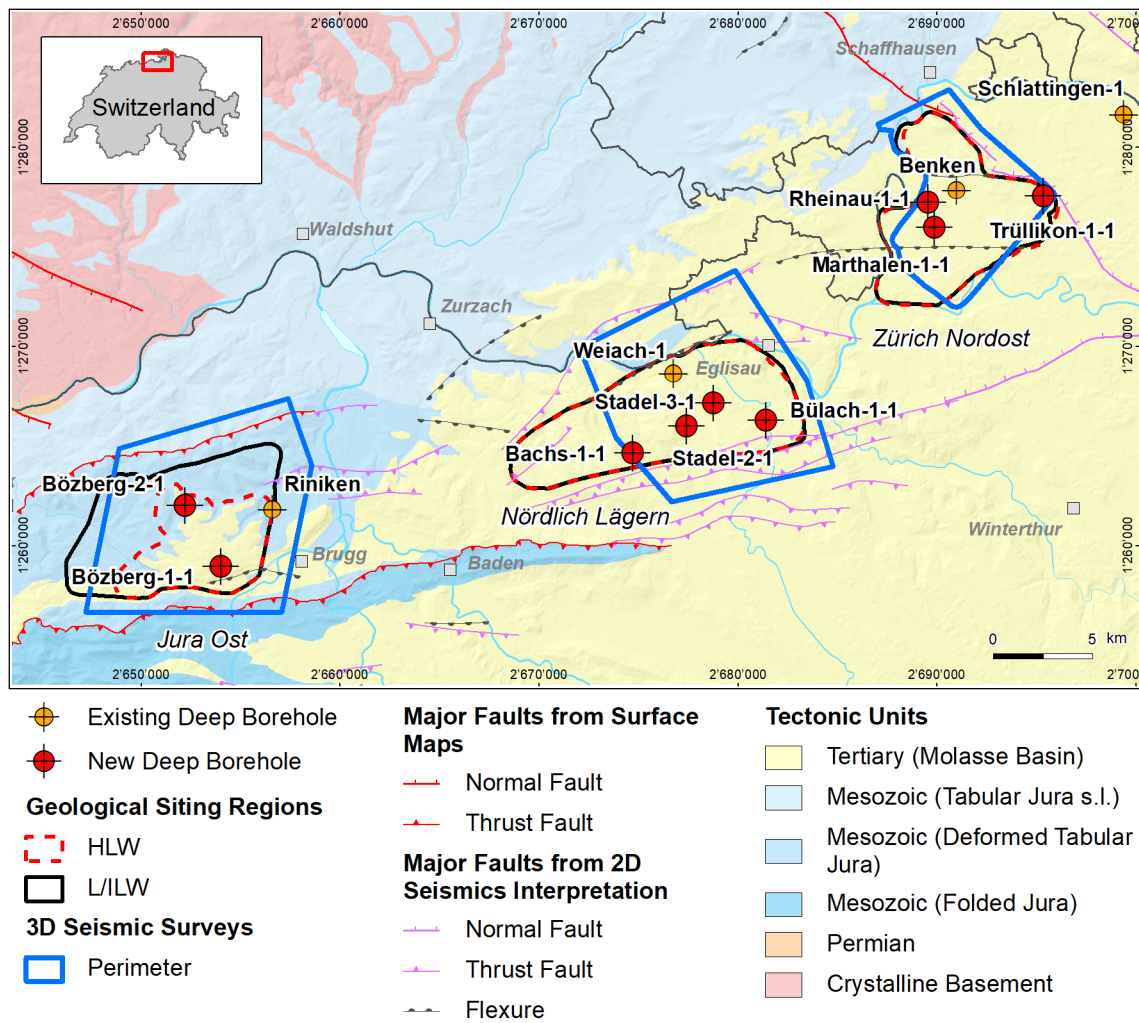


Fig. 1-1: Tectonic overview map with the three siting regions under investigation

1.2 Location and specifications of the borehole

The Bözberg-2-1 (BOZ2-1) exploratory borehole is the fifth borehole drilled within the framework of the TBO project. The drill site is located in the northern part of the Jura Ost siting region (Fig. 1-2). The vertical borehole reached a final depth of 829.11 m (MD)¹. The borehole specifications are provided in Tab. 1-1.

Tab. 1-1: General information about the BOZ2-1 borehole

Siting region	Jura Ost
Municipality	Bözberg (Canton Aargau / AG), Switzerland
Drill site	Bözberg-2 (BOZ2)
Borehole	Bözberg-2-1 (BOZ2-1)
Coordinates	LV95: 2'652'218.764 / 1'261'985.437
Elevation	Ground level = top of rig cellar: 624.33 m above sea level (asl)
Borehole depth	829.11 m measured depth (MD) below ground level (bgl)
Drilling period	11th August – 14th December 2020 (spud date to end of rig release)
Drilling company	Daldrup & Söhne AG
Drilling rig	Wirth B 152t
Drilling fluid	Water-based mud with various amounts of different components such as ² : 0 – 370 m: Bentonite & polymers 370 – 615 m: Potassium silicate & polymers 615 – 829.11 m: Pure-Bore®

The lithostratigraphic profile and the casing scheme are shown in Fig. 1-3. The comparison of the core versus log depth³ of the main lithostratigraphic boundaries in the BOZ2-1 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 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.

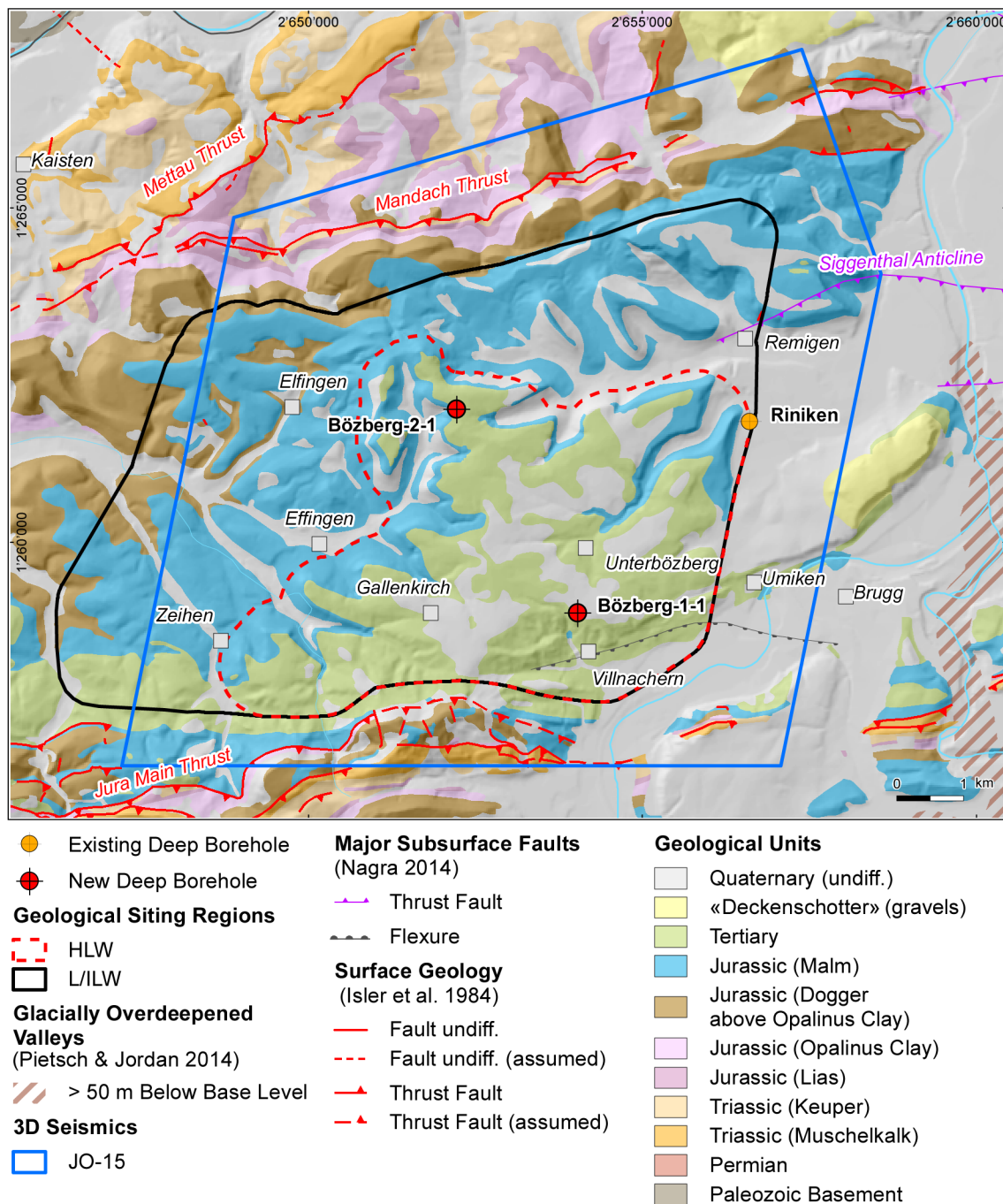


Fig. 1-2: Overview map of the investigation area in the Jura Ost siting region with the location of the BOZ2-1 borehole in relation to the boreholes Riniken and BOZ1-1

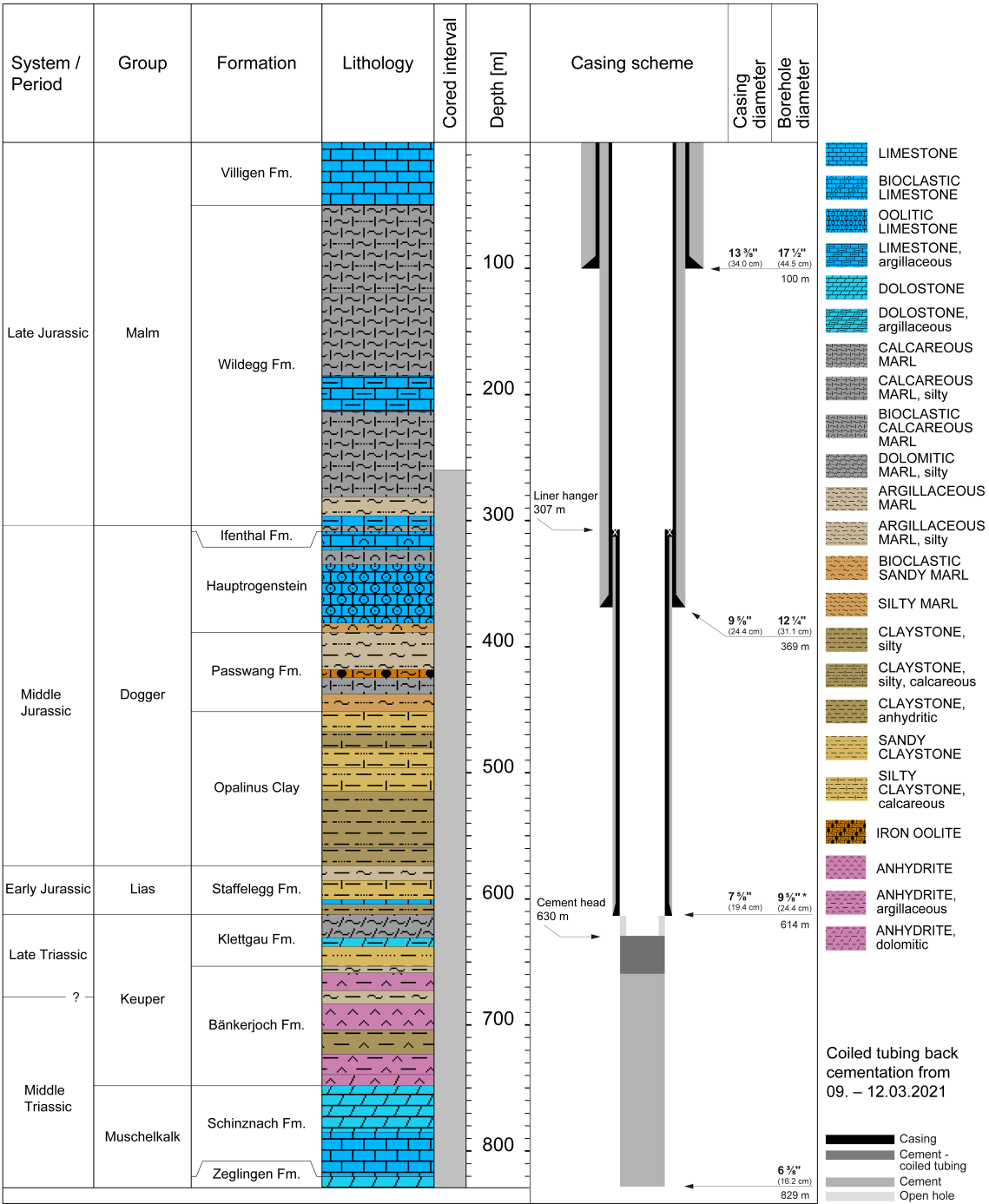


Fig. 1-3: Lithostratigraphic profile and casing scheme for the BOZ2-1 borehole⁴

⁴ For detailed information about the casing scheme see Dossier I.

Tab. 1-2: Core and log depth for the main lithostratigraphic boundaries in the BOZ2-1 borehole⁵

System / Period	Group	Formation	Core depth in m (MD)	Log
Jurassic	Malm	Villigen Formation		—
		Wildegge Formation	50.0	—
	Dogger	Ifenthal Formation	303.95	304.38
		Hauptrogenstein	308.70	309.07
		Passwang Formation	388.54	388.97
		Opalinus Clay	451.54	451.90
	Lias	Staffellegg Formation	573.68	573.89
		612.46	612.76	
Triassic	Keuper	Klettgau Formation		—
		Bänkerjoch Formation	653.45	654.70
	Muschelkalk	Schinznach Formation	748.27	749.52
			820.32	821.09
		Zeglingen Formation	829.11	829.88
			final depth	

⁵ 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 BOZ2-1 borehole

NAB 21-22 documents the majority of the investigations carried out in the BOZ2-1 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 BOZ2-1 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 21-22

Black indicates the dossier at hand.

Dossier	Title	Authors
I	TBO Bözberg-2-1: Drilling	P. Hinterholzer-Reisegger
II	TBO Bözberg-2-1: Core Photography	D. Kaehr & M. Gysi
III	TBO Bözberg-2-1: Lithostratigraphy	P. Jordan, P. Schürch, H. Naef, M. Schwarz, R. Felber, T. Ibele & M. Gysi
IV	TBO Bözberg-2-1: Microfacies, Bio- and Chemostratigraphic Analyses	S. Wohlwend, H.R. Bläsi, S. Feist-Burkhardt, B. Hostettler, U. Menkveld-Gfeller, V. Dietze & G. Deplazes
V	TBO Bözberg-2-1: Structural Geology	A. Ebert, L. Gregorczyk, S. Cioldi, E. Hägerstedt & M. Gysi
VI	TBO Bözberg-2-1: Wireline Logging, Micro-hydraulic Fracturing and Pressure-meter Testing	J. Gonus, E. Bailey, J. Desroches & R. Garrard
VII	TBO Bözberg-2-1: Hydraulic Packer Testing	R. Schwarz, M. Willmann, S. Reinhardt, S.M.L. Hardie, M. Voß & A. Pechstein
VIII	TBO Bözberg-2-1: Rock Properties, Porewater Characterisation and Natural Tracer Profiles	T. Gimmi, L. Aschwanden, L. Camesi, E. Gaucher, A. Jenni, M. Kiczka, U. Mäder, M. Mazurek, D. Rufer, H.N. Waber, P. Wersin, C. Zwahlen & D. Traber
IX	TBO Bözberg-2-1: Rock-mechanical and Geomechanical Laboratory Testing	E. Crisci, L. Laloui & S. Giger
X	TBO Bözberg-2-1: Petrophysical Log Analysis	S. Marnat & J.K. Becker
	TBO Bözberg-2-1: 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-3

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 Riniken borehole (Matter et al. 1987). 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 02.03.2021.

All depths in the core descriptions refer to core depth. Depths in the cuttings sections, where a full suite of petrophysical logs was available, refer to log 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 facility in Würenlingen. The different lithologies of a single sample were identified using a microscope, hydrochloric acid as well as colour and grain size charts. An important additional source of information was the operational geology plot produced by the mud logging company, containing data on the rate of penetration (ROP), revolutions per minute (RPM), a 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 which weight fraction was lost during sampling and sample preparation (washing and sieving) at the drill site. Therefore, the descriptions given in the field logs refer solely to the material in the washed samples and do not consider potentially lost lithologies.
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. Outcrops or cores of the Villigen Formation 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. No petrophysical logs were available from 0 m to 103 m MD (log depth). 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 this section 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. 74 m).
5. From 103 m MD (log depth) onwards, a full suite of petrophysical logs was available. Between 103 m and 260 m MD (log depth), only cuttings samples were available and lithological boundaries were occasionally modified according to the petrophysical logs, e.g. from 247.3 m to 248.7 m MD (log depth) where a limestone bed could be located more precisely on the logs than with the sample boundaries (from 246 m to 250 m MD). Depths in the text and profile for this section are accurate to one significant digit.
6. From 260 m MD (core depth) onwards (coring section), depths in the text and profile are accurate to two significant digits and refer to measured depth (MD), e.g. 612.46 m MD (core depth).

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 is feasible using patterns, symbols and plain text as indicated in Naef et al. (2019). The general objective of the field notes was to ensure a comprehensive documentation of all relevant features visible in the core. The subsequent representation of the field logs in the TerraStation profile at a scale of 1:100 required substantial graphical generalisations and, to some extent, also summaries of lithological descriptions. Beds of 20 cm thickness are 2 mm thick at a scale of 1:100 and still clearly show the lithological colour code from Naef et al. (2019). An individual lithological description is, however, not feasible. For thinner beds (< 20 cm), the patterns are increasingly difficult to identify and eventually collapse into black lines, interrupting the lithological pattern above and below (e.g. from 660.15 m to 662.27 m MD (core depth), Grünschoholz Member, Breitenmatt Member and Rickenbach Member). 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 instances, 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 limestones composed of small calcite crystals, possibly dolomitised and then dedolomitised, the term "limestone (saccharoidal)" was used exclusively. The term "saccharoidal" was used instead of, or in addition to, the Folk classification.

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

The use of the **bituminous shale** pattern was restricted to well-known organic-rich formations such as parts of the Asp Member, the Riethem Member and the 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 are 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.

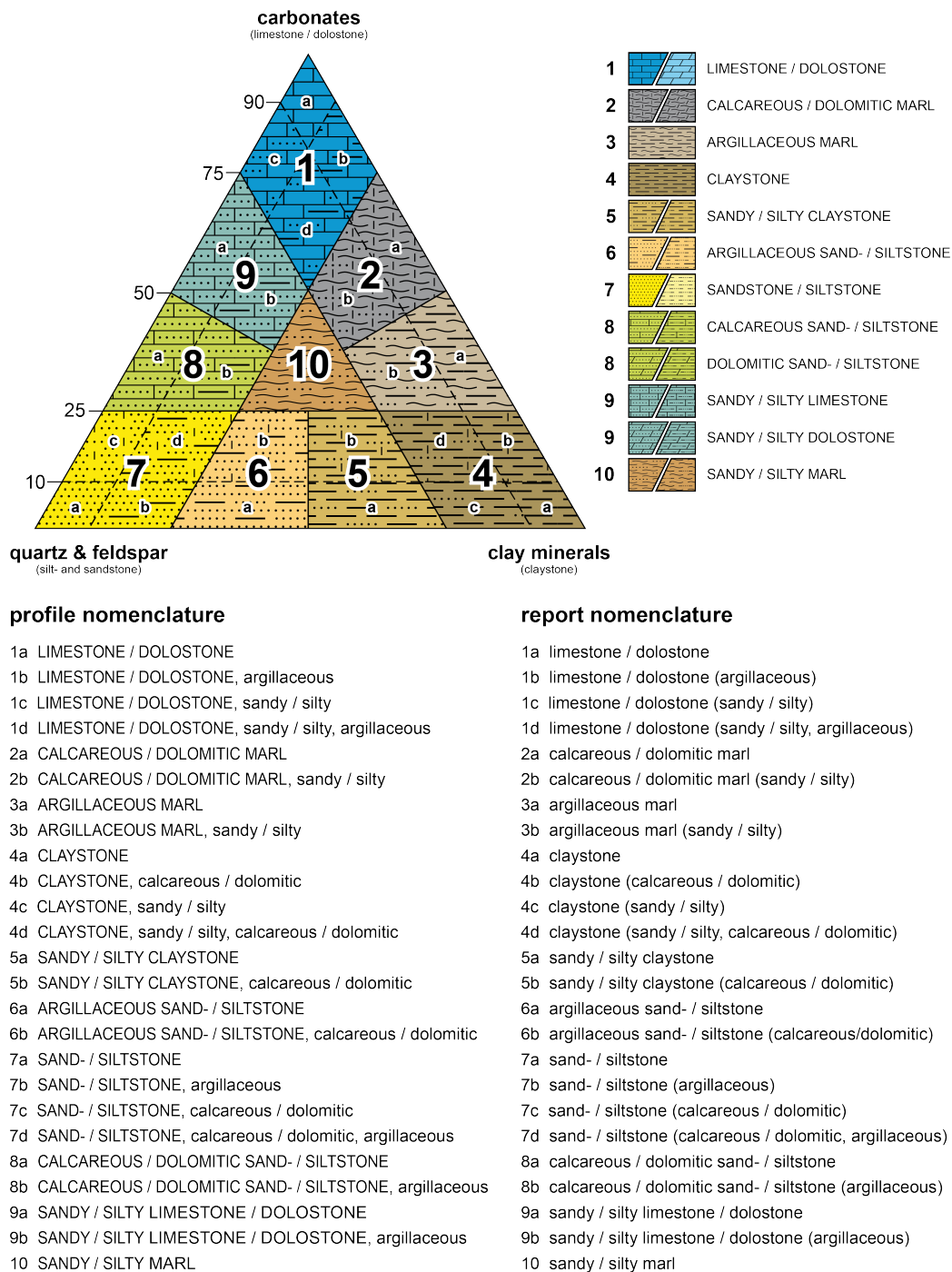
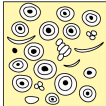
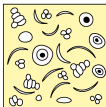


Fig. 1-4: Füchtbauer scheme for lithology names in the geological profiles and in this report
Pers. comm. S. Wohlwend modified after Naef et al. (2019)

Classification of Carbonate Rocks after Folk (1959, 1962) slightly modified after Flügel (1982) and Lokier & Junaibi (2016)										
		> 10% Allochems (grains): Allochemical Rocks				< 10% Allochems		In situ organic growth structures		
		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% Intraclasts	Intrasparite (median grains < 2mm) Intrasparrudite (median grains > 2mm)			Intramicrocrystalline (median grains < 2mm) Intramicrocrudite (median grains > 2mm)			Intraclast-bearing micrite (Intraclasts dominate)		
		Oosparite (median grains < 2mm) Oosparrudite (median grains > 2mm)			Oomicrite (median grains < 2mm) Oomicrudite (median grains > 2mm)			Ooid-bearing micrite (Ooids dominate)		
	> 25% Ooids	Biosparite (median grains < 2mm) Biosparrudite (median grains > 2mm)			Biomicrite (median grains < 2mm) Biomicrudite (median grains > 2mm)			Bioclastic micrite (Bioclasts dominate)		
		Biopelsparite			Biopelmicrite					
	< 25% Intraclasts	< 25% Ooids	Volume ratio of Fossils to Pellets							
			Volume ratio of Fossils to Pellets							
			Volume ratio of Fossils to Pellets							
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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 and sampling.

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

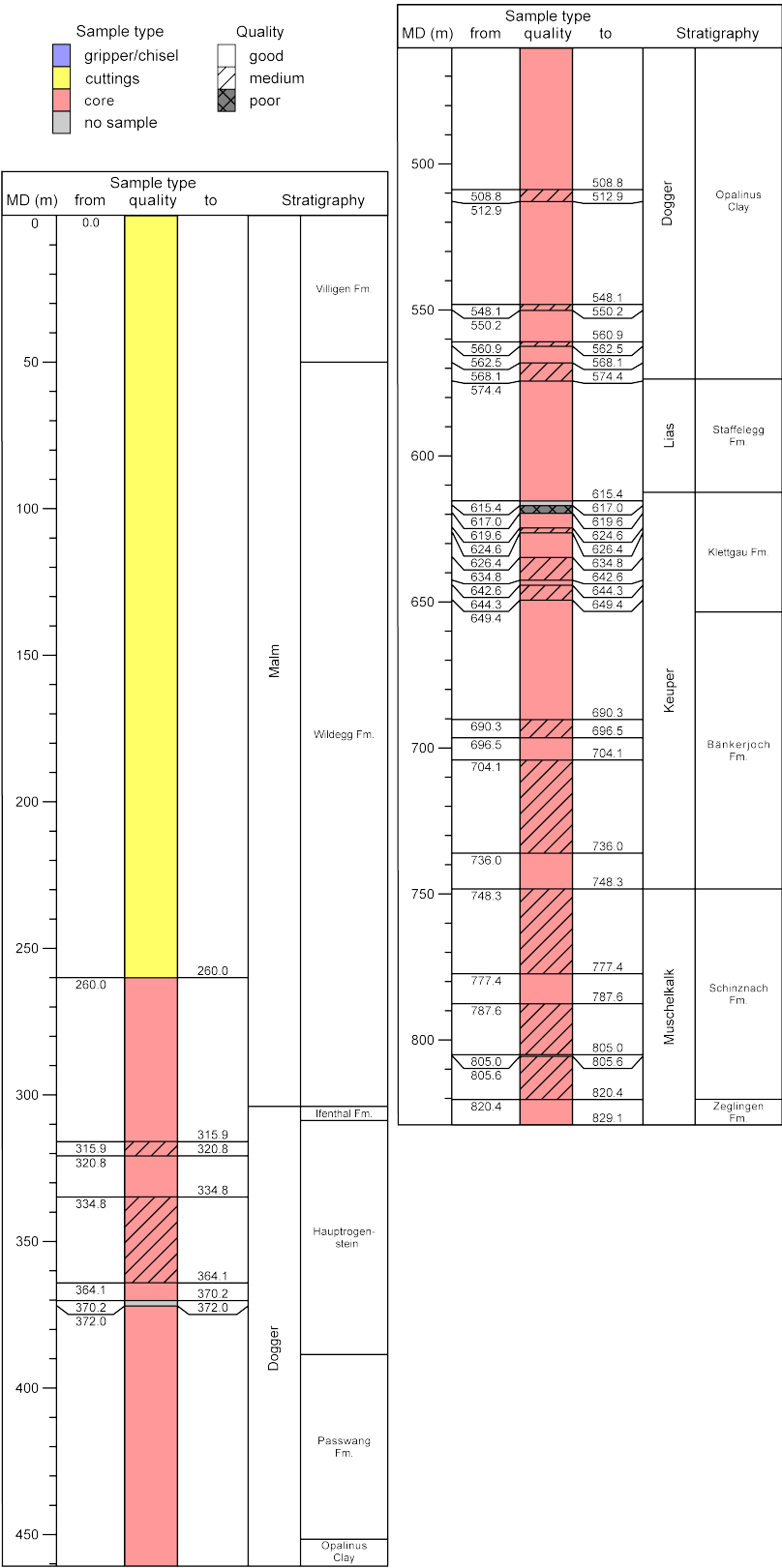


Fig. 2-1: Cuttings and core quality in BOZ2-1

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)

The BOZ2-1 borehole cellar was placed directly into solid rock; a 1-metre-thick cover of soil and subsoil has been removed prior to the construction of the borehole cellar and was not analysed for this study.

3.2 Malm Group

3.2.1 Villigen Formation, 0 m – 50 m (about 50 m)

The Villigen Formation was drilled destructively. Micritic limestone is the dominant lithology. Oolitic limestone, limestone (saccharoidal) and calcareous marl are also found.

The occurrence of sandstone (few cuttings in the interval from 0 m to 12 m) and iron-pisoids (from 8 m to 10 m) is attributed to detritus from near-surface deposits and to karst cavities, respectively.

The *upper boundary* corresponds to the top of the borehole cellar.

The *lower boundary* is set at 50 m with a distinct change in rock colour and mineralogy from beige to white limestone to medium grey calcareous marl.

Lithostratigraphic subdivision

A clear assignment to the individual members of the formation (e.g. Gygi 2000, Gygi 2012) is not possible. However, based on the occurrence and abundance of the various lithologies in the cuttings samples and the presence of glauconite, the following subdivision is suggested:

0 m – 12 m	Letzi Member (about 12 m): limestone (mudstone, micrite) with some calcareous marl (probably indicating the presence of interlayers)
12 m – 34 m	Wangen Member (about 22 m): oolitic limestone (in the upper part) and limestone (mudstone and wackestone, micrite and biomicrite, locally saccharoidal)
34 m – 50 m	Geissberg Member and Crenularis Member (about 16 m): limestone (mudstone and wackestone, micrite and biomicrite, locally saccharoidal) with glauconite

Lithology

0 m – 12 m	Limestone (mudstone, micrite), beige to beige grey, some calcareous marl, dark grey, peloids, probably from thin interlayers
	From 8 m to 10 m, iron-pisoids and claystone, pale pink to reddish orange, probably indicating the presence of karst cavities
	The few cuttings consisting of sandstone (medium-grained), light brown, are probably detritus from near-surface residual deposits

12 m – 16 m	Limestone (mudstone, micrite), beige to white, recrystallised to limestone (saccharoidal), white, oolitic limestone (packstone and grainstone, oomicrite and oosparite), white to greyish pink, fossiliferous, only few bioclasts larger than 1 mm
16 m – 34 m	Limestone (mudstone, micrite), beige to white, recrystallised to limestone (saccharoidal), white, limestone (wackestone, biopelmicrite), beige
34 m – 50 m	Limestone (mudstone, micrite), beige, glauconite, limestone (wackestone, biopelmicrite), beige, limestone (saccharoidal), white, fossiliferous The section from 46 m to 50 m is probably more argillaceous than it appears from the lithologies present in the sample, because the cuttings show a suspicious clay coating; it is suspected that most of the marl was washed out during sampling and preparation

3.2.2 Wildegg Formation, 50 m – 303.95 m (about 254 m)

The Wildegg Formation is made up of the Effingen Member and the Birmenstorf Member at its base. The Effingen Member consists of calcareous marl with limestone interbeds. The Birmenstorf Member comprises the 3.7 m thick basal limestone sequence.

In BOZ2-1, the upper part (from 50 m to 260 m) of the Wildegg Formation was drilled destructively, while the lower part was cored. Petrophysical logging started at 100 m, FMI at 112.5 m.

The *upper boundary* is set at 50 m with a distinct change in rock colour and mineralogy, from beige and white limestone to medium grey calcareous marl (silty).

The *lower boundary* is set at 309.95 m with the occurrence of a pronounced hardground separating the overlying bioclastic argillaceous marl from the underlying iron-oolite.

3.2.2.1 Effingen Member, 50 m – 300.25 m (about 250 m)

The Effingen Member is a succession of calcareous marl with limestone beds of varying thickness.

The *upper boundary* is set at 50 m with a distinct change in rock colour and mineralogy, from beige and white limestone to medium grey calcareous marl (silty).

The *lower boundary* is set at 300.25 m at the base of a thick marly bed and at the top of the compact, medium-bedded succession of bioclastic limestone, fossiliferous.

Lithostratigraphic subdivision

Limestone beds within the Effingen Member can be correlated over quite large distances (Albert & Schwab 2013, Jordan 2013, Deplazes et al. 2013). The most prominent is the Gerstenhübel Bed, which is probably represented by the interval from 185.10 m to 213.70 m in BOZ2-1. Above the Gerstenhübel Bed, three additional, thick limestone beds (from 74 m to 78 m, from 119.2 m to 125.0 m and from 171.8 m to 177.2 m) and a prominent succession rich in thin

limestone beds can be recognised (from 138.2 m to 154.9 m). Below the Gerstenhübel Bed, limestone beds are rare and thin (most prominent beds from 239.4 m to 240.6 m, from 247.3 m to 248.7 m and from 260.00 m to 260.97 m). On the other hand, glauconite becomes abundant below the Gerstenhübel Bed.

The onset of a fossil record (mainly belemnites, few ammonites) coincides with the onset of coring at 260 m and is probably purely coincidental. Conversely, the onset of sponges from 296.30 m downwards is based on the lithostratigraphy.

Lithology (cuttings section)

50 m – 64 m	Alternation of calcareous marl (silty), medium light grey, mica, with limestone (silty) (packstone, biopelmicrite), beige, biotrititic, and limestone (mudstone, micrite), beige; from 54 m to 56 m, glauconite
64 m – 74 m	Alternation of calcareous marl, medium light grey, calcareous marl (silty), medium light grey, and argillaceous marl (silty), medium grey From 66 m to 72 m, as above but argillaceous marl (silty) dominates as supposed by clay coating on cuttings; from 66 m to 68 m, very small pyrite
74 m – 78 m	Alternation of limestone (mudstone, micrite), beige and calcareous marl (silty), medium light grey
78 m – 88 m	Alternation of calcareous marl, medium light grey, calcareous marl (silty), medium light grey, and argillaceous marl (silty), medium grey; from 82 m to 88 m, very small pyrite
88 m – 104 m	Alternation of calcareous marl (silty), medium light grey, pyrite, and limestone (argillaceous) (mudstone, micrite), light grey, pyrite
104 m – 119.2 m	Calcareous marl (silty), medium light grey, pyrite, with beds of limestone (argillaceous) (mudstone, micrite), light grey, siderite (probably nodules)
119.2 m – 125 m	Alternation of limestone (argillaceous) (mudstone, micrite), light grey, pyrite, limestone (mudstone, micrite), light grey, calcareous marl, medium light grey, and argillaceous marl (silty), medium grey
125 m – 127 m	Alternation of calcareous marl (mostly silty), medium light grey, and argillaceous marl (silty), medium grey, siderite (probably nodules)
127 m – 132 m	Alternation of calcareous marl, medium light grey, argillaceous marl, medium light grey, and siderite (probably nodules)
132 m – 137 m	Alternation of calcareous marl (silty), medium light grey, argillaceous marl, (partly) silty, medium grey, and calcareous marl, medium grey
137 m – 144.8 m	Alternation of thicker beds of calcareous, locally argillaceous marl (silty), medium light grey, and thinner beds (20 cm to 50 cm) of limestone (argillaceous) (mudstone, micrite), light to medium grey

144.8 m – 162 m	Calcareous marl (partly silty), medium light grey, locally pyrite, locally mica, siderite (probably nodules) From 155.2 m to 155.8 m, limestone (argillaceous) (mudstone, micrite), light to medium grey
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The section between 162 m and 224 m can be further subdivided based on significant changes in mineral content that are clearly visible in the petrophysical logs. This allows a demarcation in the decimetre range. The following data refer to log depth.

162.0 m – 171.8 m	Alternation of calcareous marl, medium light grey, and argillaceous marl, medium grey
171.8 m – 177.2 m	Alternation of limestone (argillaceous) (mudstone, micrite), light grey, and calcareous marl, medium light grey
177.2 m – 185.1 m	Alternation of calcareous marl, medium light grey, and argillaceous marl, partly silty, medium grey, mica, pyrite
185.1 m – 194.5 m	Limestone (argillaceous) (mudstone, micrite), light grey, pyrite, argillaceous marl, medium light grey
194.5 m – 204.6 m	Limestone (mudstone, micrite), light grey
204.6 m – 208.3 m	Limestone (silty) (mudstone, micrite), light grey
208.3 m – 213.7 m	Alternation of limestone (argillaceous) (packstone, biopelmicrite), medium light grey, pyrite, arenaceous limestone, medium light grey, and calcareous marl (silty), light to medium grey
213.7 m – 224 m	Calcareous marl (silty), light grey to medium grey, glauconite, mica In the upper part (213.7 m to 218 m), additionally limestone (silty, argillaceous) (mudstone, micrite), medium light grey
224 m – 232 m	Alternation of calcareous marl, medium grey, and argillaceous marl, medium light grey to light grey, pyrite
232 m – 238 m	Calcareous marl, medium grey, glauconite, pyrite, mica
238 m – 242 m	Alternation of calcareous marl, light grey, pyrite, mica, and argillaceous marl, medium light grey to light grey From 239.40 m to 240.60 m, limestone (argillaceous) (mudstone, micrite), light grey
242 m – 247.3 m	Calcareous marl, light grey, argillaceous marl, medium light grey to light grey, pyrite
247.3 m – 248.7 m	Limestone (mudstone, micrite), slightly argillaceous, light grey, calcareous marl, light grey
248.7 m – 252 m	Calcareous marl (silty), light grey, glauconite, pyrite
252 m – 260 m	Alternation of calcareous marl, medium light grey to light grey, pyrite, and limestone (silty, argillaceous) (mudstone, micrite), light grey

Lithology (core section)

260.00 m – 269.55 m	Calcareous marl, partly silty, medium grey, pyrite, repeatedly grading upwards into limestone (argillaceous, partly silty) (mudstone, pelmicrite), light grey to beige grey, glauconite (at 261.00 m), belemnites (at 264.03 m and at 268.22 m), partly bioturbated, partly nodular From 260.97 m to 262.82 m, argillaceous marl, medium to dark grey, pyrite, and from 260.00 m to 266.02 m, burrows (mainly associated with limestone [argillaceous] beds) and bioturbation (mainly in marly beds), pyritic filling of a burrow (at 265.50 m)
269.55 m – 271.66 m	Calcareous marl to argillaceous marl (partly silty), medium grey, pyrite, with three interlayers of limestone (argillaceous, partly silty) (mudstone, pelmicrite), light grey to beige grey, belemnite (at 270.07 m), partly bioturbated, nodular
271.66 m – 281.03 m	Calcareous marl (mostly silty), medium grey, pyrite, bioturbated, with thin interlayers of limestone (argillaceous, silty) (mudstone, pelmicrite), light grey to beige grey, glauconite, belemnites, bioturbated, nodular
281.03 m – 286.09 m	Argillaceous to locally calcareous marl (silty to sandy), medium to dark grey, glauconite, pyrite, locally belemnites, ammonite (at 283.65 m), locally burrows, locally bioturbated From 282.28 m to 282.70 m, silty marl, medium grey
286.09 m – 288.36 m	Argillaceous to calcareous marl (silty to sandy), medium to dark grey, pyrite, mica, in the lower part glauconite, bioturbated, with thin interlayers of calcareous marl (silty to sandy), medium grey, pyrite concretions, siderite to calcareous nodules, ammonites (at 287.27 m and at 288.20 m)
288.36 m – 290.42 m	Calcareous marl, medium grey, with interlayers of argillaceous marl (slightly silty), dark grey, and limestone (silty, argillaceous) (mudstone, micrite), all with pyrite, locally glauconite, locally burrows
290.42 m – 296.30 m	Argillaceous to calcareous marl (slightly silty), dark grey, laminated, mica, glauconite, pyrite, burrows, locally bioturbated, in the lower part with interbeds of calcareous marl, light grey to beige grey, pyrite, belemnites, brachiopod, ammonite (at 295.30 m), burrows
296.30 m – 300.25 m	Calcareous marl (mostly silty), medium grey, and argillaceous marl (silty), dark grey, with multiple thin interbeds of bioclastic limestone (wackestone and packstone, micrite), light grey to light beige grey, all lithologies contain glauconite and are fossiliferous (sponges, echinoderms, belemnites, bivalves), burrows At 297.83 m, erosional surface overlain by lithoclasts and bioclasts, mainly sponges

3.2.2.2 Birmenstorf Member, 300.25 m – 303.95 m (3.70 m)

In BOZ2-1, typical facies of the Birmenstorf Member are found, which is not surprising because the borehole is located only around 2 km south of the type locality at the Isegrabe / Mönthal AG (Gygi 1969). The Birmenstorf Member is formed by ten limestone beds (10 cm to 40 cm thick) separated by thin calcareous marl beds (few cm to 25 cm thick). Both lithologies contain glauconite and are very rich in fossils, including sponges, ammonites, belemnites and crinoids.

The *upper boundary* is set at 300.25 m at the base of a thick marly bed and at the top of the compact, medium-bedded succession of bioclastic limestone, fossiliferous.

The *lower boundary* is set at 303.95 m at a pronounced hardground separating the overlying bioclastic argillaceous marl from the underlying iron-oolite. The bioclastic argillaceous marl contains sponges but also lithoclasts from the underlying bed.

Lithology

300.25 m – 303.95 m	Bioclastic limestone to biohermal limestone and limestone (argillaceous) (packstone and wackestone, biopelmicrite) beige grey, glauconite, fossils include sponges (abundant, locally biohermal), crinoids, belemnites, ammonites (at 301.71 m, 302.36 m, 302.59 m and 303.11 m) and bioclasts, with interlayers of bioclastic calcareous marl, medium to light grey, glauconite At the base (from 303.51 m to 303.95 m), argillaceous marl, medium to light grey, sponges, in the lower part (from 303.88 m to the base at 303.95 m) with calcareous lithoclasts (rounded, encrusted, iron-oolitic) in a marl (iron-oolitic) with glauconite.
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3.3 Dogger Group

3.3.1 Ifenthal Formation, 303.95 m – 308.70 m (4.75 m)

The Ifenthal Formation is a highly condensed succession dominated by fossiliferous marl and fossiliferous to marly limestone. In the uppermost part, thin beds of iron-oolite and limestone (iron-oolitic) are found, most of them with a hardground at the top of the beds. Sporadically, iron-ooloids also occur in the underlying sediments.

In BOZ2-1, the members and beds of the formation as defined by Bitterli-Dreher (2012) could not be clearly identified. This corresponds to the findings of Schmassmann (1945) and Bitterli (1977) who state that the condensation reaches its maximum in the area in question and most of the members found elsewhere are condensed and amalgamated here. However, two different sections can be distinguished:

In the upper section (from 303.95 m to 304.45 m) iron-oolite and limestone (iron-oolitic) dominate. Four hardgrounds can be recognised. This fossiliferous and very condensed section may correspond to the Herznach Member, Ängistein Member and Bözen Member.

The lower section (from 304.45 m to 308.70 m) is characterised by a fossiliferous (brachiopods, ammonites, bivalves, bioclasts) alternation of bioclastic limestone, limestone (argillaceous) and bioclastic calcareous marl, with a varying content of iron-ooloids. This lower section may correspond to the Schelmenloch Member.

The *upper boundary* is set at 309.95 m at a pronounced hardground separating the overlying bioclastic argillaceous marl from the underlying iron-oolite. The bioclastic argillaceous marl contains sponges but also lithoclasts from the underlying bed.

The *lower boundary* is set at 308.70 m at the top of a hardground which separates an overlying bioclastic limestone (with lithoclasts from the underlying sediment at its base) from a limestone grading downwards into bioclastic limestone (limonitic) with some iron-oids.

Lithology

- 303.95 m – 304.45 m In the upper part (from 303.95 m to 304.19 m), below an encrusted hard-ground, iron-oolite, reddish brown, with encrusted limestone (iron-oolitic) (packstone, biomicrite), fossiliferous (crinoids, belemnites, bivalves, bioclasts)
- In the middle part (from 304.19 m to 304.33 m), below a hardground, limestone (iron-oolitic) (packstone, biomicrite), light grey, fossiliferous, nodular
- In the lower middle part (from 304.33 m to 304.38 m), below a hard-ground, limestone (packstone, biomicrite), light grey, fossiliferous (mainly detritus)
- At the base (from 304.38 m to 304.45 m), coquina mainly formed by brachiopods, oysters and bivalves in a partly argillaceous, partly calcareous (partly limonitic) matrix, some of the brachiopods are filled with limestone (limonitic to iron-oolitic), other brachiopods are filled with limestone (mudstone, micrite), light grey, or calcite crystals
- 304.45 m – 306.96 m At the top (from 304.45 m to 305.43 m), below a hardground, bioclastic calcareous marl with abundant iron-oids to marl (iron-oolitic), dark grey and dark brown, very fossiliferous (bivalves [including oysters], brachiopods, ammonites [e.g. at 304.56 m and at 304.79 m], belemnites, crinoids, bioclasts), bioturbated; towards the base (from 305.20 m to 305.43 m), decrease in fossils and iron-oids; this interval (from 304.45 m to 305.43 m) probably corresponds to the Anwil Bed (Bitterli-Dreher 2012)
- In the lower part (from 305.43 m to 306.96 m), alternation of bioclastic calcareous marl, medium to dark grey, fossils (bivalves, crinoids, ammonites), and limestone (argillaceous), medium grey, bioturbated, bioclasts, partly nodular; at 306.30 m and 306.45 m, coquinas; very few iron-oids throughout the interval except in the lowermost part (from 306.88 m to 306.96 m), where iron-oids are abundant and lenses of claystone, black, are found
- 306.96 m – 308.70 m Bioclastic calcareous marl, dark grey, few iron-oids, with interlayers of bioclastic limestone (packstone, biomicrite), light grey, in both lithologies: bivalves, bioturbated
- At the base (from 308.44 m to 308.70 m), reworked clasts of underlying rock (bioclastic limestone [limonitic], reddish brown, iron-oids) in cavities of a complex cavernous hardground composed of bioclastic limestone, light grey, iron-oids, partly encrusted

3.3.2 Hauptrogenstein, 308.70 m – 388.54 m (79.84 m)

The Middle Bajocian to the Middle Bathonian epicontinental sediments of Northern Switzerland consist of shallow marine carbonates in the west (Celtic realm) and marly basinal deposits in the east (Swabian realm). The Hauptrogenstein, a formal lithostratigraphic unit in the rank of a formation, includes the carbonate series of the Celtic realm and is composed of three shallowing-upward cycles, each capped by a hardground (Gonzalez & Wetzel 1996).

The characteristic type of sediment is oolitic to oncolitic limestone in the two lower cycles and echinoderm limestone in the upper cycle. Other common sediments are bioclastic, biohermal, limonitic and iron-oolitic limestone and, mainly in the lower part of the cycles, calcareous, silty and argillaceous marl. The BOZ2-1 borehole is located at the western margin of a transitional domain from the calcareous Celtic realm to the marly Swabian realm, which is represented by the Klingnau Formation. This is documented by a slightly increased clay mineral content compared to sections further to the west.

The *upper boundary* is set at 308.70 m at the top of a hardground which separates an overlying bioclastic limestone (with lithoclasts from the underlying sediment at its base) from a limestone grading downwards into bioclastic limestone (limonitic) with some iron-oids.

The *lower boundary* is set at 388.54 m at the base of the lowermost, more than 10 cm thick bed containing calcareous ooids. Occasionally, calcitic-ooids are also found in underlying beds.

Lithostratigraphic subdivision

The correlation of the profile of BOZ2-1 with a very similar sequence in the Sulz – Cheisacher region 2 km to the north is shown in Fig. 3-1. The Sulz – Cheisacher profile is a synthetic profile compiled from various individual but overlapping recordings by Schmassmann (1945; profiles 13, 14 and 16) and Gonzalez (1993; profile Sulz 1 – "südlich Grosshalden"). A two-stage subdivision is proposed:

- 308.70 m – 334.83 m «Movelier Beds» and «Spatkalk» (26.13 m)
- 334.83 m – 388.54 m Hauptrogenstein ("sensu stricto") below «Movelier Beds» and «Spatkalk» (53.71 m)

The further subdivision of the interval and the correlation with the Sulz – Cheisacher profile (Fig. 3-1) are discussed in the respective sections.

3.3.2.1 «Movelier Beds» and «Spatkalk», 308.70 m – 334.83 m (26.13 m)

The section from 308.70 m to 329.97 m shows a good correspondence to what is described as «Spatkalk» in the nearby Sulz – Cheisacher (profile 16 of Schmassmann 1945; cf. Fig. 3-1). Accordingly, it can be divided into three subsections (Fig. 3-1). The upper subsection (308.70 m to 315.17 m) is characterised by the presence of limonite and iron-oids. It is predominantly calcareous with few marl interlayers. The middle subsection (315.17 m to 323.43 m) comprises bioclastic limestone beds separated by mostly very thin marly beds. The lower subsection (323.43 m to 329.97 m) is an alternation of bioclastic calcareous marl and bioclastic limestone. Typical for all three subsections is the high content of echinoderm bioclasts in the limestone beds (etymology of «Spatkalk»).

In line with the Sulz – Cheisacher profile (Fig. 3-1), the section from 329.97 m to 334.83 m is associated with the «Movelier Beds». The term was introduced by Mühlberg (1900) for the local Eastern Jura stratigraphy. It was later redefined by Schmassmann (1945) and adapted by Gonzalez & Wetzel (1996) as an informal unit. As in other outcrops and the area under investigation (e.g. Schmassmann 1945, Gonzalez & Wetzel 1996), the «Movelier Beds» in BOZ2-1 comprise bioclastic limestone and marl (limonitic), with corals and some iron-ooids.

Lithology

- | | |
|---------------------|---|
| 308.70 m – 310.80 m | <p>Bioclastic limestone (limonitic) (grainstone, biosparite), light grey to medium brown, iron-ooids, bryozoans, echinoderm bioclasts (thin section BOZ2-1-309.57, no iron-ooids), from 308.90 m to 310.16 m with cross-bedding, and, from 310.00 m to 310.15 m, small argillaceous lithoclasts</p> <p>At the base (from 310.16 m to 310.80 m), bioclastic calcareous marl, light grey and brown, with interlayer of claystone, dark grey, erosional surface, bored</p> |
| 310.80 m – 315.17 m | <p>Bioclastic limestone (limonitic) (packstone, biomicrite) and bioclastic limestone (packstone, biomicrite), reddish brown to light grey, iron-ooids, brachiopods, bivalves, crinoids, serpulids, echinoderm bioclasts (thin section BOZ2-1-312.93), both lithologies slightly argillaceous, at the base (from 314.33 m to 315.17 m) two beds of bioclastic calcareous marl, dark reddish brown, limonitic, iron-ooids</p> |
| 315.17 m – 319.95 m | <p>Bioclastic limestone (grainstone, locally packstone, biosparite, locally biopelsparite and biomicrite), medium light grey, echinoderm and bivalve bioclasts (thin section BOZ2-1-319.83), few larger bivalves and brachiopods, flaser bedding, bed thickness from 5 cm to 10 cm, with interlayers (up to 2 cm thick) of claystone (calcareous), black, mica, bioclasts, at the top (at 315.17 m) and at 315.76 m, at 316.60 m and at 317.60 m firmground (bored omission surfaces)</p> |
| 319.95 m – 323.43 m | <p>Bioclastic limestone (grainstone and packstone, biopelsparite and biopelmicrite), medium light grey to beige grey, bioclasts (crinoids, bivalves), few larger bivalves and brachiopods, flaser bedding, bedding thickness up to 50 cm, locally cross-bedded, locally bioturbated, with interlayers (up to 35 cm thick) of bioclastic calcareous marl, dark grey, bioclasts, with nodular interlayers (up to 5 cm thick) of bioclastic limestone (packstone, biopelmicrite), medium light grey, some belemnites</p> |
| 323.43 m – 329.97 m | <p>Bioclastic calcareous marl, medium grey, and bioclastic argillaceous marl, dark grey, with domains and (nodular) interlayers of bioclastic limestone (packstone, biopelmicrite), light to medium grey, usually sharp top of bioclastic limestone beds, grading downwards into bioclastic calcareous marl, locally bioclastic argillaceous marl, all lithologies are bioturbated and comprise crinoids and bivalves, a single belemnite is found at 327.58 m</p> |

329.97 m – 334.83 m At the top (from 329.97 m to 330.94 m), bioclastic limestone (limonitic) (grainstone and packstone, biosparite and biomicrite), iron-ooids, calcareous ooids, lithoclasts, corals, bivalves, larger echinoderm and bivalve bioclasts, serpulids, fine bioclasts and pellets (thin sections BOZ2-1-330.02 and BOZ2-1-330.66); lithoclasts and bioclasts make the section appear breccia-like

The main part (from 330.94 m to 334.83 m) consists of bioclastic calcareous marl, medium grey, limonite, few iron-ooids, crinoids, bioclasts, pellets; the breccia-like appearance probably results from intense bioturbation

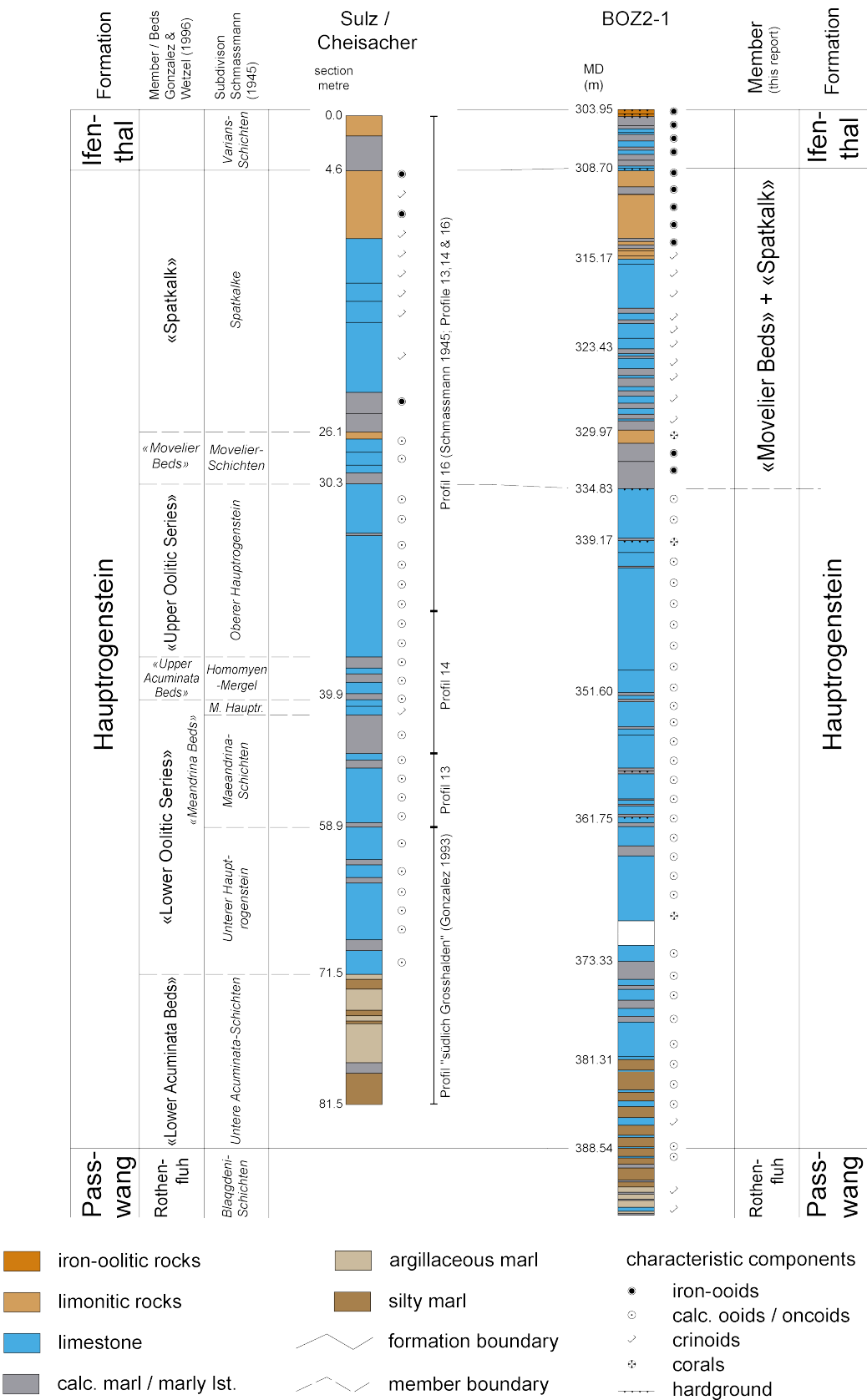


Fig. 3-1: Correlation of BOZ2-1 with the nearby Sulz – Cheisacher synthetic section
Compiled from Schmassmann (1945) and Gonzalez (1993).

3.3.2.2 Hauptrogenstein below «Movelier Beds» and «Spatkalk», 334.83 m – 388.54 m (53.71 m)

For the Sulz – Cheisacher area, Schmassmann (1945) and Gonzalez & Wetzel (1996) propose a subdivision of the sediments between the «Movelier Beds» and the Rothenfluh Member («Blagdeni-Schichten» in Schmassmann 1945) into five or six units, respectively (terminology of Schmassmann 1945, in brackets):

- «Upper Oolitic Series» («Oberer Hauptrogenstein»)
- «Upper Acuminata Beds» («Homomyen-Mergel»)
- «Lower Oolitic Series» with «Maeandrina Beds» («Mittlerer Hauptrogenstein», «Maeandrina-Schichten», «Unterer Hauptrogenstein»)
- «Lower Acuminata Beds» («Untere Acuminata-Schichten»)

In BOZ2-1, the section between 334.83 m and 351.60 m may correlate with the «Upper Oolitic Series» of the Sulz – Cheisacher area. This section is a thick, almost exclusively calcareous succession. The top is marked by a prominent hardground. A further hardground which may be correlated with the Sulz – Cheisacher section (Fig. 3-1) is found at 339.17 m. A special feature of the «Oberer Hauptrogenstein», as Schmassmann (1945) already mentioned, is the high content of oncoids, some of which have ooids or oolitic rock fragments as their nuclei (described as encrusted "Mikrogerölle" in Schmassmann, 1945).

Schmassmann (1945) and Gonzalez (1993) point to the small-scale variability of the «Upper Acuminata Beds» to the «Maeandrina Beds» section in the Sulz – Cheisacher area. The two marly but oolitic beds frame the rather calcareous «Mittlerer Hauptrogenstein» defined in Schmassmann (1945). In BOZ2-1, the section from 351.60 m to 361.75 m might correspond to this part of the Sulz – Cheisacher section (Fig. 3-1). Thicker and thinner marly beds predominate but prominent oolitic limestone beds are also present throughout the section. Dark, rimmed ooids (Wetzel et al. 1993), already mentioned in Schmassmann (1945) from nearby outcrops, are found in the upper part of this section in BOZ2-1. A bored firmground at 357.88 m may represent the top of the «Maeandrina Beds».

In the Sulz – Cheisacher area, the «Lower Oolitic Series» below the «Maeandrina Beds» are represented by thick oolitic limestone beds separated by thin oolitic and bioclastic marl beds. In BOZ2-1, the section from 361.75 m to 373.33 m or 381.31 m probably corresponds to the «Lower Oolitic Series». It consists of an alternation of mostly thick oolitic and bioclastic limestone beds and interlayers of oolitic and bioclastic calcareous marl. The two different depths are proposed as the boundary at 373.33 m indicate the top of the uppermost thick bioclastic calcareous marl, whereas the boundary at 381.31 m represents the base of the lowermost thick oolitic limestone bed, respectively. The interval from 373.33 m to 381.31 m may also be interpreted as an inter-fingering of the two informal members «Lower Oolitic Series» and «Lower Acuminata Beds».

The top and the base of the «Lower Acuminata Beds» are defined by the onset of a massive oolite facies and the base of the lowermost at least 10 cm thick oolitic limestone, respectively (Gonzalez & Wetzel 1996). The uncertainty regarding the upper boundary is discussed above. In the Sulz – Cheisacher area, only the upper part of the «Lower Acuminata Beds» could be recorded by Gonzalez (1993) (no outcrops were available at the time of Schmassmann 1945). Therefore, there is no local reference for the lower boundary. The occurrence of ooids in the bioclastic limestone bed from 388.42 m to 388.54 m, used for defining the lower boundary in BOZ2-1, is rather unique. The next higher density of ooids is found at 385.71 m. However, few ooids are also found in beds thinner than 10 cm below the limiting bed. In BOZ2-1, the section from 381.31 m to 388.54 m is characterised by bioclastic sandy marl with thin interbeds of limestone (sandy).

Lithology

- 334.83 m – 339.17 m At the top (from 334.83 m to 335.25 m), hardground with burrows reaching deep into the underlying sediment
- Oolitic limestone (packstone and grainstone, oomicrite and oosparite), light grey to light brown, oncolitic, alternating and grading into oncolitic limestone (packstone and grainstone, oncomicrite and oncosparite), light grey to light brown, oolitic, both lithologies locally slightly limonitic; the succession has less crinoids and bivalves compared to the one above, bivalve and echinoderm bioclasts, aggregate grains (thin sections BOZ2-1-334.98 and BOZ2-1-336.09), from 336.61 m to 337.10 m also pellets, with thin (up to 3 cm thick) calcareous marl interlayers; near the base (at 339.15 m) single coral fragment
- 339.17 m – 341.40 m At the top (from 339.17 m to 339.35 m), hardground with burrows deep into the underlying sediment
- Oolitic limestone (grainstone to packstone, oosparite and oomicrite), dark beige to medium light grey, oncoids, crinoids, bivalves, bioclasts, pellets, aggregate grains (thin section BOZ2-1-340.94)
- From 340.14 m to 340.21 m, thin slightly argillaceous bed, dark grey, overlying a bored omission surface
- At the base (from 341.26 m to 341.40 m), bioclastic calcareous marl, dark beige, fossiliferous (crinoids [including a larger echinoderm fragment at 341.32 m], bivalves, bioclasts)
- 341.40 m – 345.30 m At the top (at 341.40 m and at 341.58 m), two bored omission surfaces
- Oolitic limestone (grainstone, oosparite), medium light grey to dark beige, oncolitic, locally, from 341.58 m to 341.85 m, oncolitic limestone (grainstone, oncosparite), light grey to light brown, oolitic, aggregate grains (thin section BOZ2-1-341.63), both lithologies fossiliferous (crinoids, bivalves, bioclasts), pellets, bioturbated, with dark argillaceous seams
- 345.30 m – 349.25 m Oolitic limestone (grainstone, oosparite), medium light grey to dark beige, crinoids, bivalves, bioclasts, locally concentrated in coquinas (e.g. from 345.38 m to 345.45 m, at 345.99 m, from 347.24 m to 347.25 m, at 348.29 and at 349.25 m), pellets, bioturbated, with dark argillaceous seams
- 349.25 m – 351.60 m Oolitic limestone (grainstone, oosparite), light grey, crinoids, bivalves, with dark argillaceous seams
- 351.60 m – 353.20 m Fine-bedded alternation of oolitic limestone (grainstone, oosparite), light grey, with argillaceous flaser beds, bioclasts, few bivalves and few thicker interbeds of bioclastic calcareous marl to bioclastic argillaceous marl, medium grey to dark grey, ooids (some with dark rims), bioclasts, bioturbated
- 353.20 m – 357.88 m Oolitic limestone (grainstone, oosparite), medium light grey, oncoids, alternating and grading into oncolitic limestone (grainstone, oncosparite),

- medium light grey, ooids, (thin section BOZ2-1-355.15), medium light grey, with thin interbeds of bioclastic calcareous marl, medium to dark grey, oolitic, all lithologies fossiliferous (crinoids, bivalves, bioclasts, bryozoans), bioturbated
- 357.88 m – 361.75 m At the top (at 357.88 m), firmground (bored omission surface): bioclastic limestone (grainstone, biopelsparite), light grey, bivalves, echinoderms, pellets (thin section BOZ2-1-357.90)
- Medium-bedded alternation of oolitic limestone (locally argillaceous) (grainstone, oosparite), light grey, and bioclastic calcareous marl, medium to dark grey, oolitic, all lithologies fossiliferous (crinoids, bivalves, bioclasts), bioturbated
- 361.75 m – 363.84 m At the top, at 361.75 m, firmground (bored omission surface)
- Bioclastic limestone (packstone and wackestone, biomicrite), light grey, oolitic, medium-bedded, and oolitic limestone (grainstone, oosparite), light grey, bioclasts, medium-bedded, both lithologies fossiliferous (crinoids, bivalves, bioclasts) and bioturbated
- From 362.20 m to 362.46 m, bioclastic calcareous marl, medium to dark grey, oolitic, fossiliferous (crinoids, bivalves, bioclasts), bioturbated
- 363.84 m – 367.36 m Bioclastic limestone (wackestone, biomicrite), light grey, oolitic, and oolitic limestone (grainstone, oosparite), light grey, with thick (upper part) and thin interlayers of bioclastic calcareous marl, medium grey, oolitic, both lithologies fossiliferous (crinoids, bivalves, belemnite [at 366.30 m], bioclasts), dispersed and, locally, at 364.83 m, concentrated in a coquina
- 367.36 m – 370.15 m Oolitic limestone (grainstone, oosparite), medium grey, and bioclastic limestone, medium grey, oolitic, all lithologies fossiliferous (crinoids, bivalves, bioclasts); a fragment found at 369.32 m may originate from a coral
- 370.15 m – 372.00 m No core or cuttings collected
- 372.00 m – 373.33 m Oolitic limestone (wackestone to packstone, oomicrite), light grey, crinoids, bioclasts
- 373.33 m – 377.15 m Bioclastic calcareous marl, medium light grey, oolitic, bioturbated, from 375.59 m to 376.82 m with thin interlayers of oolitic limestone (packstone, oomicrite), light grey, oncoids, crinoids, bivalves, bioclasts (thin section BOZ2-1-375.11)
- At the base, from 376.82 m to 377.15 m, bioclastic argillaceous marl, medium light grey, oolitic. bioturbated
- 377.15 m – 381.31 m At the top (at 377.15 m): erosional contact, bored
- Oolitic limestone (grainstone, oosparite), light grey, crinoids, bioclasts, medium-bedded, bioclastic limestone (wackestone, biomicrite), light grey, crinoids, medium-bedded, and calcareous marl, medium light grey, oolitic, bioclasts (locally concentrated in coquinas), bioturbated

- | | |
|---------------------|--|
| 381.31 m – 386.04 m | Bioclastic sandy marl, medium grey to dark grey, silty, moderately oolitic, mica, pyrite, fossiliferous (crinoids, bivalves, belemnite [at 383.47 m], pellets, bioclasts), locally concentrated in coquinas, lenticular bedding, with thin interlayers of limestone (sandy) (wackestone, micrite), medium grey, mica |
| 386.04 m – 388.54 m | Bioclastic sandy marl, medium grey to dark grey, slightly oolitic, mica, fossiliferous (crinoids, bivalves [<i>Trigonia costata</i> at 386.47 m], belemnite [at 387.89 m], pellets, bioclasts), with 15 cm to 26 cm thick interlayers of limestone (silty to sandy) (wackestone, micrite), medium light grey, slightly oolitic (e.g. from 388.42 m to 388.54 m), mica |

3.3.3 Passwang Formation, 388.54 m – 451.54 m (63.00 m)

The current formal concept of the Passwang Formation (Burkhalter 1996) comprises five members representing five successive cycles formed mainly by siliciclastic sediments with a varying carbonate content. Each cycle is terminated or, locally, partially or fully replaced by condensed, mostly iron-oolitic sediments. In addition, the Rothenfluh Member, which was originally assigned to the Hauptrogenstein by Gonzalez & Wetzel (1996), was later incorporated into the Passwang Formation.

The allostratigraphic concept of Burkhalter (1996) was recently partially questioned by Wohlwend et al. (2019) based on additional biostratigraphic data. However, it is undisputed that the condensed succession reaches its maximum in the area under investigation. For this drilling campaign, Jordan & Deplazes (2019) proposed a provisional lithostratigraphic approach based on Wohlwend et al. (2019), which has been applied here. The Passwang Formation of BOZ2-1 is accordingly subdivided into (from top to bottom): the Rothenfluh Member, the «Humphriesi-Schichten», the combined Waldenburg and lower part of Brüggli Member (i.e. the latter without the «Humphriesi-Schichten») and the «condensed equivalents of the Sissach Member, Hauenstein Member and / or Hirnichopf Member».

The *upper boundary* is set at 388.54 m at the base of the lowermost, more than 10 cm thick bed containing calcareous ooids. Occasionally, calcitic-ooids are also found in underlying beds.

The *lower boundary* is set at 451.54 m. The sharp but undulating boundary is the base of iron-oolitic, limonitic and fossiliferous sediments of the condensed lowermost part of the Passwang Formation. Below, silty claystone (calcareous) with low fossil contents are assigned to the Opalinus Clay.

3.3.3.1 Rothenfluh Member, 388.54 m – 418.30 m (29.76 m)

The Rothenfluh Member represents the (virtually non-oolitic) base of the lowermost of the three shallowing-upward cycles of the «Hauptrogenstein Formation» *sensu* Gonzalez & Wetzel (1993). For cartographic and petrographic reasons, it is now part of the Passwang Formation (resolution of the Swiss Committee on Stratigraphy in 2004). In BOZ2-1, the Rothenfluh Member is represented by an almost regular alternation of mostly bioclastic argillaceous to sandy marl with thinner, partly nodular interbeds of bioclastic limestone (sandy).

The *upper boundary* is set at 388.54 m at the base of the lowermost, more than 10 cm thick bed containing calcareous ooids. Occasionally, iron-ooids are also found in underlying beds.

The *lower boundary* is set at 418.30 m at the top of the uppermost marl (iron-oolitic) of the «Humphriesi-Schichten».

Lithology

388.54 m – 391.68 m	Bioclastic sandy marl, medium grey to dark grey, mica, locally ooids (at 389.50 m), fossiliferous (bivalves [<i>Trigonia costata</i> at 390.92 m]), bioclasts, belemnite [at 391.68 m], pellets), with 12 cm to 30 cm thick interlayers of bioclastic limestone (sandy) (grainstone, microsparite), medium light grey, generally associated with the abundant coquinas, and bioclastic calcareous marl, medium light grey
391.68 m – 395.26 m	Bioclastic argillaceous marl to argillaceous marl (silty, bioclastic), dark grey, mica, pyrite, grading downwards into bioclastic calcareous marl (silty), dark grey and light medium grey, mica, pyrite, bioturbated, both lithologies fossiliferous (crinoids, bioclasts), rarely concentrated in coquinas (e.g. at 392.21 m), with thin interbeds of limestone (silty), light grey
395.26 m – 403.99 m	Argillaceous marl (silty, bioclastic) to bioclastic argillaceous marl, dark grey, mica, pyrite, alternating with and grading into bioclastic calcareous marl, light medium grey, mica, partly nodular, with increasingly thicker interbeds (10 cm in the upper part to 30 cm in the lower part) of bioclastic limestone (sandy), light grey, to limestone (silty), light grey, fossiliferous, with some ooids in the uppermost layer, partly nodular, all lithologies fossiliferous (crinoids, bivalves, belemnite [at 403.99 m], bioclasts, pellets), rarely concentrated in coquinas (e.g. at 399.94 m and at 400.61 m), bioturbated
403.99 m – 406.16 m	Argillaceous marl (silty, bioclastic), dark grey, mica, alternating with and grading into limestone (silty, argillaceous) (packstone, biomicrite), medium light grey, mica, nodular, crinoids very abundant in both lithologies, bioclasts
406.16 m – 412.20 m	Argillaceous marl (silty, bioclastic), dark grey, mica, pyrite (dispersed, as nodules and [at 411.91 m] as burrow fills), fossiliferous (fragment of an ammonite [at 411.92 m], crinoids, few bivalves [e.g. <i>Modiolus</i> sp. at 410.18 m], bioclasts), with mostly nodular interbeds (medium- to thin-bedded, gradual boundaries) of bioclastic limestone (packstone, biopelmicrite) (thin section BOZ2-1-407.67) to bioclastic calcareous marl, medium light grey, mica, pyrite, and limestone (silty, argillaceous), light grey, mica, pyrite, fossiliferous (crinoids, bivalves, sponges, bioclasts, pellets)
412.20 m – 418.30 m	Argillaceous marl (silty), dark grey, mica, pyrite (dispersed and as nodules), fossiliferous (crinoids, bivalves, belemnites [abundant from 412.20 m to 413.09 m], ammonite [at 418.02 m], bioclasts), bioturbated, alternating with and grading into thin interbeds (20 cm to 25 cm) of bioclastic calcareous marl (silty), light medium grey, mica, fossiliferous (crinoids, bivalves), bioturbated Near the base, from 418.06 m to 418.14 m, thin bed of calcareous marl (sandy), light grey

3.3.3.2 «Humphriesi-Schichten», 418.30 m – 424.40 m (6.10 m)

In the provisional lithostratigraphic approach proposed by Wohlwend et al. (2019), the «Humphriesi-Schichten» encompass the succession of iron-oolitic sediments between the marly Rothenfluh Member and the marly to sandy Waldenburg and lower part of Brüggli Member.

In BOZ2-1, this section can be clearly identified and demarcated. However, only around 4 m deeper (in the Waldenburg and lower part of Brüggli Member), the next iron-oolitic sequence is found. These additional beds were also observed in outcrops in the wider area of the Frick valley, with the consequence that the lower boundary of the «Humphriesi-Schichten» cannot be clearly delimited lithologically (*cf.* Burkhalter 1996).

The *upper boundary* is set at 418.30 m at the top of the uppermost iron-oolitic bed; a marl (iron-oolitic) overlain by argillaceous marl (silty).

The *lower boundary* is set at 424.40 m at the base of the lowermost iron-oolitic sediment of a sequence dominated by iron-oolite, marl (iron-oolitic) and limestone (iron-oolitic). Below claystone (calcareous) predominates without iron-oolids down to 428.90.

Lithology

- | | |
|---------------------|---|
| 418.30 m – 420.75 m | <p>At the top (from 418.30 m to 418.81 m), marl (iron-oolitic), brown, very rich in macrofossils including bivalves (oysters and others) and belemnites</p> <p>From 418.81 m to 420.75 m, iron-oolite, dark reddish brown, alternating with thin (less than 10 cm) to very thin beds of limestone (iron-oolitic) (grainstone, biosparite), ochre brown, and marl (iron-oolitic), dark brown, very rich in macrofossils including bivalves (oysters and others), ammonites (at 419.23 m, 419.41 m, 420.23 m and 420.28 m) and belemnites</p> |
| 420.75 m – 422.77 m | <p>Marl (iron-oolitic), brown to dark reddish brown, mica, with interlayers of limestone (iron-oolitic) (packstone, biomicrite), ochre to brown, locally silty (thin section BOZ2-1-422.67) and iron-oolite, dark reddish brown, all lithologies fossiliferous (belemnites, bivalves including large oysters, echinoderms, bioclasts, limonitised)</p> <p>At the base (at 422.77 m), firmground overlain by bored lithoclasts</p> |
| 422.77 m – 424.40 m | <p>At the top, from 422.77 m to 423.02 m, below the firmground, limestone (iron-oolitic) (grainstone, biosparite), ochre to brown, large oysters, bioclasts</p> <p>From 423.02 m to 423.99 m, below a hardground, calcareous marl (silty), dark grey, iron-oolids, and limestone (silty), medium grey, iron-oolids, fossiliferous (bivalves, bioclasts); at 423.51 m, additional firm- to hardground, bored</p> <p>At the base (from 423.99 m to 424.40 m), below a hardground, limestone (iron-oolitic) (packstone, biomicrite) grading into marl (iron-oolitic), ochre to brown</p> |

3.3.3.3 Waldenburg and lower part of Brüggl Member, 424.40 m – 450.53 m (26.13 m)

In BOZ2-1, the interval covering the Waldenburg Member and the Brüggl Member (without the «Humphriesi-Schichten») is represented by silty marl to calcareous and argillaceous marl (silty) with thin (and few thicker) interbeds of limestone (silty, argillaceous). Additionally, there are two iron-oolitic successions: one from 428.90 m to 430.59 m and the other from 448.62 m to 448.92 m.

The *upper boundary* is set at 424.40 m at the top of a bioclastic calcareous marl, below sediments of a sequence dominated by iron-oolite, marl (iron-oolitic) and limestone (iron-oolitic) of the «Humphriesi-Schichten».

The *lower boundary* is set at 450.53 m at the base of a thick layer of claystone (silty) overlying a succession of marl (iron-oolitic).

Lithology

424.40 m – 428.90 m	At the top (from 424.40 m to 425.10 m), limestone (argillaceous) (wackestone and packstone, biomicrite), dark grey, and bioclastic calcareous marl, medium grey, crinoids, bivalves, bioclasts, bioturbated In the main part, from 425.10 m to 428.90 m, claystone (calcareous), dark grey to black, siderite nodules, echinoderms, belemnites (at the top, at 425.10 m and at the bottom at 428.83 m), burrows, laminated
428.90 m – 430.59 m	Succession of marl (iron-oolitic), brown, limestone (iron-oolitic) (packstone, biomicrite), light grey and ochre brown, limonitic (thin section BOZ2-1-429.43), and bioclastic argillaceous marl, ochre brown, iron-oolids, all lithologies fossiliferous (crinoids, bivalves, belemnites, bioclasts, aggregate grains) From 429.30 m to 429.92 m, additionally with clasts (up to 7 cm) of limestone (iron-oolitic), claystone (silty, calcareous) dark grey, fossiliferous (crinoids, bivalves, belemnites, bioclasts) At the base (from 429.92 m to 430.59 m), claystone (silty, calcareous), fossiliferous, grading into bioclastic calcareous marl, ochre brown, iron-oolids, slightly sideritic, fossils include crinoids, bivalves, belemnites and bioclasts
430.59 m – 431.78 m	Claystone (calcareous), dark grey, locally fossiliferous, and bioclastic argillaceous marl, dark grey, bioturbated, and, in the lower part from 431.26 m to 431.78 m, bivalves and bioclasts
431.78 m – 433.06 m	Two beds of limestone (silty, the upper also argillaceous) (packstone, biomicrite), beige grey to medium light grey, fossiliferous (echinoderms, bivalves and sponges), bioturbated (thin section BOZ2-1-432.87), separated, from 432.49 m to 432.56 m, by calcareous marl, dark grey
433.06 m – 434.68 m	Calcareous marl (silty), to argillaceous marl (silty), dark grey, mica, siderite nodules, bioclasts, bioturbated

- 434.68 m – 437.78 m Calcareous marl (silty to sandy), medium grey, and argillaceous marl (silty to sandy), dark grey, grading into limestone (silty to sandy) (packstone, biomicrite), light grey, locally mica (from 435.87 m to 437.78 m), siderite nodules, belemnite (at 436.87 m), bioclasts, bioturbated
- 437.78 m – 448.62 m Silty marl (locally sandy [fine-grained]), medium grey, mica, bioclasts, bioturbated, with thin interbeds (up to 20 cm) of limestone (silty to sandy) (packstone biomicrite), bioclasts (bivalves, sponges, crinoids), bioturbated (thin section BOZ2-1-441.73), sandy limestone, light grey, bioclasts (fine-grained), strongly bioturbated (thin section BOZ2-1-447.78), and, in the lower part, thin interbeds of argillaceous marl (silty to sandy), dark grey, mica, bioclasts, bioturbated, and calcareous marl (silty to sandy), medium light grey, mica, siderite nodules, crinoids (from 439.30 m to 446.03 m), probably a serpulid bioherm (from 441.59 m to 441.77 m), bioclasts, bioturbated
- 448.62 m – 450.53 m At the top (from 448.62 m to 448.71 m), marl (iron-oolitic), brown, coral
 From 448.71 m to 448.92 m, limestone (iron-oolitic, sandy), light grey and brown, encrusted lithoclasts, fossiliferous (belemnites, bivalves, echinoderms, partly limonitic, bioclasts) (thin section BOZ2-1-448.81)
 From 448.92 m to 450.53 m, below a partly eroded hardground, claystone (silty), dark grey, pyrite, laminated, from 449.05 m to 449.07 m, nodules of limestone, light grey, and, at 450.20 m, siltstone lenses (silt-filled burrows)

3.3.3.4 «Condensed equivalents of the Sissach Member, Hauenstein Member and / or Hirnichopf Member», 450.53 m – 451.54 m (1.01 m)

In BOZ2-1, only the lowermost, 1 m thick succession of iron-oolitic sediments is addressed as «condensed equivalents of the Sissach Member to Hirnichopf Member». The ca. 30 cm thick iron-oolitic sediments located about 1.5 m above are regarded as part of the Waldenburg Member and the Brüggli Member. This is in analogy to similar configurations in other biostratigraphically well studied outcrops in the broader area under investigation (Wohlwend et al. 2019).

The *upper boundary* is set at 450.53 m at a succession of marl (iron-oolitic) which is overlain by a thick bed of claystone (silty).

The *lower boundary* is set at 451.54 m. The sharp but undulating boundary is the base of iron-oolitic, limonitic and fossiliferous sediments of the condensed lowermost part of the Passwang Formation. Below, silty claystone (calcareous) with low fossil contents are assigned to the Opalinus Clay.

Lithology

- 450.53 m – 451.54 m In the upper part (from 450.53 m to 450.96 m), marl (iron-oolitic), dark reddish brown to dark grey, bioclasts
 In the lower part (from 450.96 m to 451.54 m), succession of firm- and hardgrounds formed by marl (iron-oolitic), iron-oolite and limestone (iron-oolitic), dark grey to dark reddish brown, locally light brown,

encrusted lithoclasts, fossiliferous (belemnites, ammonite [at 451.19 m], bivalves, gastropods, bioclasts), erosional base at 451.54 m

3.3.4 Opalinus Clay, 451.54 m – 573.68 m (122.14 m)

The Opalinus Clay is generally regarded as a monotonous succession of dark grey silty claystone with silty to sandy 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, mainly in the lowermost section.

The findings in BOZ2-1 confirm the uniform lithology of the Opalinus Clay. The facies and subdivisions are in line with the concept presented in Mazurek & Aschwanden (2020).

The *upper boundary* is set at 451.54 m. The sharp but undulating boundary is the base of iron-oolitic, limonitic and fossiliferous sediments of the condensed lowermost part of the Passwang Formation. Below, silty claystone (calcareous) with a poor fossil content are assigned to the Opalinus Clay.

The *lower boundary* is set at 573.68 m at the top of the uppermost argillaceous marl, light grey, of the Staffelegg Formation. It is overlain by a more than 5 m thick succession of claystone (silty, calcareous), medium grey, with bioclasts and few macrofossils (ammonite, belemnite) at its base. The boundary is also clearly visible in the FMI and GR record.

Lithostratigraphic subdivision

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

451.54 m – 480.56 m «Sub-unit with silty calcareous beds» (29.02 m)

480.56 m – 496.09 m «Upper silty sub-unit» (15.53 m)

496.09 m – 559.75 m «Mixed clay-silt-carbonate sub-unit» (63.66 m)

559.75 m – 573.68 m «Clay-rich sub-unit» (13.93 m)

Lithology

«Sub-unit with silty calcareous beds», 451.54 m – 480.56 m (29.02 m)

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

451.54 m – 456.91 m Silty (to sandy) claystone (calcareous), dark grey, mica, locally some pyrite, bioturbated, pyrite and siderite nodules, locally burrows filled with silt and sand (locally limonitic), lenticular bedding, with thin lenses and layers (up to 5 cm thick) of siltstone to sandstone (calcareous, argillaceous), light grey, siderite, echinoderms, pellets, foresets (thin section BOZ2-1-451.83), and calcareous marl (silty), light grey, and thin lenses and layers of claystone (silty), dark grey

- 456.91 m – 467.42 m Silty claystone (calcareous), dark grey, mica, pyrite (dispersed and as nodules), laminated, with thin lenses and layers (up to 15 cm thick) of calcareous marl, medium light grey, and thin lenses and layers of siltstone (calcareous, argillaceous), light grey
- At the base (from 467.28 m to 467.42 m), above a calcareous hardground, silty marl, dark grey to medium grey, bored, partly iron-oolitic lithoclasts, fossiliferous (belemnites, bioclasts)
- 467.42 m – 472.18 m At the top (from 467.42 m to 467.56 m), calcareous hardground, matrix limestone (mudstone, micrite), light grey, fossiliferous (belemnites, bioclasts), bioturbated, with lithoclasts of limestone (iron-oolitic) (packstone), light grey, iron-oolids partly or fully replaced by calcite (thin section BOZ2-1-467.43)
- From 467.56 m to 468.97 m, silty claystone (calcareous), dark grey to medium grey, mica, pyrite, mostly laminated but locally bioturbated and lenticular bedding
- Main part from 468.97 m to 472.18 m, claystone (silty, calcareous), dark grey, mica, pyrite (dispersed and as nodules), bioturbated, laminated, thin layers of siltstone (calcareous, argillaceous), light grey
- 472.18 m – 475.36 m At the top, from 472.18 m to 472.28 m, hiatus bed formed by bioclastic calcareous marl, medium grey, fossiliferous (oysters, bioclasts), bioturbated, siderite nodules
- From 472.28 m to 472.98 m, calcareous marl (silty), medium to dark grey, mica, pyrite, bioturbated, lenticular bedding
- Main part, from 472.98 m to 475.36 m, silty claystone (calcareous), dark grey to medium grey, mica, pyrite, belemnite (at 473.14 m), laminated
- 475.36 m – 480.56 m At the top (from 475.36 m to 475.50 m), above an erosional surface, bioclastic calcareous marl, beige grey to dark grey, fossiliferous (belemnites, crinoids, bioclasts) with lithoclasts of calcareous marl, beige grey, grading downwards into siderite nodules
- From 475.50 m to 477.76 m, claystone (silty, calcareous), dark grey, mica, pyrite, mostly laminated, some lenses of siltstone (calcareous, argillaceous), light grey, bioturbation rare but more abundant than distinct burrows
- From 477.76 m to 479.94 m, as above, but burrows more abundant than bioturbation
- At the base (from 479.94 m to 480.56 m), three hiatus beds: from 479.94 m to 480.16 m limestone (argillaceous) (mudstone, micrite), beige grey, sideritic, bioturbated, nodular; from 480.16 m to 480.37 m limestone (mudstone, micrite), beige grey, bioturbated; from 480.47 m to 480.56 m septarian nodules of limestone (mudstone, micrite), beige grey, sideritic; the beds are embedded in calcareous marl, beige grey, nodular (by bioturbation), bioclastic calcareous marl (partly silty) and argillaceous marl (silty), dark grey, lithoclasts (from underlying beds), belemnites, bioclasts

«Upper silty sub-unit», 480.56 m – 496.09 m (15.53 m)

The «Upper silty 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).

- | | |
|---------------------|---|
| 480.56 m – 486.28 m | Silty claystone (calcareous), dark grey to medium grey, mica, siderite nodules often associated with crinoid detritus, pyrite (dispersed and as nodules), bioturbated, lenticular bedding, with lenses of siltstone (calcareous, argillaceous), light grey, and sandstone (calcareous, argillaceous), light grey, grading downwards into claystone (silty, calcareous), dark grey, mica, pyrite, burrows, laminated |
| 486.28 m – 496.09 m | Silty claystone (calcareous) to claystone (silty, calcareous), dark grey, mica, pyrite, bioclasts, bioturbation, lenticular bedding, with abundant laminae and lenses (mainly thinner than 1 cm) of siltstone (calcareous, argillaceous), light grey, foresets |

«Mixed clay-silt-carbonate sub-unit», 496.09 m – 559.75 m (63.66 m)

The «Mixed clay-silt-carbonate sub-unit» represents the section of the Opalinus Clay which has no distinctive characteristics typical of the other sub-units (Mazurek & Aschwanden 2020).

- | | |
|---------------------|--|
| 496.09 m – 502.39 m | Silty claystone (calcareous), dark grey, mica, pyrite (dispersed and as nodules), laminated to homogeneous, locally with burrows, in the lower part locally bioturbated

From 499.70 m to 499.81 m, argillaceous marl (silty) dark to medium grey |
| 502.39 m – 505.09 m | Claystone (silty, calcareous), dark grey, mica, pyrite, predominantly laminated, locally bioturbated, to silty claystone (calcareous), dark grey to medium grey, mica, pyrite, mostly bioturbated, thin lenses of siltstone (calcareous, argillaceous), light grey |
| 505.09 m – 511.00 m | Claystone (silty, calcareous), dark grey, mica, pyrite, laminated, burrows

From 505.51 m to 505.70 m, silty claystone (calcareous), dark grey to medium grey, mica, pyrite (dispersed and in nodules), laminated, burrows, about every 10 cm thin lenses of siltstone (calcareous, argillaceous), light grey, from 505.51 m to 505.71 m, bioclasts abundant |
| 511.00 m – 514.27 m | Silty claystone (calcareous), to claystone (silty), and claystone (silty, calcareous), dark grey, mica, pyrite (dispersed and in nodules), burrows, bioclasts, from 511.00 m to 512.10 m, bioturbated, at other places lenticular bedding, with very abundant layers and lenses of siltstone (calcareous, argillaceous), light grey, and sandstone (calcareous, argillaceous), light grey

At 511.58 m, firmground overlain by lithoclasts and bioclasts |
| 514.27 m – 519.87 m | Claystone (silty, calcareous), dark grey, mica, pyrite (dispersed and as nodules), some siderite nodules, mostly laminated, locally bioturbated, layers and nodules of silty claystone (calcareous, argillaceous), light |

	grey, from 514.61 m to 518.52 m, abundant thin (up to 1 cm thick) sideritic layers
519.87 m – 522.20 m	Claystone (silty, calcareous), and claystone (silty), dark grey, mica, pyrite, laminated
522.20 m – 536.00 m	Claystone (silty), dark grey, mica, pyrite (dispersed and as nodules), laminated, locally (at 523.85 m), burrows, abundant thin layers of siderite, beige
536.00 m – 546.17 m	Claystone (silty, calcareous), and claystone (silty), dark grey to black, mica, pyrite (dispersed and as nodules), few siderite nodules, ammonite (at 539.21 m), laminated, abundant layers with very small nodules of siderite, beige grey
546.17 m – 551.41 m	Claystone (silty) and claystone (silty, calcareous), dark grey to black, mica, pyrite (dispersed and as nodules), few layers with very small siderite nodules, from 548.09 m to 548.85 m, some fossils (ammonites [at 548.09 m and 548.85 m], brachiopods [e.g. at 548.68 m], bivalves), laminated
551.41 m – 559.75 m	Claystone (silty, locally calcareous), dark grey to black, mica, pyrite (dispersed and as nodules), fossiliferous (mainly ammonites, few bivalves), burrows, laminated

«Clay-rich sub-unit», 559.75 m – 573.68 m (13.93 m)

The dark homogeneous «Clay-rich sub-unit» has a high clay mineral content (mostly more than 60%). This sub-unit marks the base of the Opalinus Clay (Mazurek & Aschwanden 2020).

559.75 m – 563.60 m	Claystone (silty), dark grey, mica, pyrite, fossiliferous (ammonites [e.g. at 563.60 m], small shell fragments), coquina (at 561.14 m), burrows, laminated
563.60 m – 568.50 m	Claystone (silty), to claystone, dark grey to black, mica, pyrite, ammonite (at 566.72 m), small siderite nodules at 563.60 m, few calcareous nodules between 564.15 m and 564.42 m, laminated
568.50 m – 573.68 m	Claystone (silty, calcareous), dark grey, mica, pyrite, bioclasts, some fossils (belemnite [at 573.07 m], ammonite [at 573.58 m]), burrows, laminated

3.4 Lias Group

3.4.1 Staffelegg Formation, 573.68 m – 612.46 m (38.78 m)

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

The *upper boundary* is set at 573.68 m at the top of an argillaceous marl, light grey, which is overlain by a claystone (silty, calcareous), medium grey, with bioclasts and few macrofossils (ammonite, belemnite) at the basal Opalinus Clay. The boundary is also clearly visible in the FMI and GR record.

The *lower boundary* is set at 612.46 m at an erosional surface on top of a dolomitic marl, overlain by claystone (silty), bituminous.

3.4.1.1 Gross Wolf Member, 573.68 m – 576.57 m (2.89 m)

In BOZ2-1, the Gross Wolf Member (Reisdorf et al. 2011) can be divided into two parts, both very fossiliferous. The upper part (from 573.68 m to 574.50 m) is a bedded succession of argillaceous and calcareous marl. The lower part (from 574.50 m to 576.57 m) represents the typical "Jurensismergel" facies with nodular beds of limestone (argillaceous) to calcareous marl separated by argillaceous marl.

The *upper boundary* is set at 573.68 m at the top of an argillaceous marl, light grey, which is overlain by a claystone (silty, calcareous), medium grey, with bioclasts and few macrofossils (ammonite, belemnite) at the basal Opalinus Clay.

The *lower boundary* is set at 576.57 m at the base of the lowermost nodular beds of calcareous marl which coincide with the onset of bitumen content in a downward direction.

Lithology

573.68 m – 576.57 m At the top, from 573.68 m to 574.50 m, calcareous marl, medium light grey to medium grey, and argillaceous marl, medium light grey to dark grey, pyrite, glauconite, ammonites (e.g. 573.71 m), belemnites, crinoids, bioclasts

Main part, from 574.50 m to 576.57 m, as above but with nodules of limestone (argillaceous) (mudstone, micrite and biomicrite) to calcareous marl, light grey (in the lowermost part, from 576.07 m, nodules are flattened), pyrite, occasionally glauconite, ammonite (at 575.95 m), belemnites, crinoids, bioclasts

3.4.1.2 Rietheim Member, 576.57 m – 581.93 m (5.36 m)

In BOZ2-1, the Rietheim Member is distinctive due to its bitumen content which increases with depth. The upper part (from 576.57 m to 579.25 m) is characterised by argillaceous marl (partly silty) and consistently bituminous. The lower part (from 579.25 m to 581.93 m) consists of an alternation of laminated bituminous shale (in the uppermost part argillaceous marl) and laminated limestone (mudstone, micrite), moderately bituminous. The lowest limestone bed (from 580.88 m to 581.10 m) corresponds to the «Unterer Stein» (Reisdorf et al. 2011).

The *upper boundary* is set at 576.57 m at the base of the lowermost nodular beds of calcareous marl which coincide with the onset of bitumen content in a downward direction.

The *lower boundary* is set at 581.93 m at the base of the lowermost laminated bituminous shale bed. It overlies a fossiliferous bioturbated calcareous marl.

Lithology

- 576.57 m – 577.77 m At the top, from 576.57 m to 576.66 m, argillaceous marl, dark grey, including, from 576.63 m to 576.66 m, a thin, discontinuous bed of limestone (mudstone, micrite), medium grey, mica, pyrite, bituminous, fossiliferous (including, below 576.82 m, belemnites, partly pyritised), burrows (diameter < 1 mm) bringing lighter material into darker matrix
- In the lower part, from 576.66 m to 577.77 m, argillaceous marl, dark grey, mica, pyrite (including nodules and, down to 576.92 m, pyritised belemnites), siderite nodules, bituminous, fossiliferous, coquinas and accumulations of belemnites
- 577.77 m – 579.25 m Argillaceous marl (silty), dark grey, mica, bituminous, moderately fossiliferous (mainly belemnites, abundant from 577.77 m to 578.50 m)
- At the base, from 578.98 m to 579.25 m, argillaceous marl, dark grey, mica, bituminous, bioclasts
- 579.25 m – 581.93 m Bituminous shale, black, mica, pyrite, and argillaceous marl, dark grey, mica, pyrite, bituminous, ammonites (at 579.37 m and at 581.69 m) and belemnites (at 579.94 m, at 580.51 m and from 581.90 m to 581.93 m)
- At the top, from 579.25 m to 579.47 m, argillaceous marl, black, mica, pyrite, bituminous, belemnite (at 579.41 m)
- From 579.47 m to 579.71 m, two beds of limestone to limestone (argillaceous) (mudstone, micrite), medium grey to beige grey, pyrite, bituminous, fossiliferous (bioclasts), separated, at 579.61 m, by a thin (1 cm) layer of bituminous shale, black
- From 580.32 m to 580.41 m and from 580.50 m to 580.59 m, two beds of limestone to limestone (argillaceous) (mudstone, micrite), medium grey to beige grey, pyrite, bituminous, fossiliferous (bioclasts), with bivalves abundant at the base of the upper bed and in the bituminous shale separating the two beds
- From 580.88 m to 581.10 m, «Unterer Stein» consisting of limestone (mudstone, micrite), medium grey to beige grey, pyrite, bituminous, fossiliferous (bioclasts), laminated (stromatolite) (thin section BOZ2-1-581.08)
- The shale between the «Unterer Stein» and the base at 581.93 m is the most bituminous section of the member

3.4.1.3 Grünschholz Member, Breitenmatt Member and Rickenbach Member, 581.93 m – 585.24 m (3.31 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 thin and predominantly calcareous and fossiliferous members is difficult.

The *upper boundary* is set at 581.93 m at the top of the uppermost calcareous marl which is overlain by laminated bituminous shale of the Rietheim Member.

The *lower boundary* is set at 585.24 m at a bored erosional surface at the top of a succession of argillaceous siltstone (calcareous) which is overlain by bioclastic argillaceous marl.

Lithology

581.93 m – 583.81 m At the top (from 581.92 m to 582.39 m), calcareous marl, light grey to light greenish grey, pyrite, glauconite, fossiliferous (mainly belemnites), fossils partly phosphoritised (may correspond to the Müsenegg Bed, the lateral temporal equivalent of the Rickenbach Member)

From 582.39 m to 582.73 m, limestone (wackestone, biopelmicrite), light grey, pyrite, glauconite, phosphorite, mostly undulating to nodular bedding (nodular in a matrix of calcareous marl [silty], light greenish grey), bioturbated

From 582.73 m to 583.50 m, argillaceous marl (silty), dark grey to greyish green, pyrite, glauconite, very fossiliferous (predominantly large belemnites), fossils partly phosphoritised

At the base, from 583.50 m to 583.81 m, succession of calcareous hardgrounds, phosphorite, glauconite, bioturbated

The interval from 582.39 m to 583.81 m may correspond to the Breitenmatt Member, a nodular limestone and a fossiliferous argillaceous marl underlain by a succession of hardgrounds and characterised by a prominent GR peak (Reisdorf et al. 2011)

583.81 m – 585.24 m At the top, from 583.81 m to 583.96 m, arenaceous limestone, light grey to beige grey, bioclasts

In the lower part, from 583.96 m to 585.24 m, an alternation of limestone (silty), light grey and beige grey, pyrite, glauconite, phosphorite, fossiliferous (*Gryphaea*, crinoids, belemnites), and bioclastic argillaceous marl, dark grey and beige grey, pyrite, glauconite, phosphorite, fossiliferous, burrows (from 585.14 m to 585.24 m)

The interval from 583.81 m to 585.24 m may correspond to the Grünschholz Member, an alternation of slightly thicker beds of arenaceous limestone to limestone (silty) and thin beds of bioclastic argillaceous marl with *Gryphaea obliqua*

3.4.1.4 Frick Member, 585.24 m – 600.77 m (15.53 m)

In BOZ2-1, the Frick Member is a uniform succession of argillaceous siltstone (calcareous) with thin beds of siltstone (calcareous) grading downwards into silty claystone (calcareous). Fossils are rare and restricted to few horizons.

The *upper boundary* is set at 585.24 m at a bored erosional surface at the top of a succession of argillaceous siltstone (calcareous) which is overlain by bioclastic argillaceous marl.

The *lower boundary* is set at 600.77 m at the base of a thick succession of silty claystone (calcareous) and at the top of thin, pyritised, fossiliferous (including *Gryphaea arcuata*), bioclastic argillaceous marl overlying a hardground formed at the top of a bioclastic limestone.

Lithology

585.24 m – 594.24 m At the top, at 585.24 m, erosional surface, bored

Argillaceous siltstone (calcareous), dark grey to medium light grey, mica, pyrite (dispersed and in nodules), crinoids, bivalves, bioturbated, lenticular bedding, lenses and thin beds of siltstone (calcareous, argillaceous), medium grey

From 592.58 m to 593.10 m and from 593.10 m to 593.38 m, two coarsening upward sequences starting (from the bottom) with siltstone (argillaceous), medium grey, and continuing into argillaceous siltstone (calcareous), medium light grey

594.24 m – 600.77 m Silty claystone (calcareous), dark grey, mica, pyrite (dispersed and in nodules), bioturbated, wavy bedding

3.4.1.5 Beggingen Member, 600.77 m – 604.27 m (3.50 m)

In BOZ2-1, the Beggingen Member comprises two successions of thin- to medium-bedded, fossiliferous limestone separated by a marly interbed. The upper succession (from 600.77 m to 603.38 m) including the marly interbed is characterised by an abundance of *Gryphaea arcuata* and belemnites. The lower succession (from 603.38 m to 604.27 m) is characterised by iron-oids and bivalves of the genus *Cardinia*. It may correspond to the Schleithem Bed (Reisdorf et al. 2011).

The *upper boundary* is set at 600.77 m at the base of a thick succession of silty claystone (calcareous) and at the top of thin, pyritised, fossiliferous (including *Gryphaea arcuata*), bioclastic argillaceous marl overlying a hardground formed at the top of a bioclastic limestone.

The *lower boundary* is set at 604.27 m at an erosional surface separating the overlying bioclastic limestone with iron-oids from a bioclastic argillaceous marl.

Lithology

600.77 m – 603.38 m At the top, from 600.77 m to 600.89 m, bioclastic argillaceous marl, dark grey, silty, pyrite nodule (at 600.88 m), very fossiliferous including *Gryphaea arcuata*, belemnites, crinoids

From 600.89 m to 602.72 m, bioclastic limestone (packstone, biosparite), medium to light grey, phosphorite nodules, very fossiliferous (bivalves including *Gryphaea arcuata*, belemnites, crinoids, bioclasts), fossils partly phosphoritised, locally pellets, thick-bedded with some mm to few cm thin and two thicker interlayers (from 602.72 m to 602.82 m and from 602.94 m to 603.38 m) of bioclastic calcareous locally also argillaceous marl, dark grey, fossiliferous

- 603.38 m – 604.27 m At the top, from 603.38 m to 603.70 m, below two bored omission surfaces at 603.38 and at 603.45m, bioclastic limestone (packstone, biosparite), dark grey to brown, iron-oids, fossiliferous (thin- and thick-shelled bivalves, crinoids, bioclasts)
- From 603.70 m to 603.83 m, bioclastic calcareous marl, medium grey and brown, iron-oids, bivalves, crinoids
- From 603.83 m to 603.98 m, bioclastic limestone (packstone, biosparite), dark grey, no iron-oids
- At the base, from 603.98 m to 604.27 m, bioclastic limestone (packstone, biosparite), dark grey to brown, iron-oids, fossiliferous (thin- and thick-shelled bivalves, crinoids, bioclasts), bivalve shells convex side up and bored

3.4.1.6 Schambelen Member, 604.27 m – 612.46 m (8.19 m)

In BOZ2-1, the Schambelen Member can be subdivided into an upper part (from 604.27 m to 609.80 m) with claystone (silty, calcareous), slightly bituminous, with interlayers of bioclastic calcareous marl, and a lower part (from 609.80 m to 612.46 m) with claystone (silty), bituminous. This corresponds to the findings at other locations within the area under investigation (Jordan 1983, Reisdorf et al. 2011).

The *upper boundary* is set at 604.27 m at an erosional surface separating the overlying bioclastic limestone with iron-oids from a bioclastic argillaceous marl.

The *lower boundary* is set at 612.46 m at an erosional surface on top of a dolomitic marl, light greyish green, overlain by claystone (silty), bituminous, black.

Lithology

- 604.27 m – 609.80 m At the top, from 604.27 m to 604.39 m, below an erosional surface, bioclastic argillaceous marl, dark grey, fossiliferous (coquina, bivalves, crinoids)
- Claystone (silty, calcareous), dark grey to black, laminated, pyrite (dispersed and in nodules), mica, slightly bituminous, fossiliferous (mostly bivalves, bioclasts), mostly laminated, locally bioturbated, with abundant thin interbeds of bioclastic calcareous marl, medium light grey, most of these beds are coquinas (bivalves, bioclasts, from 605.50 m to 605.67 m also belemnites), shells often coated with pyrite
- From 605.17 m to 605.18 m, argillaceous siltstone, light grey, bioclastic

- 609.80 m – 612.46 m Claystone (silty), black, bituminous, mica, pyrite (dispersed, in nodules, and from 611.30 m to 611.70 m as burrow fills), mostly laminated, locally bioturbated, various thin layers (max. 8 cm) of argillaceous siltstone, light grey, bioclastic, and, at 611.35 m, nodule of limestone (argillaceous) (mudstone, micrite), light grey
- At the base, from 612.34 m to 612.46 m, argillaceous marl, dark grey, glauconite, pyrite, dolomitic lithoclasts, coquina (bivalves, belemnite)

3.5 Keuper Group

3.5.1 Klettgau Formation, 612.46 m – 653.45 m (40.99 m)

The Klettgau Formation is a heterogeneous succession dominated by variegated playa (coastal, sabkha and continental) sediments with mostly silty claystone and dolocrete. Fine-grained to coarse-grained calcareous or siliciclastic sediments represent fluvial channels and overspills. Thick dolostone beds document a marine ingress (Jordan et al. 2016).

In BOZ2-1, the Belchen Member and the Seebi Member are not encountered.

The *upper boundary* is set at 612.46 m at an erosional surface on top of a dolomitic marl, light greyish green, overlain by claystone (silty), bituminous, black.

The *lower boundary* is set at 653.45 m at the top of the regional dolostone marker bed delimiting the Bänkerjoch Formation (Jordan et al. 2016).

3.5.1.1 Gruhalde Member, 612.46 m – 630.96 m (18.50 m)

The Gruhalde Member is characterised by dolomitic marl with few interbeds of argillaceous marl and dolostone. According to the type locality, the Gruhalde clay pit (Jordan et al. 2016) located some 9 km to the west, there is a distinct change in colour with depth: in the upper part (from 612.46 m to 624.49 m), light colours such as grey violet and pale yellowish green prevail. This section probably corresponds to the obsolete "Knollenmergel". The middle part (from 624.49 m to 627.47 m) is reddish brown to dark reddish-brown in colour and corresponds to the part 2 of the Gruhalde Member at the type locality in Frick («Rote Wand», Jordan et al. 2016). The lowest part (from 627.47 m to 630.96 m) shows lighter colours again.

The *upper boundary* is set at 612.46 m at an erosional surface on top of a dolomitic marl, light greyish green, overlain by claystone (silty), bituminous, black.

The *lower boundary* is set at 630.96 m at the top of a thin bed of dolostone (argillaceous), showing desiccation cracks and tepee structures. This bed forms the top of a succession showing a beige and pink lamination. This configuration shows a great resemblance to the top of the Gansingen Member at the Gruhalde clay pit, a reference section of the member (Jordan et al. 2016).

Lithology

- 612.46 m – 615.40 m At the top, from 612.46 m to 612.63 m, dolomitic marl (calcareous), pale yellowish green, underlain by dolomitic marl, alternating between pale yellowish green and greyish violet
- 615.40 m – 617.00 m No core or cuttings collected

- 617.00 m – 624.49 m Dolomitic marl, patchy, alternating between grey violet and pale yellowish green, grading downwards into dolomitic marl (silty) (locally also sandy), grey violet, root structures (from 617.00 m to 620.40 m), with nodules of dolostone, pale yellowish green, and, from 620.10 m to 620.40 m, lithoclasts of dolomitic marl, pale yellowish green, laminated
Near the base, at 624.31 m, lithoclasts (diameter up to 2 cm, rounded) of dolostone, reddish grey, oolitic
- 624.49 m – 627.47 m At the top, from 624.49 m to 624.67 m, desiccation cracks filled by dolomitic marl, pale yellowish green
Dolomitic marl, reddish brown to dark reddish brown, locally (reduction halos) very light grey to light greenish grey, locally alternating with argillaceous marl, dark grey, locally dolostone beds, light grey, and nodules of dolostone (argillaceous), light greenish grey
- 627.47 m – 630.96 m Dolomitic marl (mostly silty), light greenish grey to pale pink, occasionally pyrite, mostly laminated (change in colour from pale pink to light greenish grey) with lamination disrupted by desiccation cracks in the lower part (from 627.75 m to 628.10 m) or bioturbation
From 628.90 m to 628.97 m and from 629.73 m to 629.79 m, two thin beds of dolostone, light grey

3.5.1.2 Gansingen Member, 630.96 m – 637.82 m (6.86 m)

The Gansingen Member provides evidence of a marine ingression from the west, with a strong lateral variation of lithofacies in an E-W direction. Furthermore, the member was locally subject to early post-depositional erosion (Jordan et al. 2016). The section in BOZ2-1 shows a high resemblance to the fully developed, non-eroded reference section at the Gruhalde clay pit (9 km to the west of BOZ2-1). In contrast, the similarity with the condensed and eroded section at the Gansingen type locality (4.6 km to the north) is low.

In BOZ2-1, the upper part of the Gansingen Member (from 630.96 m to 634.99 m) is a mostly laminated (visible by a change in colour) section varying between dolostone (argillaceous), dolomitic marl and argillaceous marl. The lower part (from 634.99 m to 637.82 m) consists of dolostone and dolostone (argillaceous) locally with bivalves, partly porous and partly brecciated.

The *upper boundary* is set at 630.96 m at the top of a thin bed of dolostone (argillaceous), showing desiccation cracks and tepee structures. This bed forms the top of a succession showing a beige and pink lamination. This configuration is the same as the top of the Gansingen Member at the Gruhalde clay pit, a reference section of the member (Jordan et al. 2016).

The *lower boundary* is set at 637.82 m at the sharp but irregular base of the lowermost massive dolostone (argillaceous) bed.

Lithology

- 630.96 m – 632.92 m Thin-bedded alternation of dolomitic marl (silty), beige to pink, laminated, pyrite and argillaceous marl (dolomitic), greyish blue green, pyrite
- From 630.96 m to 631.03 m, dolostone (argillaceous), beige, with desiccation cracks and tepee structures
- From 632.08 m to 632.92 m, dolostone (argillaceous), beige to pink, with thin interlayers of argillaceous marl (dolomitic), medium grey, pellets, vugs
- 632.92 m – 634.99 m mostly laminated section transitioning from dolomitic marl (locally silty), beige to pink, pyrite, to argillaceous marl (dolomitic), greyish blue green, pyrite, and back
- 634.99 m – 637.82 m In the upper part, from 634.99m to 636.08 m, dolostone, beige grey, bivalves (voids), up to cm-wide vugs and druses, partly filled with dolomite crystals
- From 636.08 m to 636.73 m, dolostone (argillaceous), beige grey, laminated
- From 636.73 m to 637.45 m, breccia, dolomitic (monomict), beige grey, vugs
- From 637.45 m to 637.82 m, dolostone (argillaceous), beige grey, with microbial mats

3.5.1.3 Ergolz Member, 637.82 m – 653.45 m (15.63 m)

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

In BOZ2-1, the upper part of the Ergolz Member (from 637.82 m to 644.73 m) represents a distal overspill facies; argillaceous marl (silty) and silty marl prevail. Nodules and nodular beds of dolostone document paleosoils. Argillaceous sandstone (fine-grained) (dolomitic) is evidence of more proximal overspill events. In the lower part (from 644.73 m to 653.45 m), sandy claystone to argillaceous sandstone with mostly thin layers of sandstone (fine-grained) prevails, representing a proximal overspill environment close to fluvial channels.

The *upper boundary* is set at 637.82 m at a sharp irregular surface separating the dolomitic marl section from the overlying massive dolostone (argillaceous) of the Gansingen Member.

The *lower boundary* is set at 653.45 m at the top of the regional dolostone marker bed delimiting the Bänkerjoch Formation (Jordan et al. 2016).

Lithology

- 637.82 m – 643.05 m Alternation of argillaceous marl (mostly silty), greyish blue green, sandy marl and silty marl, pale green, occasionally pyrite (dispersed and in nodules) and dolostone nodules, light grey, thin layers of dolomitic marl, medium grey and dolomitic siltstone (argillaceous), from 641.24 m to

- 641.41 m, three beds of dolostone, beige grey, in argillaceous marl, greyish blue green
- 643.05 m – 644.73 m Argillaceous marl (silty), dark reddish brown and greyish blue green, silty marl, dark reddish brown, argillaceous sandstone (fine-grained) (dolomitic), dark reddish brown, and, from 643.80 m to 643.84 m, sandstone (fine-grained), pale green
- 644.73 m – 648.51 m Argillaceous sandstone, light grey and dark grey, mica, plant remains, wavy to flaser bedding, in the middle part (from 645.97 m to 648.51 m) alternating with sandy claystone, dark grey, mica, plant remains, and sandstone (argillaceous), light grey, mica, plant remains, wavy to flaser bedding, occasionally with small ripples
- 648.51 m – 653.45 m Sandy claystone, light grey and dark grey, locally with reddish hue, mica, in the lower part, also pyrite, plant remains, wavy to flaser bedding, mostly thin and one thicker layer (from 652.32 m to 652.67 m) of sandstone (fine-grained) (argillaceous), light grey, mica, plant remains on bedding planes, flaser bedding; GR and reddish hue point to high potassium feldspar content
- At the base, from 652.67 m to 653.45 m, claystone (dolomitic), dark grey to black, pyrite

3.5.2 Bänkerjoch Formation, 653.45 m – 748.27 m (94.82 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 (Jordan et al. 2016, Bernasconi et al. 2017).

The *upper boundary* is set at 653.45 m at the top of the regional dolostone marker bed delimiting the Bänkerjoch Formation in the eastern Folded Jura region (Jordan et al. 2016).

The *lower boundary* is set at 748.27 m at the top of the uppermost massive dolostone bed of the Schinznach Formation.

Lithostratigraphic subdivision

There is still no formal subdivision of the Bänkerjoch Formation. Jordan & Deplazes (2019) propose using the informal subdivision based on earlier core records of Nagra (Dronkert et al. 1990) for this campaign. The upper three of five sub-units were identified in BOZ2-1. The lowermost part of the formation mostly shows properties of «Banded massive anhydrite» (Sub-unit IV of Dronkert et. al. 1990) with few argillaceous to dolomitic marl interlayers. The «Dolomite and anhydrite» (Sub-unit V) seems to be missing (as known from other locations, e.g. Jordan et al. 2016).

653.45 m – 683.23 m: «Claystone with anhydrite nodules» (Sub-unit I of Dronkert et al. 1990), 29.78 m

683.23 m – 704.07 m «Cyclic sequence» (Sub-unit II), 20.84 m

- 704.07 m – 739.32 m «Thin-layered anhydrite and claystone sequence» (Sub-unit III), 35.25 m, including the selenite «Anhydrite Marker Bed of Riniken» from 718.97 m to 719.76 m and the «Marker Horizon II» from 737.51 m to 737.61 m
- 739.32 m – 748.27 m «Banded massive anhydrite» (Sub-unit IV), 8.95 m

Lithology

«Claystone with anhydrite nodules», 653.45 m – 683.23 m (39.78 m)

This is the lithologically most heterogeneous unit of the entire formation. Anhydrite nodules are found in almost the whole unit embedded in argillaceous marl. However, they are not a unique feature because they are also abundant in the underlying «Cyclic sequence» unit. Veins of anhydrite are found in the whole unit, but are particularly abundant from 659.57 m to 672.75 m. The sub-unit can be described as follows (from top to base):

- 653.45 m – 658.81 m At the top, from 653.45 m to 653.71 m, dolostone, light greenish grey, massive (cloudy) in the upper part, rather nodular in the lower part, fine-layered (broken)
- Below, alternation of argillaceous marl, dark grey to black, dolomitic marl, light greenish grey, and claystone (dolomitic), dark grey to black, anhydrite veins and inclined anhydrite nodules
- 658.81 m – 666.43 m At the top, from 658.81 m to 659.57 m, anhydrite, light grey, formed by abundant anhydrite nodules, beds and veins, white, with claystone matrix, black, locally pyrite
- Below, alternation of anhydrite (argillaceous), dark grey, formed by anhydrite veins (inclined and horizontal), layers and nodules, white, in a claystone matrix, and argillaceous marl, dark grey and dark reddish brown, with anhydrite veins (inclined and / or horizontal) and nodules
- 666.43 m – 672.75 m Alternation of anhydrite (argillaceous), dark grey, formed by anhydrite veins (inclined and horizontal), layers and nodules, white, in claystone matrix, black, and argillaceous marl, dark grey and dark reddish brown, with anhydrite veins (inclined and / or horizontal) and nodules, white, and locally, anhydrite (nodular, chickenwire), white
- 672.75 m – 683.23 m Alternation of argillaceous marl, greenish grey and dark reddish brown, with some anhydrite nodules, white, claystone (anhydritic) greyish green and dark reddish brown, with some anhydrite nodules, white, anhydrite (argillaceous), formed by anhydrite veins (inclined and / or horizontal), layers and nodules, white (veins also pink), in claystone matrix, black, anhydrite (nodular, chickenwire), white, inclined anhydrite veins, white and pink, abundant

«Cyclic sequence», 683.23 m – 704.07 m (20.84 m)

The unit consists mainly of anhydrite with varying fabrics and bedding: beds of densely packed nodules, laminated anhydrite with thin claystone intervals, massive anhydrite that lacks internal structures, and anhydrite nodules organised in a chickenwire structure. Clay minerals are less abundant than in the overlying sub-unit «Claystone with anhydrite nodules». They are concentrated in thin claystone to claystone (anhydritic) layers. Veins of anhydrite are exclusively developed in thick interbeds of claystone (anhydritic) and become rare in the lower part. The sub-unit can be described as follows (from top to base):

- 683.23 m – 691.95 m At the top, from 683.23 m to 683.43 m, dolomitic marl to dolostone, light greenish grey to greyish pink, with desiccation cracks
- Alternation of anhydrite, white, massive, with beds (up to 50 cm) often laminated in the upper part and nodular (chickenwire structure) in the lower part, claystone (anhydritic), dark grey, dark reddish brown and greyish green, with some anhydrite nodules, anhydrite (argillaceous) (fine-bedded alternation to lamination of anhydrite, white, and claystone [anhydritic]), locally, anhydrite (arenitic), medium grey, inclined anhydrite veins, pink and white, abundant
- From 688.47 m to 688.65 m, enterolitic folding (i.e. folding as a result of sulphate rock diagenesis)
- 691.95 m – 694.18 m Anhydrite, white, nodular to massive, no bedding, grading into anhydrite (argillaceous), medium grey, composed of anhydrite (nodular), white, and thin interlayers of claystone (anhydritic) dark grey to black
- From 692.35 m to 693.05 m, enterolitic folding
- 694.18 m – 699.01 m Alternation of anhydrite, white, nodular to massive, no bedding, claystone (anhydritic), dark grey, with thin beds and veins of anhydrite, white, anhydrite (argillaceous), medium grey, consisting of the two lithologies described above in fine-bedded alternation, nodular anhydrite (chickenwire), white, locally inclined anhydrite veins, pink to white
- 699.01 m – 704.07 m At the top, from 699.01 m to 699.40 m, anhydrite bed, white, with fossil dykes filled with claystone (dolomitic), dark grey
- Anhydrite, white, nodular and laminated, locally massive with interbeds of claystone (anhydritic) dark grey, anhydrite (argillaceous), medium grey, where thin claystone beds are more abundant
- From 699.62 m to 699.76 m and from 702.24 m to 702.43 m, two slightly thicker intervals of claystone (anhydritic) dark grey, the latter with inclined anhydrite vein, pink

«Thin-layered anhydrite and claystone sequence», 704.07 m – 739.32 m (35.25 m)

This unit is characterised by numerous beds of claystone (mostly anhydritic and dolomitic) to argillaceous marl. Another feature is the reddish hue of different parts of the unit. The massive anhydrite bed from 718.97 m to 719.76 m could correlate with the «Anhydrite Marker Bed» in Riniken (Matter et al. 1987) and the dolomitic sandstone from 737.51 m to 737.61 m could be identified as «Marker Horizon II» (Jordan et al. 2016). The sub-unit can be described as follows (from top to base):

704.07 m – 708.07 m	Claystone (anhydritic), dark grey, with abundant anhydrite nodules and veins, grading locally into anhydrite, argillaceous, medium grey, and thin beds of anhydrite, white, locally inclined anhydrite veins, pink
708.07 m – 714.93 m	Alternation of argillaceous marl, dark grey, with abundant thin (few mm) and few thicker, partly wavy layers of dolomitic marl, dark grey, claystone, black, and anhydrite, white, claystone (anhydritic) dark grey to black, with thin layers and small nodules of anhydrite, white, anhydrite (argillaceous), medium grey, formed by thin-bedded alternation of anhydrite, dolomitic marl, and claystone From 712.22 m to 712.70 m, disturbed layering with disrupted laminated anhydrite beds From 713.75 m to 713.89 m, enterolitic folding and tepee structures
714.93 m – 718.97 m	Distinctly laminated section with argillaceous marl, dark grey, with abundant thin (few mm) and few thicker, partly wavy layers of dolomitic marl, dark grey, claystone, black and anhydrite, white, and, from 716.92 m, thick interbeds of claystone (anhydritic and dolomitic), dark grey to black, with thin layers and small nodules of anhydrite, white, anhydrite (argillaceous), medium grey, formed by thin-bedded alternation of anhydrite, dolomitic marl, and claystone, locally inclined anhydrite veins, pink From 717.33 m to 717.52 m, irregular bedding
718.97 m – 719.76 m	Anhydrite, white, laminated, with selenite ghosts
719.76 m – 723.09 m	Claystone (dolomitic and anhydritic), to argillaceous marl, dark grey, locally with anhydrite nodules, in the lower part (from 722.05 m to 722.90 m), inclined anhydrite veins, pink From 720.84 m to 721.34 m and from 721.46 m to 721.70 m, anhydrite (argillaceous) formed by very abundant, slightly flattened anhydrite nodules, white, in a claystone (dolomitic) matrix, dark grey
723.09 m – 725.53 m	Anhydrite (argillaceous), medium grey, formed by thin-bedded alternation of anhydrite, white, partly nodular, partly detritic (lithoclasts up to a few mm), dolomitic marl, dark grey, and claystone, black, laminated From 723.62 m to 723.81 m, thick interval of dolomitic marl, dark grey
725.53 m – 727.83 m	Heterogeneous, thin-bedded alternation of claystone (anhydritic) and claystone (dolomitic), dark grey to dark reddish brown, with few small anhydrite nodules, anhydrite (argillaceous), medium grey, formed by thin-bedded alternation of anhydrite, dolomitic marl and claystone, and dolomitic marl At the base (from 727.55 m to 727.83 m), anhydrite, light grey, massive but partly composed of anhydrite lithoclasts, white

- 727.83 m – 729.44 m Laminated to medium-bedded alternation with prominent enterolitic folding formed by claystone (anhydritic), dark grey to dark reddish brown, argillaceous marl, dark grey, dolomitic marl, beige grey, and anhydrite (dolomitic), beige grey
At 729.10 m nodular anhydrite, white (of selenite or microbial mat origin) covering desiccation cracks
- 729.44 m – 732.03 m Anhydrite, white, to anhydrite (argillaceous), light grey, mostly laminated, locally nodular (chickenwire)
From 730.59 m to 730.71 m, prominent interlayer of claystone (dolomitic), dark grey
- 732.03 m – 733.50 m Claystone (anhydritic), dark grey, to anhydrite (argillaceous), medium grey, laminated, anhydrite (argillaceous), light grey
- 733.50 m – 737.51 m Anhydrite (argillaceous), dark grey, and anhydrite (dolomitic), light grey, mostly laminated (mm-thin laminae of anhydrite, white, dolomitic marl, beige grey, and claystone, black)
At 734.10 m and from 735.21 m to 735.51 m, enterolitic folding, the latter interval includes tepees resulting in a distinct irregular bedding
- 737.51 m – 739.32 m At the top, from 737.51 m to 737.61 m, dolomitic sandstone (fine- to medium-grained) (argillaceous), beige grey, anhydritic, overlying a nodular anhydrite bed
Anhydrite (argillaceous), dark grey, and anhydrite (dolomitic), light grey, mostly laminated (as above) sandwiched by two successions of dolomitic marl, beige grey, from 739.00 m to 739.06 m, breccia horizon with angular clasts

«Banded massive anhydrite», 739.32 m– 748.27 m (8.95 m)

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

- 739.32 m – 742.14 m Anhydrite (argillaceous), dark grey, and anhydrite (dolomitic), light grey, laminated (mm-thin laminae of anhydrite, white, dolomitic marl, beige grey, and claystone, black), enterolitic folding and disturbed layering (tepee, imbrication, dissection) at several levels
- 742.14 m – 744.71 m Anhydrite (dolomitic to argillaceous), white to beige grey, laminated (as above), anhydrite, white
At 742.57 m and from 744.44 m to 744.71 m, anhydrite (dolomitic, sandy [fine- to coarse-grained]), beige grey, from 744.44 m to 744.71 m with small elongated black flakes (possibly plant remains)
- 744.71 m – 745.85 m Argillaceous marl, dark grey, grading into dolomitic marl, light grey, partly bioturbated, with anhydrite and dolostone nodules, enterolitic folding

- 745.85 m – 748.27 m Anhydrite (dolomitic), white to beige grey, and anhydrite (argillaceous), beige grey with abundant selenite ghosts
- At the base, from 747.79 m to 747.96 m and from 748.12 m to 748.27 m, dolostone (argillaceous, anhydritic), medium grey, with very small anhydrite nodules

3.6 Muschelkalk Group

3.6.1 Schinznach Formation, 748.27 m – 820.32 m (72.05 m)

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

The *upper boundary* is set at 748.27 m at the top of the uppermost massive dolostone bed of the Asp Member. It is overlain by a thin-bedded alternation of dolostone (argillaceous) and anhydrite (partly dolomitic) of the basal Bänkerjoch Formation.

The *lower boundary* is set at 820.32 m at an erosional surface which separates the lowermost limestone (dolomitic) from the underlying dolostone.

3.6.1.1 Asp Member, 748.27 m – 752.64 m (4.37 m)

The Asp Member (Pietsch et al. 2016) of BOZ2-1 consists of dolostone which is occasionally bituminous in the upper part and fossiliferous bituminous shales with dolostone interbeds in the lower part.

The *upper boundary* is set at 748.27 m at the top of the uppermost massive dolostone bed of the Asp Member. It is overlain by a thin-bedded alternation of dolostone (argillaceous) and anhydrite (partly dolomitic) of the basal Bänkerjoch Formation.

The *lower boundary* is set at 752.64 m at the base of the lowermost (thin) bituminous claystone layer overlying the erosional top of the dolomitic Stamberg Member.

Lithology

- 748.27 m – 751.18 m At the top, from 748.27 m to 748.30 m, dolostone (argillaceous), silicified components, unidentified fossils (brachiopods?)
- Dolostone, beige grey (alternating to brown when exposed), locally pale pink and (from 748.90 m to 749.12 m) light grey, locally bituminous, mostly laminated in the lower part, several thin intervals of dolostone (argillaceous) to dolomitic marl, medium light grey to medium grey, locally fossiliferous, laminated, from 748.30 m to 748.82 m, many small and few larger irregularly shaped anhydrite nodules, white, from 749.12 m to 750.69 m, dark pellets, from 749.50 m to 750.95 m, anhydrite nodules, at the base, at 751.18 m, foresets

751.18 – 752.64 m	Claystone to claystone (dolomitic), dark grey, bituminous, partly fossiliferous (brachiopods: <i>Lingula</i> sp.), laminated
	From 751.34 m to 751.37 m, dolostone (argillaceous), medium grey, and, from 752.07 m to 752.57 m, dolostone, light grey, bituminous, bioturbated, druse with calcite seam

3.6.1.2 Stamberg Member, 752.64 m – 785.00 m (32.36 m)

The Stamberg Member is a thick succession of dolostone in the upper part of the Schinznach Formation. Its definition (Pietsch et al. 2016) follows a purely petrographic approach: its lower boundary is given by the lower boundary of a post-sedimentary, persistent and complete dolomitisation (commonly of a limestone that was initially at least partially marine).

In BOZ2-1, the Stamberg Member is a quite monotonous succession of thick-bedded to massive, variably porous dolostone, with virtually no fossils. It contains some pellets and indications of bioturbation with many anhydrite nodules. Oolitic intervals as known from other sections (e.g. Pietsch et al. 2016) are not found.

The *upper boundary* is set at 752.64 m at the erosional top of the dolomitic Stamberg Member overlain by bituminous shales of the Asp Member.

The *lower boundary* is set at 785.00 m at the lower limit of the persistent and complete dolomitisation. It coincides with a change in colour from darker hues of the Stamberg Member to lighter hues of the Liedertswil Member.

Lithology

752.64 m – 753.35 m	Dolostone, light grey to beige, strongly bioturbated, pellets, vugs From 752.96 m to 753.01 m, undulating marly interlayer
753.35 m – 756.51 m	Dolostone, beige grey, homogeneous, dense, vugs, several claystone drapes, dark grey, few anhydrite nodules, white
756.51 m – 760.90 m	Dolostone, beige to beige grey, porosity changes from high (above 756.82 m) to extremely high (from 756.82 m to 756.95 m) and back to moderate (below 756.95 m), open vugs (up to 2 cm) partly filled with calcite lamellae typical of "Rauhwacke", few anhydrite nodules, white
760.90 m – 763.32 m	Dolostone, beige, with an irregular network of veins and nodules of anhydrite, white, from 761.52 m to 761.73 m, large vugs
763.32 m – 766.66 m	At the top, from 763.32 m to 763.36 m, dolostone, beige, dense Dolostone, beige grey, with small irregularly shaped anhydrite nodules, white, anhydrite nodules, white, from 765.00 m to 766.66 m, pellets
766.66 m – 769.28 m	Dolostone, beige grey, with mostly irregularly and some spherically shaped large and many small anhydrite nodules, pellets (from 766.66 m to 766.82 m and at 769.16 m), locally bioturbated

769.28 m – 770.20 m	Dolostone, beige, from 769.62 m to 769.90 m, abundant small anhydrite nodules, white, some nodules in the other parts
770.20 m – 771.28 m	Dolostone, beige, strongly bioturbated, with abundant irregularly shaped anhydrite nodules, white
771.28 m – 772.98 m	Dolostone, beige, bioturbated in the upper part (down to 772.15 m) without pores, vugs or nodules, except at 771.74 m where small anhydrite nodules are found
772.98 m – 777.12 m	Dolostone, beige, bioturbated, with many, mainly open, often large vugs, some larger and many small irregularly shaped anhydrite nodules, occasionally pyrite From 776.09 m to 776.12 m, coquina
777.12 m – 778.20 m	Dolostone, beige
778.20 m – 780.28 m	Alternation of dolostone, light grey, bioturbated, partly nodular and ca. 10 cm thick beds of dolostone (argillaceous), beige, bioturbated, few vugs (from 778.22 m to 778.24 m) At the base, from 780.05 m to 780.28 m, fine-layered to laminated alternation of dolostone, light grey, and dolostone (slightly argillaceous), medium grey
780.28 m – 785.00 m	Dolostone (partly argillaceous), beige, strongly bioturbated, with few open vugs, except from 780.78 m to 780.80 m, at 781.06 m and from 783.15 m to 783.22 m where larger open vugs are found

3.6.1.3 Liedertswil Member, 785.00 m – 793.79 m (8.79 m)

The Liedertswil Member is defined as reaching from the lower boundary of post-sedimentary persistent and complete dolomitisation down to the uppermost bed consisting of more than 10% of crinoids at its base (Pietsch et al. 2016).

In BOZ2-1, the Liedertswil Member is a well-bedded succession of mostly bioturbated micritic limestone. The fossil content (bivalves, undefined bioclasts) is mainly concentrated in the abundant coquinas.

The upper boundary is set at 785.00 m at the lower limit of the persistent and complete dolomitisation. It coincides with a change in colour from the darker hues of the Stamberg Member to the lighter hues of the Liedertswil Member.

The *lower boundary* is set at 793.79 m at the top of the uppermost bed consisting of more than 10% crinoids (Pietsch et al. 2016).

Lithology

785.00 m – 787.60 m	At the top, from 785.00 m to 785.76 m, limestone (dolomitic) formed by limestone (mudstone, micrite), light grey, nodular due to intense bioturbation, partly altered to dolostone, beige grey, mostly at places where bioturbation is severe
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	Limestone (mudstone, micrite), light grey, bioturbated, locally (787.00 m to 787.60 m) strongly bioturbated, alternating with limestone (slightly argillaceous and argillaceous) (mudstone, micrite), bioturbated
787.60 m – 791.73 m	Limestone (mudstone, micrite), light grey and beige, thin- to medium-bedded, partly bioturbated, locally nodular, claystone drapes, dark grey to black, with interbeds of bioclastic limestone (grainstone, biosparite), light grey, comprising a succession of coquinas, at 791.50 m druses partly filled with calcite crystals
791.73 m – 793.79 m	Thin-bedded alternation of limestone (mudstone, micrite), light grey, locally bioturbated, bioclastic limestone (grainstone, biosparite), light grey, dolostone, beige, and claystone drapes, black, at 793.34 m bored surface

3.6.1.4 Leutschenberg Member and Kienberg Member, 793.79 m – 820.32 m (26.53 m)

According to Jordan & Deplazes (2019), the Leutschenberg Member and the overlying Kienberg Member should be combined because it is often difficult to separate them. Generally, both members consist of limestone with a very low clay content and a varying content of biogenic components, including crinoids. The argument for delimiting the Kienberg Member from the overlying Liedertswil Member is the uppermost occurrence of abundant crinoids in one, at least 10 cm thick, bed (Pietsch et al. 2016). In BOZ2-1, such a bed is found from 793.79 m to 793.89 m. Remarkably, in the underlying interval from 793.89 m to 800.05 m, crinoids are absent. Typical "Trochitenkalk" is found from 800.05 m to 811.39 m.

The *upper boundary* is set at 793.79 m at the top of the uppermost bed which consists of more than 10% crinoids.

The *lower boundary* is set at 820.32 m at an erosional surface which separates the lowermost limestone (dolomitic) from the underlying dolostone.

Lithology

793.79 m – 795.65 m	At the top, from 793.79 m to 793.89 m, coquina: bioclastic limestone (grainstone, biosparite), light grey, with abundant crinoids, bivalves and brachiopods Nodular (as a result of bioturbation), thin- to medium-bedded alternation of limestone (mudstone to wackestone, biomicrite), light grey, and dolostone to limestone (dolomitic), beige grey, at 794.50 m coquina
795.65 m – 797.76 m	Alternation of limestone (mudstone, micrite), light grey, partly nodular, limestone (wackestone, biomicrite), light grey, from 796.15 m to 796.39 m and from 796.89 m to 797.08 m, successions of coquinas, claystone drapes, dark grey to black At the base, from 797.64 m to 797.76 m, bioclastic limestone (packstone and grainstone, biomicrite and biosparite), beige grey with large bored lithoclasts, dark grey

797.76 m – 800.05 m	Limestone (mudstone, micrite), light grey, bioturbated, claystone drapes, dark grey to black, from 798.07 m to 798.35 m, pellets (pelmicrite), from 799.18 m to 799.24 m, bioclastic limestone (packstone, biomicrite), light grey, bivalves, bioclasts
800.05 m – 810.53 m	From 800.05 m to 804.60 m, thin- to medium-bedded alternation of limestone (mudstone, micrite), light grey, mostly bioturbated, and limestone to bioclastic limestone (wackestone, packstone and grainstone, biomicrite and biosparite), bioclasts including echinoderm bioclasts, at least partly crinoids, from 801.87 m to 801.92 m, large vugs and druses partly filled with calcite crystals, from 801.94 m to 802.00 m, conglomerate, calcareous (monomict), at 802.34 m, lithoclasts, calcareous, beige grey, occasionally encrusted From 804.60 m to 805.04 m, limestone (mudstone, micrite), light grey, mostly bioturbated, crinoids From 805.04 m to 805.60 m, no core or cuttings collected From 805.60 m to 810.53 m, medium-bedded alternation of thick beds of limestone (mudstone, micrite), light grey, mostly bioturbated, and thin beds (coquinas) of limestone to bioclastic limestone (predominantly grainstone, biosparite), with abundant crinoids, from 805.87 m to 806.12 m bioclastic limestone as above with very large crinoids (single trochites up to 1 cm) From 807.37 m to 807.47 m, bioclastic limestone (predominantly grainstone, biosparite) as above with crinoids and lithoclasts, from 809.68 m to 809.72 m, with lithoclasts and pellets, from 809.99 m to 810.17 m, with lithoclasts, crinoids, brachiopods and bivalves
810.53 m – 811.39 m	Bioclastic limestone (predominantly grainstone, biosparite), light grey, coquina with large crinoids (single trochites up to 1 cm), brachiopods, bivalves and lithoclasts, very porous (in the upper part) to porous
811.39 m – 812.10 m	Limestone (wackestone, biomicrite), light grey, bivalves, bioclasts, pellets
812.10 m – 814.20 m	Limestone (mudstone, micrite), light grey, burrows
814.20 m – 817.87 m	Limestone (mudstone, micrite), light grey, fine-bedded to laminated by claystone drapes, dark grey (now overprinted by stylolites)
817.87 m – 818.76 m	Limestone (mudstone and, locally, wackestone, micrite and biomicrite) medium grey, locally pellets and lithoclasts, from 818.21 m to 818.44 m two biotrititic layers (coquinas)
818.76 m – 820.32 m	Limestone (dolomitic), beige to light grey, down to 819.80 m, porous (vugs up to 2 cm), from 819.07 m to 819.14 m, ooid ghosts, at 820.14 m, coquina (bivalves) At the base, from 820.23 m to 820.32 m, limestone, beige grey, bioclasts, lithoclasts, chert nodule, vugs

3.6.2 Zeglingen Formation, 820.32 m – 829.11 m (> 8.79 m)

The Zeglingen Formation (Jordan 2016) is an evaporite sequence. In BOZ2-1, probably only the uppermost of the informal members, the «Dolomitzone», was encountered before final depth was reached. From 828.15 m to 828.87 m, thin anhydrite beds and nodular horizons were found, possibly an indication of the proximity to the upper boundary of the «Sulfatzone».

The *upper boundary* is set at 820.32 m at an erosional surface which separates the lowermost limestone (dolomitic) from the underlying dolostone.

Lithology

«Dolomitzone», 820.32 m – 829.11 m (> 8.79 m)

820.32 m – 823.45 m	At the top, from 820.32 m to 820.66 m, dolostone (calcareous), beige grey, microbial mats Dolostone, beige grey to dark beige, porous, chert nodules, claystone drapes, dark grey
823.45 m – 826.56 m	Dolostone, beige grey to dark beige, porous, chert nodules (one is a nucleus in a dense, bored dolostone nodule)
826.56 m – 827.70 m	At the top, from 826.56 m to 826.75 m, dolostone, beige grey, with detritic horizons (lithoclasts) alternating with fine-grained dolostone From 826.75 m to 826.81 m: conglomerate, anhydritic (polymict) with darker clasts of dolomitised microbial mats with borings From 826.81 m to the base (at 827.70 m), dolostone, beige, small, irregularly shaped chert and anhydrite nodules
827.70 m – 829.11 m	Dolostone, dark beige, laminated, microbial mats, partly brecciated, small anhydrite nodules, white (from 828.15 m to 828.18 m) From 828.82 m to 828.87 m: anhydrite, white From 828.87 m to 829.11 m, dolostone, grey beige, microbial mats, chert nodule

4 Comparison with the forecast profile

Generally, there are only minor differences between the findings from BOZ2-1 and the forecast profile (Nagra 2016). Deviations from the forecast profile of 10 m or more in thickness or depth are:

- The thickness of the Villigen Formation is about 50 m (cuttings section), which is 10 m less than expected.
- The thickness of the Wildegg Formation is 254 m, which is 29 m more than expected.

Being within the cuttings section and without FMI or petrophysical log to hand, the demarcation of the Villigen Formation is uncertain. The deviation of about 10 m from the forecast is therefore insignificant.

The thickness of the Wildegg Formation is 254 m, which is 18% or 29 m more than expected. It is almost identical to the thickness of the Wildegg Formation in BOZ1-1 (259 m, Schwarz et al. 2021) about 3.5 km to the southeast of BOZ2-1.

The nearly 5 m of the Ifenthal Formation encountered in BOZ2-1 are exactly in line with the forecast.

The Hauptrogenstein of BOZ2-1 corresponds well (not only in terms of facies but also of thickness [80 m]) with the findings in the outcrops in the Sulz-Cheisacher area (Schmassmann 1945, Gonzalez & Wetzel 1996) 2 km north of the borehole. The forecast (85 m) assumed erroneously that the thickness would increase about 5 metres to the south.

While the thickness of the Passwang Formation was correctly estimated (63 m measured, 65 m in the forecast), the thickness of the Opalinus Clay was slightly overestimated (122 m measured and 130 m in the forecast).

Because these minor deviations are mutually balanced, the top of the Lias Group, was found only 1.3 m shallower than expected.

The discrepancies between the findings and the prognosis are also minor in the Staffelegg Formation (39 m measured, 35 m in the forecast) and the Klettgau Formation (41 m measured, 45 m in the forecast). Their cumulative thickness, however, is exactly as predicted. This also applies to the thickness of the Bänkerjoch Formation (95 m both measured and in the forecast). As a consequence, the deviation between prognosis and findings is only 1.7 m at the top of the Muschelkalk Group.

In the lowermost fully penetrated unit, the Schinznach Formation, the deviation between prognosis (70 m) and findings (72 m) is also small. Finally, the base of this formation was found 0.32 m below the forecasted depth.

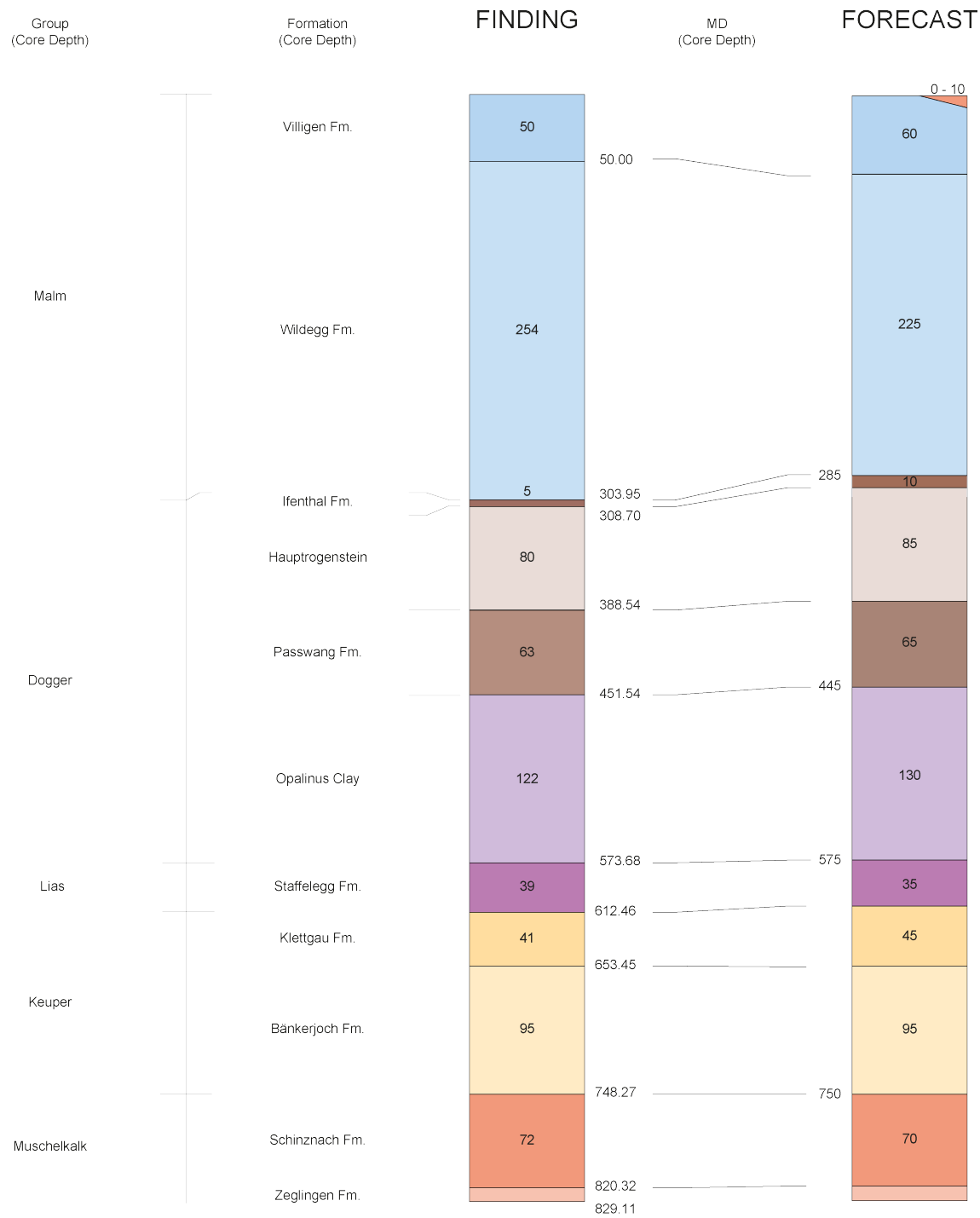


Fig. 4-1: Comparison of the forecast with the actual findings of BOZ2-1

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