

Arbeitsbericht NAB 20-09

**TBO Trüllikon-1-1:
Data Report**

**Dossier III
Lithostratigraphy**

June 2021

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

Hardstrasse 73
P.O. Box 280
5430 Wettingen
Switzerland
Tel. +41 56 437 11 11

www.nagra.ch

Arbeitsbericht NAB 20-09

TBO Trüllikon-1-1: Data Report Dossier III Lithostratigraphy

June 2021

M. Schwarz¹, P. Jordan¹, P. Schürch¹, H. Naef¹,
T. Ibele¹, R. Felber¹ & M. Gysi²

¹Arbeitsgemeinschaft geosfer – Gruner Böhlinger

²Nagra

Keywords:

TRU1-1, Zürich Nordost, TBO, deep drilling campaign,
lithostratigraphy, lithostratigraphic profile, geological
description, drill cores, cuttings

National Cooperative
for the Disposal of
Radioactive Waste

Hardstrasse 73
P.O. Box 280
5430 Wettingen
Switzerland
Tel. +41 56 437 11 11

www.nagra.ch

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

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

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

This Dossier was prepared by a project team consisting of:

M. Schwarz (cuttings and core description, profile compilation, writing and QC)

P. Jordan (core description and QC)

R. Felber (cuttings and core description)

T. Ibele (cuttings and core description)

P. Schürch (writing, QC)

H. Naef (QC), S. Wohlwend (QC), H.R. Bläsi (QC), G. Deplazes (QC)

M. Gysi (project management, conceptualization and QC)

Editorial work: Geomecon and the graphics and editing teams at Nagra

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

"Copyright © 2021 by Nagra, Wettingen (Switzerland) / All rights reserved.

All parts of this work are protected by copyright. Any utilisation outwith the remit of the copyright law is unlawful and liable to prosecution. This applies in particular to translations, storage and processing in electronic systems and programs, microfilms, reproductions, etc."

Table of Contents

Table of Contents	I
List of Tables.....	III
List of Figures	III
List of Appendices	III
1 Introduction	1
1.1 Context.....	1
1.2 Location and specifications of the borehole	2
1.3 Documentation structure for the TRU1-1 borehole	4
1.4 Scope and objectives of this dossier	7
1.5 Petrophysical logs available	8
1.6 Work undertaken	8
1.6.1 General workflow	8
1.6.2 Description and representation of the cuttings samples.....	9
1.6.3 Description and representation of cores.....	10
2 Inventory and quality of cores and cuttings samples	15
3 Stratigraphy and lithology of drilled formations and members.....	17
3.1 Unconsolidated rocks (Quaternary), 0 – 24 m (about 24 m)	17
3.2 Upper Marine Molasse Group, 24 – 50 m (about 26 m).....	17
3.3 Lower Freshwater Molasse Group, 50 – 470 m (about 420 m).....	18
3.4 Siderolithic Group, 470 – 474 m (about 4 m).....	19
3.5 Malm Group	19
3.5.1 «Felsenkalke» + «Massenkalk», 474 – 628.87 m (about 155 m)	19
3.5.2 Schwarzbach Formation, 628.87 – 653.29 m (24.42 m).....	23
3.5.3 Villigen Formation, 653.29 – 714 m (about 61 m).....	24
3.5.3.1 Hornbuck Member, 696.42 – 714 m (about 18 m).....	25
3.5.4 Wildegg Formation, 714 – 724.85 m (about 11 m)	26
3.5.4.1 Effingen Member, 714 – 722.18 m (about 8 m)	26
3.5.4.2 Birmenstorf Member and «Glaukonitsandmergel Bed» sensu Gygi (1977, 2000, 2012), 722.18 – 724.85 m (2.67 m)	27
3.6 Dogger Group	29
3.6.1 Wutach Formation, 724.85 – 727.13 m (2.28 m)	29
3.6.2 Variansmergel Formation, 727.13 – 738.97 m (11.84 m)	29
3.6.3 «Parkinsoni-Württembergica-Schichten», 738.97 – 774.55 m (35.58 m)	30
3.6.4 «Humphriesioolith Formation», 774.55 – 787.50 m (12.95 m).....	32
3.6.5 Wedelsandstein Formation, 787.50 – 815.51 m (28.01 m).....	33
3.6.6 «Murchisonae-Oolith Formation», 815.51 – 816.42 m (0.91 m).....	34
3.6.7 Opalinus Clay, 816.42 – 927.91 m (111.49 m).....	35

3.7	Lias Group	38
3.7.1	Staffelegg Formation, 927.91 – 971.68 m (43.77 m)	38
3.7.1.1	Gross Wolf Member, 927.91 – 934.73 m (6.82 m)	39
3.7.1.2	Rietheim Member, 934.73 – 944.68 m (9.95 m)	40
3.7.1.3	Breitenmatt and Rickenbach Members, 944.68 – 949.15 m (4.47 m)	40
3.7.1.4	Grüns Holz Member, 949.15 – 949.90 m (0.75 m)	41
3.7.1.5	Frick Member, 949.90 – 962.09 m (12.19 m)	42
3.7.1.6	Beggingen Member, 962.09 – 965.83 m (3.74 m)	42
3.7.1.7	Schambelen Member, 965.83 – 971.68 m (5.85 m)	44
3.8	Keuper Group	45
3.8.1	Klettgau Formation, 971.68 – 1'027.22 m (55.54 m)	45
3.8.1.1	Belchen Member, 971.68 – 973.09 m (1.41 m)	45
3.8.1.2	Gruhalde Member (upper part), 973.09 – 989.64 m (16.55 m)	46
3.8.1.3	Seebi Member, 989.64 – 1'003.95 m (14.31 m)	47
3.8.1.4	Gruhalde Member (lower part), 1'003.95 – 1'013.39 m (9.44 m)	48
3.8.1.5	Gansingen Member, 1'013.39 – 1'015.49 m (2.10 m)	48
3.8.1.6	Ergolz Member, 1'015.49 – 1'027.22 m (11.73 m)	49
3.8.2	Bänkerjoch Formation, 1'027.22 – 1'084.01 m (56.79 m)	50
3.9	Muschelkalk Group	54
3.9.1	Schinz nach Formation, 1'084.01 – 1'154.25 m (70.24 m)	54
3.9.1.1	Asp Member, 1'084.01 – 1'090.46 m (6.45 m)	54
3.9.1.2	Stamberg Member, 1'090.46 – 1'119.16 m (28.70 m)	55
3.9.1.3	Liedertswil Member, 1'119.16 – 1'131.33 m (12.17 m)	56
3.9.1.4	Kienberg and Leutschenberg Members, 1'131.33 – 1'154.25 m (22.92 m)	57
3.9.2	Zeglingen Formation, 1'154.25 – 1'204.5 m (about 50.25 m)	58
3.9.3	Kaiseraugst Formation, 1'204.5 – 1'233.2 m (about 28.7 m)	60
3.10	Buntsandstein Group	62
3.10.1	Dinkelberg Formation, 1'233.2 – 1'246.1 m (about 12.9 m)	62
3.11	Permo-Carboniferous sediments	63
3.11.1	Weitenau Formation, 1'246.1 – 1'259.7 m (about 13.6 m)	63
3.12	Crystalline Basement, 1'259.7 – 1'310.0 m (> 50.3 m)	64
4	Comparison with the forecast profile	67
5	References	71

List of Tables

Tab. 1-1:	General information about the TRU1-1 borehole.....	2
Tab. 1-2:	Core and log depth for the main lithostratigraphic boundaries in the TRU1-1 borehole	5
Tab. 1-3:	List of dossiers included in NAB 20-09	6

List of Figures

Fig. 1-1:	Tectonic overview map with the three siting regions under investigation	1
Fig. 1-2:	Overview map of the investigation area in the Zürich Nordost siting region with the location of the TRU1-1 borehole in relation to the boreholes Benken and Schlattingen	3
Fig. 1-3:	Lithostratigraphic profile and casing scheme for the TRU1-1 borehole	4
Fig. 1-4:	Füchtbauer scheme as applied for lithology names in geological profiles and continuous text in the report	12
Fig. 1-5:	Folk classification as applied to the description of carbonate rocks in Folk (1959, 1962), Flügel (1982), Lokier & Al Junaibi (2016)	13
Fig. 2-1:	Cuttings and core quality in TRU1-1.....	16
Fig. 4-1:	Comparison of the forecast with the actual findings of TRU1-1	68

List of Appendices

App. A:	Lithostratigraphy profile Trüllikon-1-1, 1:2'500, 0.00 m to 1'310.00 m MD core depth
App. B:	Lithostratigraphy profile Trüllikon-1-1, 1:1'000, 0.00 m to 1'310.00 m MD core depth
App. C-1:	Lithostratigraphy profile Trüllikon-1-1, 1:100, 0.00 m to 290.00 m MD core depth
App. C-2:	Lithostratigraphy profile Trüllikon-1-1, 1:100, 280.00 m to 570.00 m MD core depth
App. C-3:	Lithostratigraphy profile Trüllikon-1-1, 1:100, 560.00 m to 850.00 m MD core depth
App. C-4:	Lithostratigraphy profile Trüllikon-1-1, 1:100, 840.00 m to 1'130.00 m MD core depth
App. C-5:	Lithostratigraphy profile Trüllikon-1-1, 1:100, 1'120.00 m to 1'310.00 m MD core depth
App. D:	Lithostratigraphy patterns, colours, weathering index and symbols for lithostratigraphy

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

1 Introduction

1.1 Context

To provide input for site selection and the safety case for deep geological repositories for radioactive waste, Nagra has drilled a series of deep boreholes 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 Trüllikon-1-1 borehole.

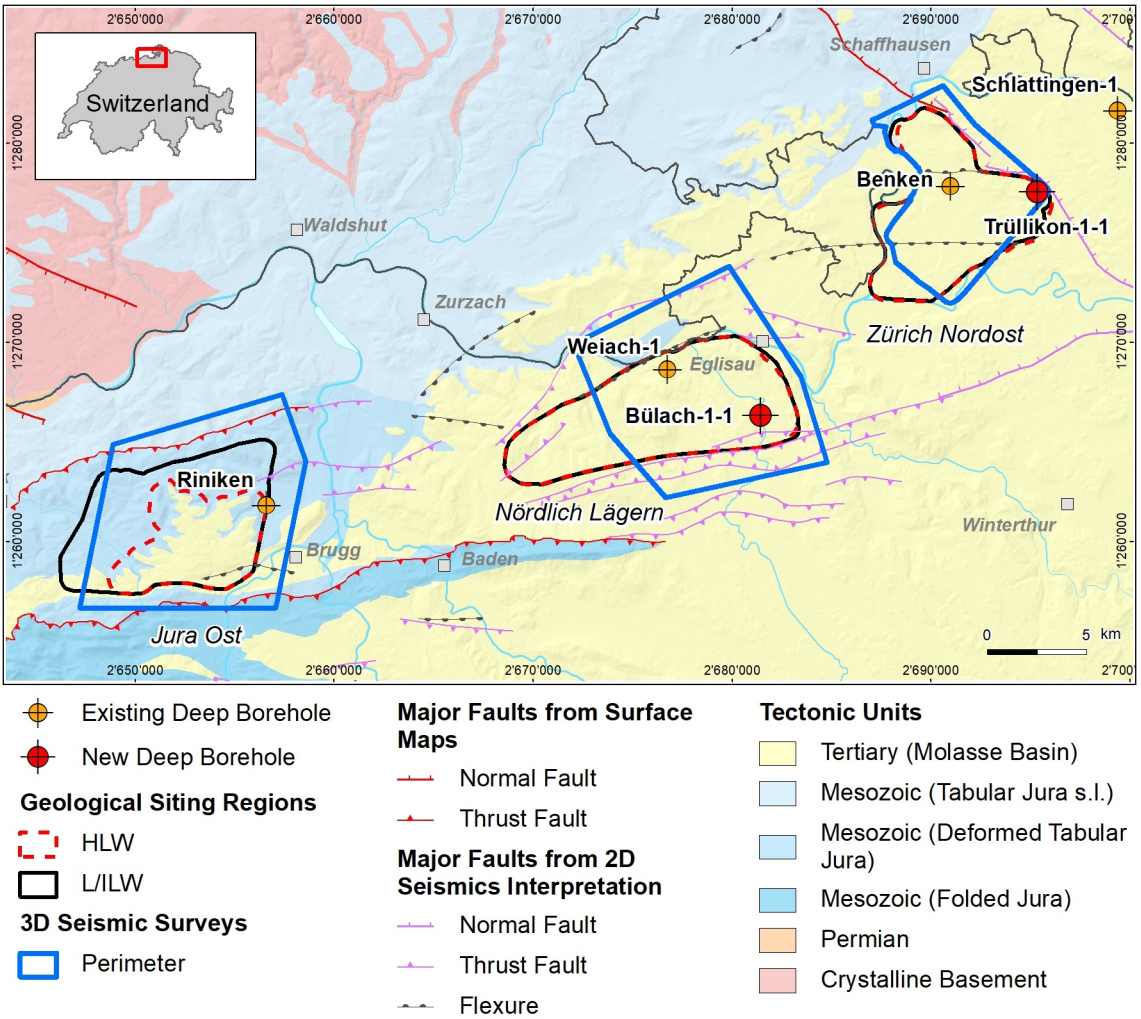


Fig. 1-1: Tectonic overview map with the three siting regions under investigation

1.2 Location and specifications of the borehole

The Trüllikon-1-1 (TRU1-1) exploratory borehole is the second borehole drilled within the framework of the TBO project. The drill site is located in the eastern part of the Zürich Nordost siting region (Fig. 1-2). The vertical borehole reached a final depth of 1'310 m (MD)¹. The borehole specifications are provided in Tab. 1-1.

Tab. 1-1: General information about the TRU1-1 borehole

Siting region	Zürich Nordost
Municipality	Trüllikon (Canton Zürich / ZH), Switzerland
Drill site	Trüllikon-1 (TRU1)
Borehole	Trüllikon-1-1 (TRU1-1)
Coordinates	LV95: 2'695'372.648 / 1'277'548.076
Elevation	Ground level = top of rig cellar: 475.07 m above sea level (asl)
Borehole depth	1'310.0 m measured depth (MD) below ground level (bgl)
Drilling period	15. August 2019 – 5. April 2020 (spud date to end of rig release)
Drilling company	PR Marriott Drilling Ltd.
Drilling rig	Rig-16 Drillmec HH102
Drilling fluid	Water-based mud with various amounts of different components such as ² : 46 – 712 m: Pure-Bore® 712 – 1'161 m: Potassium silicate 1'161 – 1'310 m: Sodium chloride & polymers

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 TRU1-1 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.

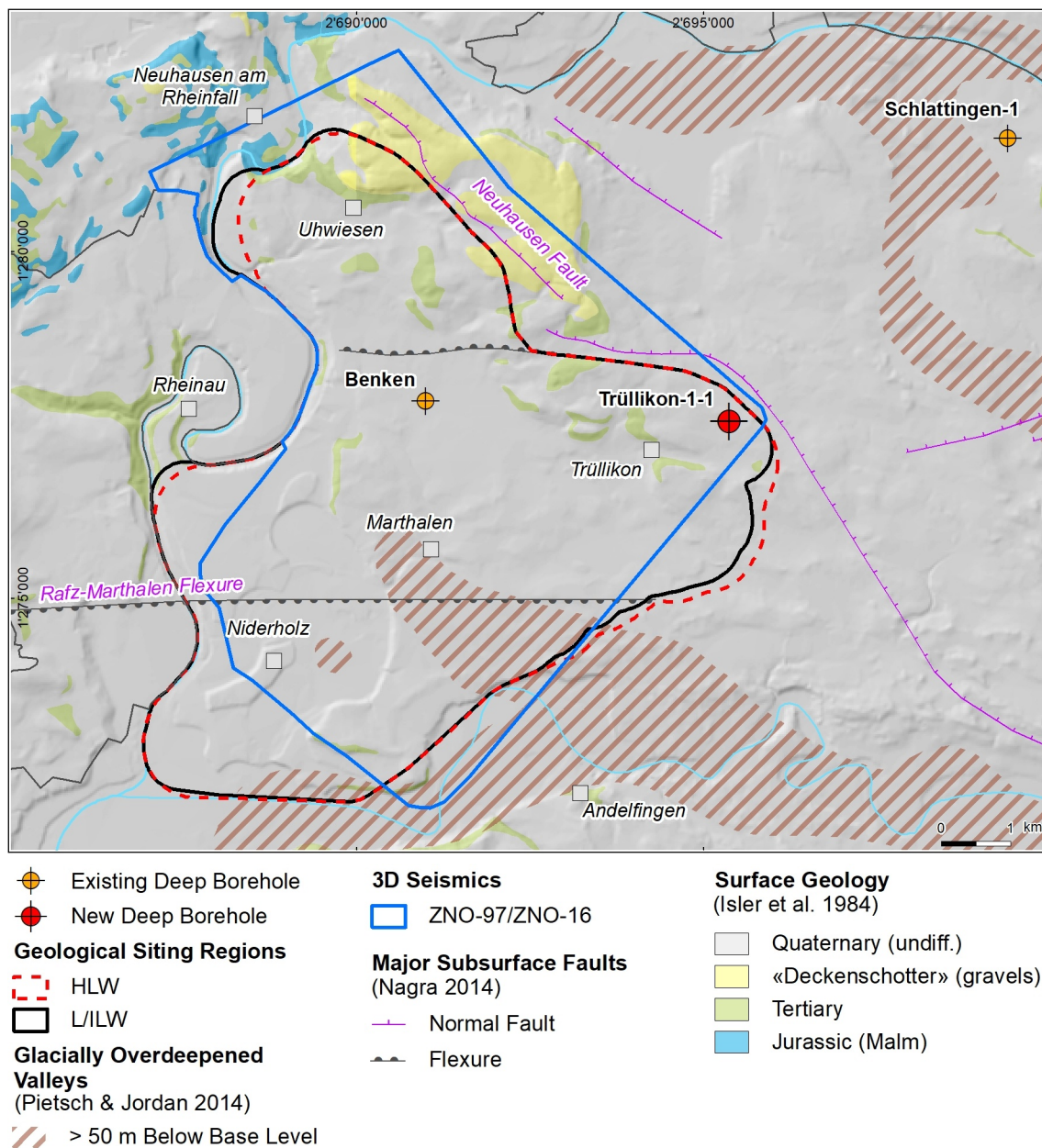
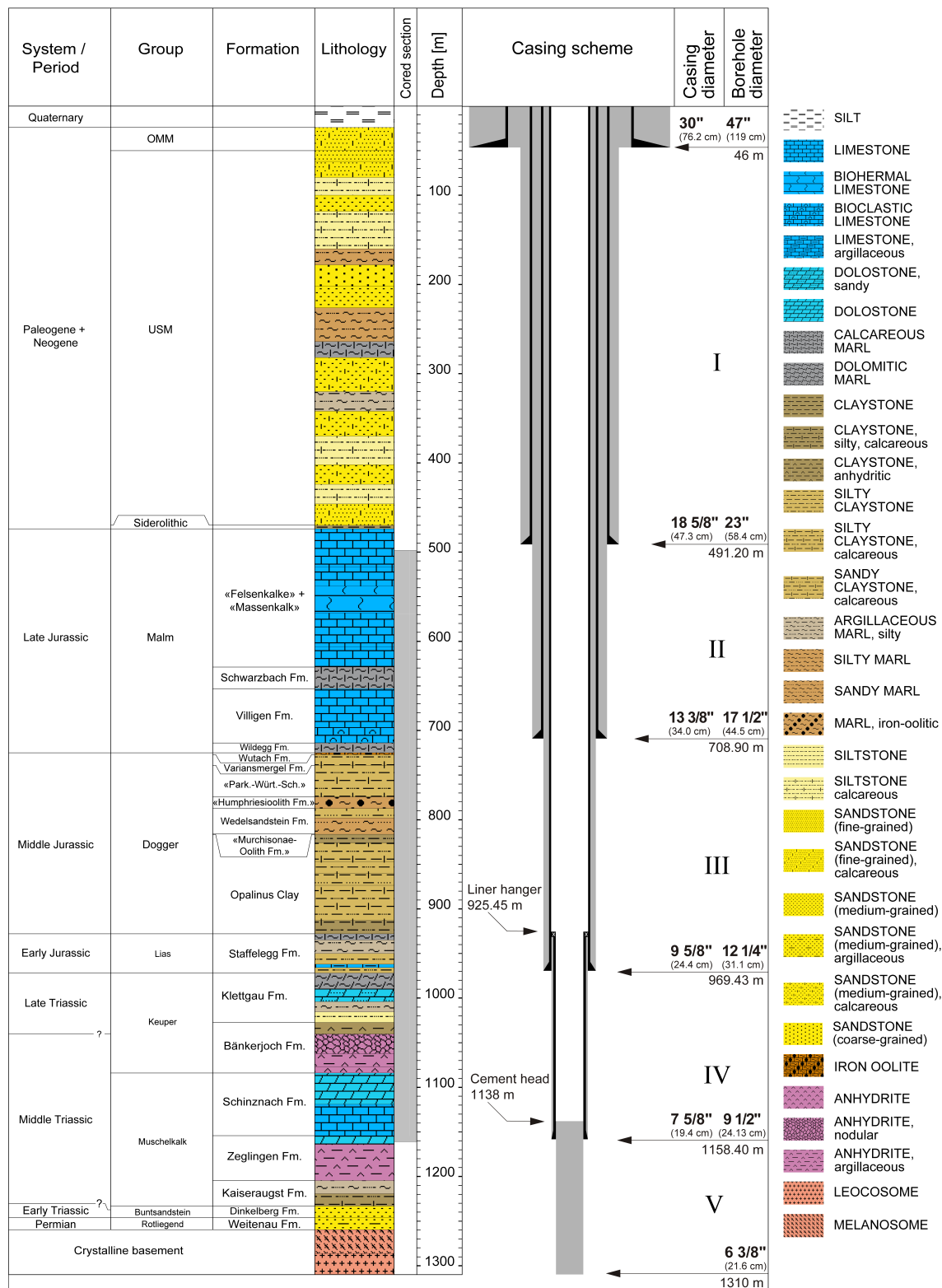


Fig. 1-2: Overview map of the investigation area in the Zürich Nordost siting region with the location of the TRU1-1 borehole in relation to the boreholes Benken and Schlattigen

Fig. 1-3: Lithostratigraphic profile and casing scheme for the TRU1-1 borehole⁴⁴ For detailed information see Dossier I and Chapter 3.

Tab. 1-2: Core and log depth for the main lithostratigraphic boundaries in the TRU1-1 bore-hole⁵

System / Period	Group	Formation	Core depth in m (MD)	Log
Quaternary				
			24.0	—
Paleogene + Neogene	OMM		50.0	—
	USM		470.0	—
	Siderolithic		474.0	—
		«Felsenkalke» + «Massenkalk»		
	Malm	Schwarzbach Formation	628.87	628.75 —
		Villigen Formation	653.29	653.15 —
		Wildegge Formation	714.00	714.00 —
		Wutach Formation	724.85	725.03 —
		Wutach Formation	727.13	727.27 —
		Variansmergel Formation	738.97	739.06 —
Jurassic		«Parkinsoni-Württembergica-Schichten»	774.55	774.66 —
	Dogger	«Humphriesioolith Formation»	787.50	787.55 —
		Wedelsandstein Formation	815.51	815.50 —
		«Murchisonae-Oolith Formation»	816.42	816.43 —
		Opalinus Clay	927.91	927.87 —
	Lias	Staffelelegg Formation	971.68	971.55 —
	Keuper	Klettgau Formation	1027.22	1027.44 —
		Bänkerjoch Formation	1084.01	1084.22 —
		Schinznach Formation	1154.25	1154.43 —
Triassic	Muschelkalk	Zeglingen Formation	1204.5	—
		Kaiseraugst Formation	1233.2	—
	Buntsandstein	Dinkelberg Formation	1246.1	—
Permian	Rotliegend	Weitenau Formation	1259.7	—
		Crystalline Basement	1310.0	final depth

⁵ For details regarding lithostratigraphic boundaries see Chapter 3; for details about depth shifts (core goniometry) see Dossier V.

1.3 Documentation structure for the TRU1-1 borehole

NAB 20-09 documents the majority of the investigations carried out in the TRU1-1 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 TRU1-1 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 20-09

Black indicates the dossier at hand.

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

1.4 Scope and objectives of this dossier

The dossier at hand (Dossier III) documents the work of the lithostratigraphy experts. The objectives of the report are:

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

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

1.5 Petrophysical logs available

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

- total natural gamma ray borehole and potassium corrected (GR)
- spectral gamma ray: hostile environment natural gamma ray standard gamma ray (HSGR) and hostile environment natural gamma ray 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 Benken borehole (Nagra 2001a, 2001b). 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 monthly with all parties involved, including Nagra project managers. This enabled rapid implementation of improvements to the workflow. The QC team used green ink to make further complementary notes on the field logs. After approval of the field logs by the QC team, the 1:100 profile was drawn using the software TerraStation (TERRASCIENCES Inc.). To corroborate the lithological identification and representation in the 1:100 profile, the lithostratigraphy experts received regular updates of the petrophysical logs and lab analyses.

The lithostratigraphic classification in this report is based on system / period, group, formation and member boundaries at the data-freeze on 05.06.2020.

All depths in this report refer to metres measured depth (MD) core 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 metres. 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 and 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), rotations per minute (RPM), calcimetry, a quick-look lithological composition of the cuttings of the shale shakers and gas chromatography (for more details on drilling operation, see Dossier I).

Besides the general limitations associated with the interpretation of cuttings, the following points have been 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. Molasse lithologies are often insufficiently lithified and the lost fraction is therefore more likely part of fine-grained clastic lithologies such as silt-, claystones or marls. Therefore, the descriptions given in the field logs refer solely to the material in the washed samples and do not consider potentially lost lithologies. Thus, the lithologies presented for the Molasse cuttings sections are systematically overestimated with respect to coarser-grained lithologies such as sandstones.
2. It was agreed to quantify all distinguishable lithologies with a proportion of 10% or more of the total sample volume, and to specify the three dominant lithologies in detail. This is also applicable for the description of mixed lithologies and small-scale interbedding of different lithologies.
3. Whilst Molasse rock sequences in outcrops or cores often show a small-scale interbedding of different lithologies, destructive drilling evens out this complexity over the 2 m sample interval. The pattern of the dominant lithology was used for the graphical display in the 1:100 TerraStation profile. Minor lithologies are mentioned in the lithological description only.
4. In section I (46 – 494 m), the GR log as the only available log was used in a very general way to corroborate lithology. While each individual sample had to be described in detail for the field logs, samples with the same primary lithology were combined into larger sections for the 1:100 TerraStation profile and described in summary form. All lithological boundaries in section I of the TerraStation profile correspond to sample boundaries along the 2 m intervals. Depths in the text and on the profile are rounded to full metres (e.g. 188 m).
5. In section V (1'161.03 – 1'310.0 m), the cuttings samples are accompanied by a full suite of petrophysical logs. Therefore, the primary lithology was determined by comparison of the sample description with the petrophysical logs, primarily FMI, GR, APLC and RHO8. In addition, lithological boundaries were drawn with the help of the FMI. Depths in the text and in the profile in this section are accurate to one significant digit and refer to log depth (e.g. 1'204.5 m).
6. A detailed description of grain size, sorting, grain shape, colour, cement and accessory minerals was provided for sandstones.

While each individual sample had to be described in detail for the field logs, samples with the same primary lithology were combined into larger sections for the 1:100 TerraStation profile and described in summary form.

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 depths 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 measure 2 mm in thickness 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. They were described together with adjacent lithological units instead. 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. 973.09 m, Belchen Member). Nevertheless, within the weathering plot, this may still be a desired visual effect for depicting argillaceous interlayers within more competent rock (e.g. limestone) or thin limestone beds in successions of marl, clay- or siltstones. 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-oolites within the Opalinus Clay are always recorded with actual depths, irrespective of thickness; thin iron-oolite layers may be represented with the corresponding symbol instead of a lithological pattern
- breccia patterns must be used for beds with a thickness of more than 50 cm, otherwise the corresponding breccia 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; depths are given with two significant digits

While lithological boundaries were first identified in the core, the FMI often provides extra information to allow the exact depth range of a given lithology to be set. 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 is assessed by comparison between 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. 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 lithological terms differ slightly for use in profiles compared to continuous text in the report (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 (see Naef et al. 2019), 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 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).

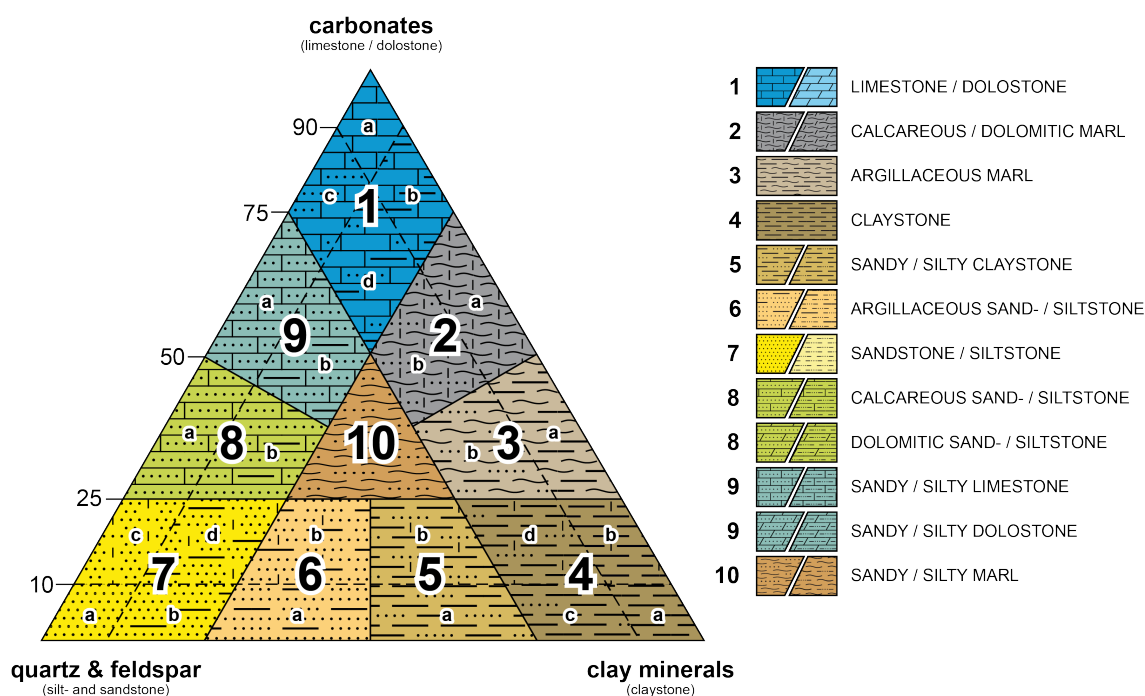
For the description of limestones, the Folk and Dunham classifications were also applied in the best possible manner (see also Naef et al. 2019). However, neither classification is fully suited for a macroscopic classification, because they rely heavily on the distinction of very small components and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

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

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

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

Lithological patterns were chosen according to the primary lithotype of a core section. In the field log, all patterns had to be labelled according to the Füchtbauer scheme (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.



profile nomenclature

- 1a Limestone / Dolostone
- 1b Limestone / Dolostone, argillaceous
- 1c Limestone / Dolostone, sandy / silty
- 1d Limestone / Dolostone, sandy / silty, argillaceous
- 2a Calcareous / Dolomitic Marl
- 2b Calcareous / Dolomitic Marl, sandy / silty
- 3a Argillaceous Marl
- 3b Argillaceous Marl, sandy / silty
- 4a Claystone
- 4b Claystone, calcareous / dolomitic
- 4c Claystone, sandy / silty
- 4d Claystone, sandy / silty, calcareous / dolomitic
- 5a Sandy / Silty Claystone
- 5b Sandy / Silty Claystone, calcareous / dolomitic
- 6a Argillaceous Sand- / Siltstone
- 6b Argillaceous Sand- / Siltstone, calcareous / dolomitic
- 7a Sand- / Siltstone
- 7b Sand- / Siltstone, argillaceous
- 7c Sand- / Siltstone, calcareous / dolomitic
- 7d Sand- / Siltstone, calcareous / dolomitic, argillaceous
- 8a Calcareous / Dolomitic Sand- / Siltstone
- 8b Calcareous / Dolomitic Sand- / Siltstone, argillaceous
- 9a Sandy / Silty Limestone / Dolostone
- 9b Sandy / Silty Limestone / Dolostone, argillaceous
- 10 Sandy / Silty Marl

report nomenclature

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

Fig. 1-4: Füchtbauer scheme as applied for lithology names in geological profiles and continuous text in the report

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

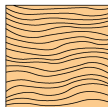
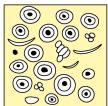
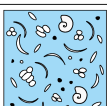
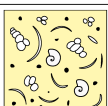
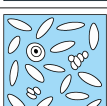
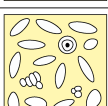
Classification of Carbonate Rocks after Folk (1959, 1962) slightly modified after Flügel (1982) and Lokier & Junaibi (2016)									
		> 10% Allochems (grains): Allochemical Rocks				< 10% Allochems		In situ organic growth structures	
		Sparry Allochemical rocks		Microcrystalline Allochemical rocks	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

Fig. 1-5: Folk classification as applied to the description of carbonate rocks in Folk (1959, 1962), Flügel (1982), Lokier & Al Junaibi (2016)

Pers. comm. S. Wohlwend & H.R. Bläsi.

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

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

2 Inventory and quality of cores and cuttings samples

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

The core quality in respect of the lithostratigraphic investigations 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

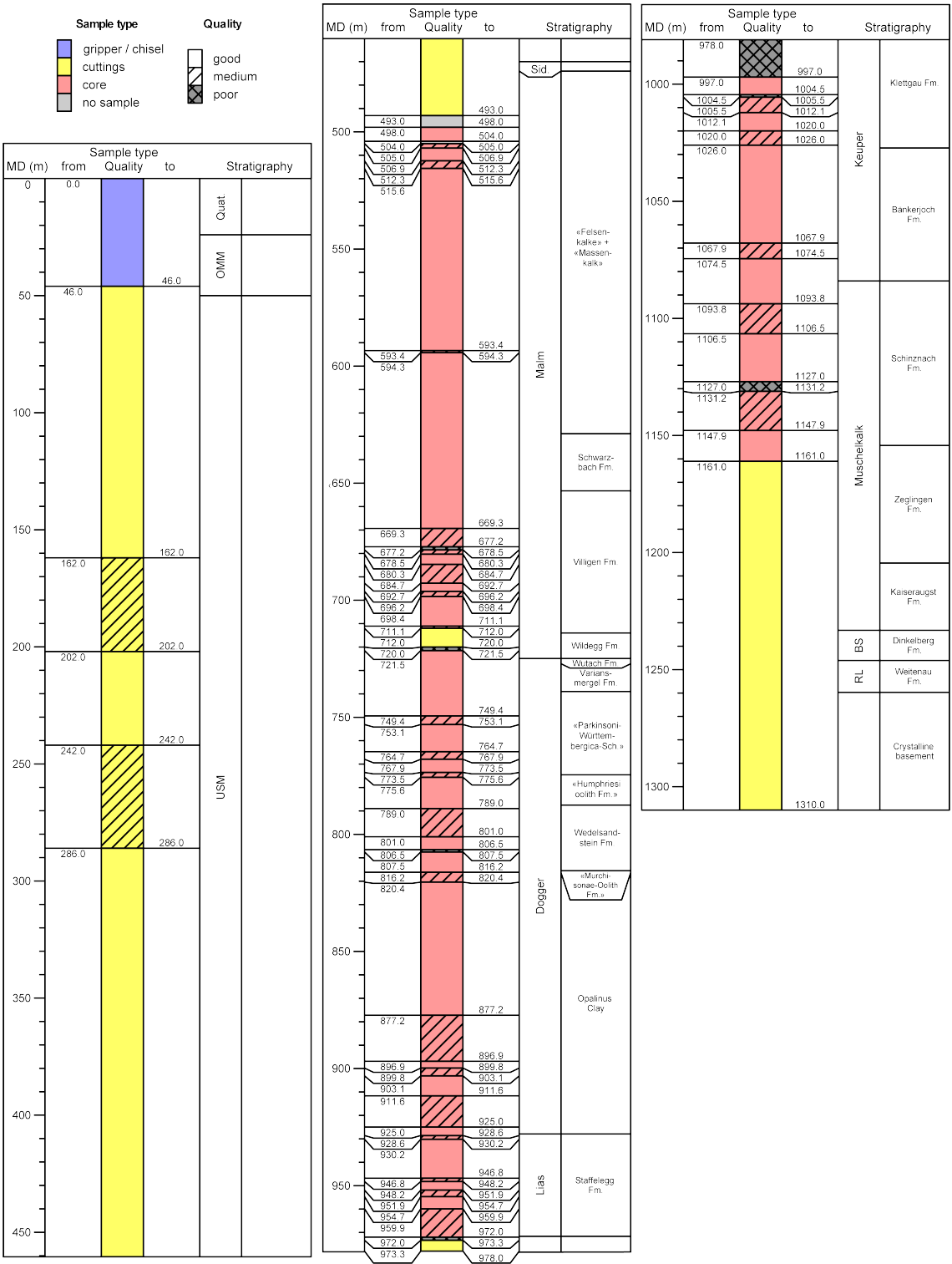


Fig. 2-1: Cuttings and core quality in TRU1-1

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

3 Stratigraphy and lithology of drilled formations and members

3.1 Unconsolidated rocks (Quaternary), 0 – 24 m (about 24 m)

Unconsolidated rocks were only encountered in the conductor pipe excavation.

Lithostratigraphic subdivision

The interval from 0 m to 2 m represents reconstituted ground.

The section from 2 m to 24 m includes gravel of alpine origin. It is interpreted as a fluvio-glacial sediment.

Lithology

The reconstituted ground from 0 m to 2 m consists of sandy gravel.

The section from 2 m to 24 m is composed of silt in transition to clay and varying fractions of sand and gravel. It is separated by an interval with a preponderance of gravel over clay to sand from 7 m to 13 m. The section is overall pale to light yellowish brown. The gravel clasts are subangular to rounded, poorly sorted and with polished surfaces. The gravel is polymict and of alpine origin. It shows features that may be interpreted as glacial striations.

The interval from 20 m to 24 m (base) is slightly gravelly and moderately to well sorted. The gravel is angular to rounded.

3.2 Upper Marine Molasse Group, 24 – 50 m (about 26 m)

The Molasse-type sediments are identified as Upper Marine Molasse Group (OMM, Obere Meeresmolasse) for two reasons:

1. The OMM crops out in the vicinity of the drill site (Hofmann & Hantke 1964, Hofmann 1967).
2. The occurrence of glauconite is distinctive of the OMM.

The section from 24 m to 42 m is composed of sandstone (fine-grained) (calcareous), variegated, moderately to well sorted, moderately cemented.

The section from 42 m to 46 m is composed of siltstone (calcareous, sandy), greyish green, glauconitic.

The section from 46 m to 50 m is composed of sandstone (medium- to coarse-grained) (calcareous), greyish (blue) green, moderately to well sorted, glauconitic, well cemented.

3.3 Lower Freshwater Molasse Group, 50 – 470 m (about 420 m)

The Lower Freshwater Molasse Group (USM, Untere Süßwassermolasse) is identified by the absence of minerals typical of marine environments (e.g. glauconite).

The upper boundary is set at 50 m. It is the lowermost occurrence of glauconite within the OMM. It coincides with the sharp change in colour from the grey shades of the OMM above to the variegated colours of the USM below.

The lower boundary is set at 470 m. It is placed at the uppermost occurrence of iron-pisoids of the Siderolithic Group below.

Lithostratigraphic subdivision

The lithostratigraphy of the USM is commonly based on heavy minerals which were not analysed for TRU1-1. Thus, the lithostratigraphic classification relies on the lithology. The whole section shows the characteristic "granitic composition" of the «Obere Bunte (Granitische) Molasse». It consists of a succession of mostly fine- to medium-grained terrestrial sediments (predominantly silt- and sandstones) of variable thickness. The calcimetry of whole rock samples corroborates the uniform lithology with a carbonate content of mostly less than 10%.

Lithology

In the whole section from 50 m to 470 m, four main lithologies of variable abundance were identified:

- Sandstone (mostly medium- to coarse-grained), (very) light grey and beige, subangular to subrounded, variegated quartz, a minor fraction of plagioclase, sparse mica, moderately to well sorted, very poorly to poorly cemented

In many samples there are almost no rock chips of this lithology because it was milled to loose sand. This rock type is known as «Granitischer Sandstein» because its grain composition roughly corresponds to the mineralogy of granite

The whole section contains five intervals of «Granitischer Sandstein». Their thickness ranges from 4 m to 20 m with sharp boundaries to the adjacent lithologies. These five intervals are evenly distributed between 178 m and 362 m

- Sandstone (predominantly fine- to medium-grained) (partly silty), light to medium grey, beige, and reddish brown, subrounded quartz, sparse mica, poorly to moderately sorted, partly in mm-thick lamination with siltstone, moderately to well cemented by calcite
- Siltstone (sandy [fine- to coarse-grained], calcareous), predominantly (dark) beige, grey pink and reddish brown, partly micaceous to very micaceous, in some intervals with reddish-brown pedogenic features (root tubes?)
- Silty, argillaceous and calcareous marl, light to medium grey, dark beige to beige and rarely reddish brown.

A minor fraction of claystone (partly calcareous and sandy), reddish brown, is often associated with the occurrence of siltstone and silty-, argillaceous- and calcareous marl.

3.4 Siderolithic Group, 470 – 474 m (about 4 m)

The argument for the Siderolithic Group is the presence of iron-pisoids («Bohnerz»). Further characteristic features of the Siderolithic Group were not observed.

The upper boundary is set at 470 m. It coincides with the first occurrence of iron-pisoids.

The lower boundary is set at 474 m. It corresponds to a very sharp drop in the GR log from the Siderolithic Group above to the Malm Group below. Cuttings of limestone which are typical of the Malm occur above 474 m. This suggests a boundary between the two units slightly above 474 m but within the vertical resolution of the GR log. Cuttings with iron-pisoids appear down to 484 m. The iron-pisoids could be either cavings or karst infill.

Lithology

The Siderolithic Group consists of claystone, ochre to light brown, with iron-pisoids.

3.5 Malm Group

3.5.1 «Felsenkalk» + «Massenkalk», 474 – 628.87 m (about 155 m)

According to the informal stratigraphic scheme for the current deep drilling campaign (Jordan & Deplazes 2019), the Jurassic carbonate rocks above the Schwarzbach Formation are summarised as «Felsenkalk» + «Massenkalk», an informal unit in the rank of a formation. The term alludes to the two interfingering facies realms replacing each other laterally and vertically: the mostly massy sponge bioherms («Massenkalk») and the mostly well bedded limestone deposits in between where sponges are rare or absent («Felsenkalk»).

In the «Massenkalk» facies, dolomitisation and dedolomitisation processes cause a saccharoidal texture in the limestone. These processes may also spread to the «Felsenkalk» in the vicinity of the «Massenkalk» (e.g. Lang 1964, Fritz 1966). Consequently, internal layering of a saccharoidal limestone can be blurred or virtually absent.

Stylolites are common in the «Felsenkalk» + «Massenkalk». They occur as solitary features at regular intervals or concentrate in clusters at irregular intervals. This results in a diagenetic stylo-bedding (Logan & Semeniuk 1976, Pawellek & Aigner 2002) of both the «Felsenkalk» and the «Massenkalk». In consequence, the term "bedded" alone does not allow a differentiation between «Felsenkalk» and «Massenkalk».

The upper boundary is set at 474 m. It corresponds to a very sharp drop of the GR log from the Siderolithic Group above to the Malm Group below.

The lower boundary is set at 628.87 m at the top of the first calcareous marl bed of the underlying Schwarzbach Formation exceeding a few centimetres in thickness.

Lithostratigraphic subdivision

In the core section, the separation of the two formations is inconclusive. The transition is often unclear, repetitive and gradual. Consequently, a well-defined lithostratigraphic subdivision is not yet possible. The following subdivision is therefore based on lithology and lithofacies but not on bedding:

474 – 494.00 m Cuttings section; probably «Felsenkalke» facies, limestone is mostly formed as mudstone

494 – 498 m Neither core nor cuttings

498.00 – 516.60 m «Felsenkalke» facies; limestone as mudstone to wackestone

Saccharoidal limestone as an alternation of non-biohermal limestone and biohermal limestone from 516.60 m to 568.30 m:

516.60 – 568.30 m «Massenkalk» facies; limestone (saccharoidal), with distinct bioherms (boundstone) from 538.25 m to 543.97 m and from 552.40 m to 568.30 m

Non-saccharoidal limestone from 568.30 m to 593.50 m, as an alternation of non-biohermal limestone and subordinate biohermal limestone:

568.30 – 571.78 m «Felsenkalke» facies; limestone as wackestone

571.78 – 576.58 m «Massenkalk» facies, biohermal limestone (boundstone)

576.58 – 579.45 m «Felsenkalke» facies; limestone as mudstone and wackestone, slightly saccharoidal

579.45 – 580.28 m «Massenkalk» facies, biohermal limestone (boundstone)

580.28 – 584.40 m «Felsenkalke» facies; limestone as wackestone

584.40 – 586.45 m «Massenkalk» facies, biohermal limestone (boundstone)

586.45 – 591.14 m «Felsenkalke» facies; limestone as mudstone and wackestone

591.14 – 593.50 m «Massenkalk» facies, biohermal limestone (packstone and boundstone)

Dolomitic interval from 593.50 m to 598.00 m:

593.50 – 598.00 m «Felsenkalke» facies; dolostone and limestone (dolomitic) (wackestone)

Limestone sequence from 598.00 m to 615.95 m without intense bioturbation:

598.00 – 605.90 m «Felsenkalke» facies; limestone as mudstone and wackestone

605.90 – 611.23 m «Felsenkalke» facies; limestone as mudstones interbedded by calcareous marl

611.23 – 615.95 m «Felsenkalke» facies; mostly limestone as mudstone and wackestone

Limestone sequence from 615.95 m to 628.87 m enclosing layers (cm – dm) with chaotic texture due to intense bioturbation:

615.95 – 621.03 m	«Felsenkalke» facies; limestone as wackestone, in sections slightly saccharoidal
621.03 – 623.91 m	Intermediate facies, limestone as wackestone and packstone
623.91 – 628.87 m	«Felsenkalke» facies; limestone as wackestone

Lithology (cuttings section from 474 – 498.00 m)

474 – 494.00 m	Limestone (mudstone, micrite), dark beige to white, with minor karst fissures down to 484 m, filled with claystone, sandstone, siltstone and possibly iron-pisoids
494 – 498 m	Neither core nor cuttings
498.00 – 516.60 m	Limestone (mudstone and wackestone, biopelmicrite), dark beige to beige and white, sparse to moderate fossil content (biodetritus, bivalves, sponges, belemnites), medium- to thick-bedded, in some intervals vertical karst fissures (aperture mm to 20 cm), filled with claystone and solitary vugs filled with calcite
516.60 – 538.25 m	Limestone (saccharoidal), white, in the lower part beige, in the upper half some sponges and biodetritus (thin section TRU1-1-525.17), mostly thick-bedded, in some intervals karstification, lowermost occurrence of karst vertical fissures (aperture mm to 1 cm) at 538.25 m, mostly filled with claystone, open and filled vugs frequent, chert nodules sparse
538.25 – 543.97 m	Biohermal limestone (saccharoidal), beige to beige grey, very fossiliferous (sponge bioherm), in the lower part some vugs, chert nodules sparse
543.97 – 552.40 m	Limestone (saccharoidal), beige to beige grey, repeated occurrence of intervals rich in sponges, medium- to thick-bedded, chert nodules sparse
552.40 – 568.30 m	Biohermal limestone (saccharoidal), dark beige and light grey mottled, very fossiliferous (sponges), medium-bedded to massive but in some intervals breccia-like appearance with fissures and vuggy framework
568.30 – 571.78 m	Limestone (wackestone, biopelmicrite; thin section TRU1-1-571.08), dark beige, sponges both dispersed and in layers, thick-bedded, frequent open vugs, chert nodules sparse
571.78 – 576.58 m	Biohermal limestone (boundstone, biopelmicrite), dark and light grey mottled, very fossiliferous (sponges), medium- to thick-bedded, vugs and chert nodules sparse
576.58 – 579.45 m	Limestone (mudstone and wackestone, biopelmicrite, now slightly saccharoidal), dark beige, a few sponges and bivalves, medium-bedded

579.45 – 580.28 m	Biohermal limestone (boundstone, biopelmicrite), dark beige very fossiliferous (sponge bioherms), a few chert nodules
580.28 – 584.40 m	Limestone, from 582.44 m to 584.40 m dolomitic (wackestone, biopelmicrite), dark beige and light grey, moderately fossiliferous (dispersed sponges, bivalves sparse), medium- to thick-bedded, vugs sparse, chert nodules frequent
584.40 – 586.45 m	Biohermal limestone (boundstone, biopelmicrite), dark beige and light grey mottled, very fossiliferous (sponges), thick-bedded, some open vugs, glauconite sparse
586.45 – 591.14 m	Limestone (mudstone and wackestone, biopelmicrite), medium grey to beige grey, fossiliferous (sponges, biotritus sparse), mostly thick-bedded, some chert nodules
591.14 – 593.50 m	Biohermal limestone (packstone and boundstone, biomicrite), medium grey to beige grey, moderately to very fossiliferous (vugs frequent, as fossil ghosts of sponges [sponge bioherms], partly filled with argillaceous marl, dark greyish brown), thick-bedded, partly breccia-like appearance; at the base thin (12 cm) layer of claystone, dark greyish brown, tectonised
593.50 – 594.65 m	Dolostone beds (thin section TRU1-1-594.07), dark greyish brown, some sponges, thick-bedded
594.65 – 598.00 m	Limestone (dolomitic) (wackestone, pelmicrite), beige grey, medium-bedded with seams of claystone (silty), dark grey to black, chert nodules frequent
598.00 – 605.90 m	Limestone (mudstone and wackestone, biopelmicrite, slightly saccharoidal), beige grey, medium- to thick-bedded by seams of claystone (silty), dark grey to black, chert nodules frequent; and layers of biohermal limestone with abundant sponge detritus
605.90 – 611.23 m	Limestone sequence with beds of calcareous marl at the top and at the base: • limestone: limestone (mudstone, micrite), beige grey, medium-bedded by seams (max. 1 cm) of argillaceous marl, dark grey to black • calcareous marl: at the top calcareous marl (dolomitic; thin section TRU1-1-605.97), at the base calcareous marl (silty and dolomitic; thin section TRU1-1-611.22), greyish green and dark grey to black, glauconitic
611.23 – 615.95 m	Limestone (mudstone and wackestone, biopelmicrite), beige grey, moderately fossiliferous (detritus of sponges and brachiopods, fossils often pyritised), medium-bedded, bioturbated

615.95 – 621.03 m	Limestone (wackestone, biopelmicrite), beige grey, fossiliferous (sponge detritus, biodetritus, fossils often pyritised), medium-bedded; frequent layers consisting of sponge clasts and limestone clasts in a matrix of calcareous marl (thin section TRU1-1-619.58)
621.03 – 623.91 m	Lowermost biohermal limestone in the «Felsenkalke» + «Massenkalk» (wackestone and packstone, biomicrite), beige grey to light grey, pyritic, very fossiliferous (abundant sponges, biodetritus, brachiopods, ammonites, belemnites), medium-bedded; with three thin (< 10 cm) layers consisting of sponge clasts and limestone clasts (mudstone, micrite)
623.91 – 628.87 m	Limestone (wackestone, biomicrite), beige grey, fossiliferous (dispersed sponges), medium-bedded, with some layers consisting of sponge clasts and limestone clasts (biomicrite) with seams of calcareous marl

3.5.2 Schwarzbach Formation, 628.87 – 653.29 m (24.42 m)

The Schwarzbach Formation represents a marl interval within the predominantly limestone formations of the Malm Group. In the present section, it is delimited following the purely lithostratigraphic definition of Jordan & Deplazes (2019).

The *upper boundary* of the Schwarzbach Formation is set at 628.87 m at the top of the first thick (1.07 m) calcareous marl interval.

The *lower boundary* is set at 653.29 m at a hardground. The surface separates an alternation of calcareous marl and limestone (argillaceous) of the Schwarzbach Formation above from limestone with cm-thick layers of argillaceous marl of the Villigen Formation below.

There is no formal subdivision of the Schwarzbach Formation. In TRU1-1, the Schwarzbach Formation consists of calcareous marl with two thicker, nodular interbeds of limestone.

Lithology

628.87 – 631.30 m	From 628.87 m to 629.75 m: Calcareous marl, medium grey, pyritised biodetritus, bioturbated From 629.75 m to 631.30 m: Limestone (wackestone, biopelmicrite), beige grey, biodetritic, partly disintegrated into nodules with seams of argillaceous marl
631.30 – 644.20 m	Calcareous marl (partly silty), dark grey, glauconitic, bioturbated; with a few intervals of mostly thin (≤ 15 cm) nodular interbeds of limestone (argillaceous) (mudstone, micrite), dark grey, glauconitic
644.20 – 648.10 m	Bioclastic limestone (partly dolomitic) (wackestone and packstone, biopelmicrite; TRU1-1-646.21), beige grey, very fossiliferous (belemnites and brachiopods, as well as sponges, echinoderms and two ammonites; bioclastic limestone towards the base increasingly disintegrated into nodules by interbeds (max. 20 cm) of calcareous marl, dark grey, calcareous marl intensely bioturbated

648.10 – 653.29 m	Calcareous marl, dark grey, rarely glauconitic, bioturbated, at the base hardground with encrusted bioclasts and intraclasts of calcareous marl; with a few interbeds (≤ 50 cm) of limestone (argillaceous) (mudstone, biomicrite), beige grey, bioturbated
-------------------	---

3.5.3 Villigen Formation, 653.29 – 714 m (about 61 m)

In the Villigen Formation, well-bedded micritic limestone prevails, other forms of limestone are rare, and calcareous or even argillaceous marl are restricted to bed-separating drapes and a few thicker beds.

The *upper boundary* is set at 653.29 m at a hardground. It separates the marl succession of the Schwarzbach Formation above from the micritic limestone of the Villigen Formation below.

The *lower boundary* is set at 714 m within a cuttings section. It corresponds to the lower boundary of the Villigen Formation. The boundary was placed at a rather sharp change in the raw data of the GR log (different from the final GR displayed in the profiles in Appendix B and C). Above, the shape of the GR log changes from smooth and straight above to undulating below. The undulations are indicative of the alternation of marl and limestone of the underlying Wildegg Formation compared to the more uniform lithology and somewhat higher carbonate content of the overlying Villigen Formation. The cuttings description corroborates the change in lithology at 714 m.

Lithostratigraphic subdivision

According to Gygi (2000), the Villigen Formation is subdivided into four members in the western realm and up to three members in the eastern realm. The ZNO region where TRU1-1 is located belongs to the eastern realm (Jordan & Deplazes 2019). The three members are the Wangental, Küssaburg and Hornbuck Members (from top to base). However, this scheme cannot be fully applied to TRU1-1. Firstly, the Küssaberg Member and the Wangental Member are distinguished by the separating glauconitic «Knollen Bed». This typical nodular marker bed could not be recognised in TRU1-1. Additionally, the Küssaburg Member differs from the Wangental Member by thicker and more numerous marl interbeds and less fossil content (Gygi 1969, Geyer & Gwinner 1991). The vertical trend in both lithology and fossil content is not observed in TRU1-1. Therefore, a boundary between the two members could not be established for TRU1-1. In contrast, the Hornbuck Member as the lowermost member of the Villigen Formation can be delineated by the occurrence of frequent macrofossils (particularly sponges).

Lithology (above the Hornbuck Member)

653.29 – 656.56 m	Limestone (wackestone, biopelmicrite), beige grey, abundant peloids, a few belemnites and crinoids, medium-bedded by cm-thick layers of argillaceous marl, dark grey, with many sponges, belemnites and crinoids
656.56 – 690.02 m	Limestone (mudstone, micrite; thin section TRU1-1-683.33), beige grey to medium grey, often intensely bioturbated, medium-bedded by cm-thick layers of argillaceous marl, dark grey, and claystone (calcareous), black, both lithologies with echinoderms

690.02 – 694.43 m	Limestone (mudstone and wackestone, pelmicrite), beige grey to medium grey, in sections interspersed with black peloids (sponge tuberooids?), intensely bioturbated, medium-bedded by seams of claystone (calcareous), black, large belemnites atop the basal hardground
694.43 – 696.42 m	Limestone (mudstone, micrite), dark greyish brown to medium grey, medium-bedded by interbeds of argillaceous marl, dark grey, but thicker and more numerous than from 653.29 m to 694.43 m

3.5.3.1 Hornbuck Member, 696.42 – 714 m (about 18 m)

In TRU1-1, the Hornbuck Member consists mainly of two bioclastic successions which enclose an interval of biohermal limestone in the middle part.

The *upper boundary* is set at 696.42 m. It corresponds to the transition from the fossil-sparse micritic limestone from the upper part of the Villigen Formation above to bioclastic limestone with abundant and large sponges of the Hornbuck Member below.

The *lower boundary* is set at 714 m within a cuttings section. It corresponds to the lower boundary of the Hornbuck Member. The boundary was placed at a rather sharp change in the raw data of the GR log (different from the final GR displayed in the profiles in Appendix B and C). Above, the shape of the GR log changes from smooth and straight above to undulating below. The undulations are indicative of the alternation of marl and limestone of the underlying Effingen Member compared to the more uniform lithology and somewhat higher carbonate content of the overlying Hornbuck Member. The cuttings description corroborates the change in lithology at 714 m.

Lithology (cored to 711.97 m followed by cuttings section from 711.97 – 714 m)

696.42 – 702.95 m	Bioclastic limestone (wackestone and packstone, biopelmicrite), mostly dark greyish brown to medium grey, medium-bedded with interbeds (max. 16 cm) of calcareous marl, dark grey; both lithologies very fossiliferous (large sponges, echinoderms, brachiopods)
702.95 – 707.67 m	Biohermal limestone (wackestone and boundstone, biomicrite; thin section TRU1-1-705.65), dark greyish brown and beige grey, medium-bedded with interbeds (mostly < 10 cm, max. 12 cm) of calcareous marl, dark grey to black; both lithologies very fossiliferous (abundant very large sponges [partly larger than the core diameter], echinoderms, ammonites)
707.67 – 711.97 m	Bioclastic calcareous marl, dark grey to dark greyish brown, with limestone nodules of the same composition as in the limestone (mudstone, pelmicrite) interbeds (max. 35 cm), dark greyish brown, above the base of the calcareous marl intervals many large sponges, with echinoderms and belemnites, otherwise both limestone and calcareous marl almost devoid of macrofossils
711.97 – 714 m	Cuttings section; alternation of calcareous marl to limestone (argillaceous), dark grey and limestone (micrite), beige to white

3.5.4 Wildegg Formation, 714 – 724.85 m (about 11 m)

The Wildegg Formation is made up of the upper Effingen Member and the lower Birmenstorf Member. The Effingen Member consists of calcareous marl with limestone interbeds. In contrast, the Birmenstorf Member has a similar lithology but with a somewhat higher carbonate content and is rich in fossils. It is only a couple of metres thick in most cases (e.g. Gygi 2000). For practical reasons, the thin oncolitic-stromatolitic and silty-glaconitic marl beds at its base are included in the Birmenstorf Member (Jordan & Deplazes 2019).

The *upper boundary* is set at 714 m within a cuttings section. It corresponds to the upper boundary of the Wildegg Formation. The boundary was placed at a rather sharp change in the raw data of the GR log (different from the final GR displayed in the profiles in Appendix B and C). Above, the shape of the GR log changes from smooth and straight above to undulating below. The undulations are indicative of the alternation of marl and limestone of the underlying Wildegg Formation compared to the more uniform lithology and somewhat higher carbonate content of the overlying Villigen Formation. The cuttings description corroborates the change in lithology at 714 m.

The *lower boundary* is set at 724.85 m at a pronounced hardground. The hardground marks the lowermost occurrence of glauconite of the Wildegg Formation above. This coincides with a marked increase in content of iron-oooids below the hardground which form the iron-oolitic Wutach Formation.

3.5.4.1 Effingen Member, 714 – 722.18 m (about 8 m)

The Effingen Member is a predominantly calcareous marl section with beds of limestone (argillaceous). A continuous content of silt and sand (fine-grained) is characteristic of this unit (Deplazes et al. 2013). Petrophysical logs allows a detailed subdivision of the Effingen Member over large horizontal distances even into rather condensed geological profiles (Deplazes et al. 2013).

TRU1-1 drilled through the conventional lithologies mentioned before. However, the destructive drilling process hampers a detailed reconstruction of the marl – limestone alternation.

The *upper boundary* is set at 714 m within a cuttings section. It corresponds to the upper boundary of the Effingen Member. The boundary was placed at a rather sharp change in the raw data of the GR log (different from the final GR displayed in the profiles in Appendix B and C). Above, the shape of the gamma ray log changes from smooth and straight above to undulating below. The undulations are indicative of the alternation of marl and limestone of the underlying Effingen Member compared to the more uniform lithology and somewhat higher carbonate content of the overlying Hornbuck Member. The cuttings description corroborates the change in lithology at 714 m.

The *lower boundary* is set at 722.18 m. This coincides with the top of a conspicuous conglomeratic layer. It separates the calcareous marl (silty) of the overlying Effingen Member from the glauconitic calcareous marl with interbeds of limestone (argillaceous) of the underlying Birmenstorf Member. The lithological change is in line with an abrupt increase in fossil abundance, especially of ammonites, distinctive of the Birmenstorf Member.

Lithology (cuttings from 714 – 720.00 m, core from 720.00 – 722.18)

714 – 720.00 m	Calcareous marl, dark grey to dark greyish brown; with interbeds of limestone (micrite), beige to white
720.00 – 722.18 m	Calcareous marl (slightly silty), dark grey to medium grey, moderately fossiliferous (biodetritus, some sponges, bivalves, belemnites, crinoids), moderately bioturbated

3.5.4.2 Birmenstorf Member and «Glaukonitsandmergel Bed» sensu Gygi (1977, 2000, 2012), 722.18 – 724.85 m (2.67 m)

From its type locality in the Aargau area towards the ZNO region, the Birmenstorf Member is gradually replaced, from its base upwards, by condensed units (Gygi 2012). According to Gygi (1977, 2000, 2012), the condensed units are denoted from top to base «Mumienkalk Bed», «Mumienmergel Bed» and «Glaukonitsandmergel Bed». Jordan & Deplazes (2019) integrated the oncolytic «Mumienkalk Bed» and the «Mumienmergel Bed» as informal units into the Birmenstorf Member. The lowermost unit «Glaukonitsandmergel Bed» sensu Gygi (1977, 2000, 2012) is characterised by micaceous, argillaceous to calcareous marl (silty). All units are glauconitic to a varying degree and contain frequent sponges as well as ammonites, the latter partly as cores of oncoids. The condensed units contain iron-oids in variable proportions.

In TRU1-1, all units seem to be present, but an unambiguous distinction between them is not possible. The following description is therefore purely lithological.

The *upper boundary* is set at 722.18 m at the top of a conglomeratic layer. This surface coincides with a downward increase in content of both carbonate and fossils. Lithologically, the calcareous marl (silty) of the overlying Effingen Member is replaced by calcareous marl with beds of limestone (argillaceous) of the underlying Birmenstorf Member. Furthermore, the surface marks the onset of glauconite of the Birmenstorf Member.

The *lower boundary* is set at 724.85 m. A conspicuous hardground at that depth marks the lowermost occurrence of glauconite of the «Glaukonitsandmergel Bed». Beneath, the abundance of iron-oids is characteristic of the Wutach Formation.

Lithology

722.18 – 723.90 m	Calcareous marl (partly dolomitic), dark grey, glauconitic, with interbeds of limestone (argillaceous) (packstone, biomicrite), light grey, both lithologies moderately to very fossiliferous (bivalves, belemnites, ammonites, rarely sponges, encrusted foraminifera; thin section TRU1-1-723.04) Lithologically, this interval correlates closest to what is known as the "uncondensed" Birmenstorf Member elsewhere. However, encrusted fossils already indicate a redeposition of some sedimentary material
723.90 – 724.24 m	Interval dominated by oncolitic limestone, partly limonitised, medium grey, glauconitic, encrusted clasts of limestone and bioclasts: limestone clasts: biomicritic, light grey, well rounded (circular), with limonitic crust, medium grey, macroscopically not laminated, up to a few cm in size including the crust, rarely with ammonite fragments in the limestone

- bioclasts: sparser than the limestone clasts, grey violet, oval to prolate, limonitic and sparitic crust, up to a few cm in size including the crust, fossil type not clearly identifiable
- argillaceous marl, dark grey, as seams around the clasts

This interval correlates most closely to what is known as the «Mumienkalk Bed»

724.24 – 724.59 m

Interval dominated by limestone (iron-oolitic), light grey to dark beige, glauconitic, encrusted clasts of oncolitic limestone in a matrix of argillaceous marl:

- abundant clasts of iron-oolite, well rounded (circular), dark beige, if iron-oids less numerous then iron-oolite is light grey, with large belemnites, glauconitic (medium-grained), stromatolitic crust (thin section TRU1-1-724.25)
- minor fraction of limestone clasts and bioclasts as described from 723.90 m to 724.24 m, possibly representing clasts of the oncolitic limestone
- argillaceous marl: dark grey, in the upper part as seams around the clasts, becoming more dominant towards the base with the clasts decreasing in size and number in the same direction, with large belemnites, one ammonite (at 724.30 m), glauconitic (medium-grained)
- at the base (from 724.54 m to 724.59 m) argillaceous marl without any clasts and minor number of iron-oids

This interval correlates most closely to what is known as the «Mumienmergel Bed»

724.59 – 724.85 m

Interval dominated by marl (iron-oolitic), dark grey, glauconitic, very fossiliferous (belemnites, some ammonites):

- at the top (from 724.59 m to 724.64 m) limestone (iron-oolitic), light to medium grey, both surfaces covered by belemnites
- beneath (from 724.64 m to 724.85 m) calcareous marl (silty; thin section TRU1-1-724.78), with abundant iron-oids and glauconite as well as belemnites

This interval correlates most closely to what is known as the «Glaukonit-sandmergel Bed»

3.6 Dogger Group

3.6.1 Wutach Formation, 724.85 – 727.13 m (2.28 m)

The Wutach Formation is a highly condensed succession dominated by iron-oolites and is rich in fossils (Dietl 2010). The iron-oolites and fossils are embedded in a matrix of argillaceous marl, more rarely in either calcareous marl or limestone (Frank et al. 1975). In TRU1-1, the Wutach Formation is even more reduced in thickness than at its type locality.

The *upper boundary* is set at 724.85 m at a pronounced hardground. The hardground separates the glauconitic and marl-dominated «Glaukonitsandmergel Bed» above from the limestone (iron-oolitic) of the Wutach Formation just below.

The *lower boundary* is set at 727.13 m, associated with a sharp change in colour. The surface corresponds to the base of the reddish-brown iron-oolite of the Wutach Formation above and the top of a grey, nodular and fossiliferous limestone of the underlying Variansmergel Formation.

Lithology

724.85 – 725.65 m	Repeated gradual transition from limestone (iron-oolitic), light to medium grey, at the top (thin section TRU1-1-724.86) into marl (iron-oolitic), medium to dark grey at the base; base developed as erosional surface. The iron-oolites are concentrated in patches. Their proportion decreases downwards from some 25% in the limestone (iron-oolitic) to some 10% in the marl (iron-oolitic). Both lithologies are very fossiliferous with large belemnites and bivalves, fewer and smaller sized echinoderms and a large ammonite at 725.08 m
725.65 – 727.13 m	Iron-oolite (argillaceous), ochre brown to reddish brown and dark grey. The background sediment is a limestone, light grey, at the top, passing into argillaceous marl, dark grey, further down. The iron-oolites are evenly distributed. They disappear from 727.06 m to 727.13 m at the base of the succession. The whole interval is as fossiliferous as above with biotritus, bivalves, belemnites, some crinoids and ammonites

3.6.2 Variansmergel Formation, 727.13 – 738.97 m (11.84 m)

The Variansmergel Formation usually consists of silty to sandy marl with a variable carbonate content (Geyer et al. 2011, Bläsi et al. 2013). The marl-dominated succession contains some uneven to nodular interbeds of micritic limestone. Both lithologies display a moderate to high fossil content, especially of brachiopods and bivalves.

In TRU1-1, the Variansmergel Formation mainly consists of silty claystone (calcareous). The lithological composition, thickness and the occurrence of interbedded limestone are similar to adjacent boreholes.

The vertical lithological structure of the Variansmergel Formation of TRU1-1 shows three parts. The limestone interbeds are mainly concentrated at the top and at the base of the formation. In between, the silty claystone (calcareous) dominates, almost devoid of interbeds. However, variations in grey shades of the claystone and in the FMI suggest a systematic variation of the carbonate content. According to the XRD data, however, the variations do not cross the lithological classification boundaries of Füchtbauer (1988).

The *upper boundary* is set at 727.13 m. It is the lowermost occurrence of iron-oooids from the reddish-brown Wutach Formation above. Below the boundary, the grey, nodular and fossiliferous limestone of the Variansmergel Formation takes over.

The *lower boundary* is set at 738.97 m. This is the base of the lowermost distinct limestone bed being part of an alternation of thin, fossiliferous limestone and silty claystone (calcareous). Beneath, in the «Parkinsoni-Württembergica-Schichten», distinct interbeds are much rarer, their fossil content lower and they are mostly composed of calcareous marl.

Lithology

727.13 – 729.35 m	Silty claystone (calcareous), dark grey, very fossiliferous (biodetritit, bivalves), with four interbeds (max. 30 cm) of limestone (argillaceous) (packstone, biomicrite), light grey, at the top nodular. Both lithologies contain biodetritit and bivalves
729.35 – 734.87 m	Silty claystone (sandy [fine-grained], calcareous), dark grey, very micaceous, with a layered transition to beds with a somewhat higher carbonate content but almost devoid of distinct interbeds. The fossil content of biodetritit and bivalves is sparse compared to the intervals above and below
734.87 – 738.97 m	This is the most calcareous interval of the formation: silty claystone (calcareous), as above but with several interbeds of limestone (partly argillaceous) (mudstone and wackestone, biopelmicrite), light to medium grey, and beige grey as well as sandy marl (thin section TRU1-1-735.58). The fossil record of both lithologies comprises some cm-thick layers of biodetritit and bivalves

3.6.3 «Parkinsoni-Württembergica-Schichten», 738.97 – 774.55 m (35.58 m)

The informal «Parkinsoni-Württembergica-Schichten» represent a uniform succession of micaceous claystone (calcareous) to argillaceous marl (Bläsi et al. 2013). Interbeds of bright calcareous marl and limestone occur at variable distances in the succession. All lithologies are silty to sandy (fine-grained). Their fossil content (fine biodetritit, belemnites and bivalves) is mostly low.

In TRU1-1, the main lithology throughout the entire unit is a silty to sandy claystone (calcareous) with local transition to sandy marl as the main lithology. An iron-oolite bed between 766.15 m and 767.35 m is quite fossiliferous, otherwise the content of macrofossils is as expected quite low.

The *upper boundary* is set at 738.97 m. It correlates with the base of an alternation composed of fossiliferous limestone and silty claystone (calcareous) of the Variansmergel Formation above. The distinct interbeds in the «Parkinsoni-Württembergica-Schichten» are much rarer, composed of calcareous marl rather than of limestone and of lower fossil content.

The *lower boundary* is set at 774.55 m. It indicates the uppermost occurrence of iron-oooids of the underlying «Humphriesiolith Formation».

Lithostratigraphic subdivision

Traditionally, the informal «Parkinsoni-Württembergica-Schichten» are subdivided by an iron-oolite bed, the informal «Parkinsoni-Oolith», into «Württembergica-Schichten» (upper part) and «Parkinsoni-Schichten» (lower part). The iron-oolite bed between 766.15 m and 767.35 m may be correlated with the «Parkinsoni-Oolith». If this is the case, the main part of the section will correspond to the informal «Württembergica-Schichten».

738.97 – 766.15 m	«Württembergica-Schichten»
766.15 – 774.55 m	«Parkinsoni-Schichten» including «Parkinsoni-Oolith» from 766.15 m to 767.35 m

Lithology

738.97 – 766.15 m	Silty claystone (calcareous, partly sandy), dark grey, micaceous, interbedded by distinct layers of calcareous marl (often silty), medium grey, at regular distances of 1 – 2 m. Additionally, a few interbeds of limestone (wackestone and packstone, biopelmicrite; thin section TRU1-1-742.22), light grey, occur in the upper half Vertical variations in the grey shades of the succession, also visible in the FMI log, occur with increasing frequency towards the top. They possibly indicate a variable carbonate content Overall, the fossil record is quite sparse compared to the units above and below. However, two intervals with a mass occurrence of serpulids occur from 761.16 m to 761.62 m and from 762.45 m to 762.84 m
766.15 – 767.35 m	Mainly marl (iron-oolitic, sandy), light to dark grey, with nodular interbeds of limestone (iron-oolitic), light grey (thin section TRU1-1-766.72). The iron-oids are smaller (≤ 1 mm) than in most other oolitic units of the Dogger Group. The background sediment is argillaceous marl interbedded by calcareous marl and limestone mainly in the upper part Below a pronounced hardground at 767.25 m, the interval ends with a nodular limestone (silty) (wackestone, biomicrite; thin section TRU1-1-767.30), with bivalves and echinoderms but without iron-oids Above the hardground, all lithologies are rich in biotritus and belemnites but sparser in bivalves and ammonites
767.35 – 774.55 m	Silty claystone (calcareous), as above 766.15 m, but with just two thin interbeds of calcareous marl (sandy), light to medium grey. The succession does not show the vertical variations in colour which were found in the unit above 766.15 m The fossil record of both lithologies includes scattered biotritus, belemnites and bivalves

3.6.4 «Humphriesioolith Formation», 774.55 – 787.50 m (12.95 m)

According to Bläsi et al. (2013), the informal «Humphriesioolith Formation» encompasses a marly interval with limestone beds which is sandwiched between two iron-oolitic beds at the top and at the base, all being very fossiliferous.

In TRU1-1, the interval between 774.55 m and 787.50 m matches the definition of Bläsi et al. (2013) of the informal «Humphriesioolith Formation» quite well.

The *upper boundary* is set at 774.55 m with the uppermost occurrence of iron-oolids from the «Humphriesioolith Formation» below.

The *lower boundary* is set at 787.50 m with the lowermost occurrence of iron-oolids from the «Humphriesioolith Formation» above.

Lithostratigraphic subdivision

The «Humphriesioolith Formation» can be divided reliably into the three subunits (Jordan & Deplazes 2019) by the rather sharp onset and offset of iron-oolids. However, the informal lithostratigraphic terms (from top to base: «Subfurcaten-Oolith», «Blagdeni-Schichten» and «Humphriesi-Oolith») will no longer be used as they contain names which could predetermine the age of the unit within the succession. The further use of the informal subunits would generate additional confusion, because the biostratigraphic ages do not fit with the expected age from the naming (Bläsi et al. 2013). The following subdivision into an upper and lower iron-oolitic interval, interbedded by a marly interval, can be correlated to the nearby Benken borehole (Bläsi et al. 2013) with the same lithostratigraphic succession:

774.55 – 778.12 m	Upper iron-oolitic interval (3.57 m)
778.12 – 783.92 m	Marly interval with limestone beds without iron-oolids (5.80 m)
783.92 – 787.50 m	Lower iron-oolitic interval (3.58 m)

Lithology

774.55 – 778.12 m	Mostly thin-bedded alternation of predominantly iron-oolite, limestone (iron-oolitic) and marl (iron-oolitic), with gradual transitions: - iron-oolite: iron-oolite, dark greyish brown, background sediment is argillaceous marl, dark grey - limestone: limestone (iron-oolitic) (packstone and boundstone, oomicrite; thin sections TRU1-1-774.93, TRU1-1-776.41, TRU1-1-776.49), medium grey - marl: marl (iron-oolitic), dark to medium grey, background sediment is calcareous marl
-------------------	--

The iron-oolids are irregularly distributed in all lithologies and may reach 3 mm in diameter. The fossil content varies vertically from moderate to very high. It comprises very large specimens of bivalves (oysters), ammonites, echinoderms, belemnites and sponges, in the lower part also serpulids (thin section TRU1-1-777.50)

778.12 – 783.92 m	Silty to sandy claystone (calcareous), dark to medium grey, micaceous; interbedded (max. 25 cm) by calcareous marl (silty to sandy) and more rarely by sandy limestone, with rounded bioclasts, both lithologies light grey. All lithologies are fossiliferous including biodetritus, belemnites, in distinct sections also bivalves (oysters) and crinoids, partly concentrated in coquina
783.92 – 787.50 m	Alternation of marl (iron-oolitic) and limestone (iron-oolitic) to iron-oolite (silty; thin section TRU1-1-784.67): • marl: marl (iron-oolitic), variegated (dark grey to dark greyish brown, dark grey to dark greyish red), background sediment is argillaceous marl in the upper part, in the lower part calcareous marl • limestone: limestone (iron-oolitic) (packstone, oomicrite), brown to dark greyish brown, and red brown, from 784.60 m to 785.05 m with large rounded clasts of sparse limestone (mudstone, micrite), medium grey, and bioclastic limestone (packstone, biomicrite), with belemnites and bryozoa in the clasts The iron-oolites are clustered and smaller than in the upper iron-oolitic interval (774.55 – 778.12 m) All lithologies are very fossiliferous with serpulids, limonitised bivalves (thin section TRU1-1-785.68), belemnites, gastropods and ammonites

3.6.5 Wedelsandstein Formation, 787.50 – 815.51 m (28.01 m)

Usually, a considerable proportion of quartz sand and a rather sparse content of macrofossils are diagnostic for the Wedelsandstein Formation compared to the formations above and below (Jordan & Deplazes 2019). The main body of the formation is described as silty to sandy marl with interbeds of biodetritic and sandy limestone.

In TRU1-1, the background sediment of the Wedelsandstein Formation is classified as silty to sandy claystone (calcareous) and sandy marl. The interbeds consist of biodetritic limestone (sandy) but a few beds at the base show a transition to calcareous sandstone and even to sandstone (calcareous).

Both the background lithology and the interbeds are unevenly distributed. Therefore, the formation can be divided into several lithological subunits. However, as often pointed out (e.g. Franz et al. 2004, Bläsi et al. 2013), the lateral continuity of the beds is restricted. A division into lithostratigraphic subunits, as often practised for adjacent regions (e.g. in Hahn 1971), cannot be performed conclusively for TRU1-1. At the base, a calcareous marl (sandy) with encrusted clasts of iron-oolites stands out. It may correspond to the «Sowerbyi-Oolith».

The characteristic ichnofossil *Zoophycos* is easily recognisable on the core surfaces throughout the entire formation.

The *upper boundary* is set at 787.50 m. This surface defines the base of dark reddish-brown iron-oolite of the overlying «Humphriesioolith Formation». Beneath, the light grey and ooid-free sandy limestone of the Wedelsandstein Formation sets in. The sandy limestone displays the characteristic grey shades and a considerable content of quartz sand.

The *lower boundary* is set at 815.51 m at the basal surface of the potential «Sowerbyi-Oolith». Beneath, the silty claystone of the «Murchisonae-Oolith Formation» sets in.

Lithology

787.50 – 790.80 m	Argillaceous sandstone (calcareous), dark grey, micaceous, wavy- to flaser-bedded by laminae of siltstone, light grey; towards the top passing into a sandy limestone, light grey, with bioclasts of oysters (?)
790.80 – 797.91 m	Silty claystone (calcareous), passing downwards into sandy claystone (calcareous) and sandy marl, all medium to dark grey and micaceous
797.91 – 807.35 m	Repetition (twice) from top to base: • silty to sandy marl, medium to beige grey, interbedded by thin layers of sandy limestone, light grey, in the uppermost part of each sequence Silty to sandy marl almost devoid of macrofossils, with mica, in parts pyritic and in alternation with each other, which results in irregular wavy bedding • silty claystone (calcareous), dark greyish brown Silty claystone almost devoid of macrofossils, with mica, in parts pyritic and in alternation with each other, which results in irregular wavy bedding • sandy limestone: biotrititic with echinoderms and bivalves (thin sections TRU1-1-798.92, TRU1-1-804.83), partly or completely disintegrated into nodules
807.35 – 815.51 m	From 807.35 m to 815.40 m: Sandy marl, beige grey to dark grey, micaceous and bioturbated, irregular wavy-bedded by laminae of sandy claystone (calcareous), dark grey. The succession is interspersed by beds (max. 46 cm) of sandy limestone in transition to calcareous sandstone (thin sections TRU1-1-808.86, TRU1-1-810.82) at regular vertical distances of 0.5 – 1 m. Again, the marl is almost devoid of fossils. The sandy limestone beds are biotrititic as above From 815.40 m to 815.51 m: Calcareous marl (sandy), dark grey, with some rounded intraclasts of iron-oolite (thin section TRU1-1-815.44), medium to beige grey, some clasts bored beneath a stromatolitic crust with a thickness of about 0.5 cm; with a large mold of a bivalve The description of the interval including the exemplary occurrence of large bivalves fits well with the «Sowerbyi-Oolith»

3.6.6 «Murchisonae-Oolith Formation», 815.51 – 816.42 m (0.91 m)

In boreholes in the ZNO region, the «Murchisonae-Oolith Formation» is strongly reduced in thickness or even missing (Albert et al. 2012, Bläsi et al. 2013).

In TRU1-1, the formation is composed of a silty claystone above a thin layer of calcareous marl with iron-oolids (now replaced by calcite), separated from each other by a hardground.

The *upper boundary* is set at 815.51 m. This is the base of the ooid-bearing calcareous marl which is believed to correspond to the «Sowerbyi-Oolith» of the overlying Wedelsandstein Formation.

The *lower boundary* is set at 816.42 m. The grey limestone (iron-oolitic) of the «Murchisonae-Oolith Formation» is replaced by the dark claystone of the Opalinus Clay. Setting the lithostratigraphic boundary at this surface is strongly corroborated by the GR log readings, the electrofacies of the FMI logs as well as by the carbonate content evidence (*cf.* Dossier IV).

Lithology

815.51 – 816.26 m	Silty claystone (calcareous), dark grey, micaceous, lenticular-bedded by laminae of siltstone and sandstone, both very light grey
816.26 – 816.42 m	Mainly a limestone (iron-oolitic), light grey, separated by a thin layer of argillaceous marl. At the base due to higher concentration of iron-ooids in transition to iron-oolite (calcareous; thin sections TRU1-1-816.28, TRU1-1-816.40), light grey, with angular to rounded limestone clasts, light grey, angular to rounded bioclasts (echinoderms, bivalves) with limonitic (?) crusts, light greenish grey. The diameter of the iron-ooids is less than 1 mm

3.6.7 Opalinus Clay, 816.42 – 927.91 m (111.49 m)

The Opalinus Clay is generally regarded as a monotonous succession of dark grey silty claystone with silty to sandy lenses. It is interbedded very sparsely by thin layers of sandstone and limestone (Wetzel & Allia 2003). Fossils are very rare.

The findings in TRU1-1 confirm the uniform lithology of the Opalinus Clay. The facies of the Opalinus Clay are in line with the concept of Mazurek & Aschwanden (2020) and thus meet the expectations. The fossil content is restricted to solitary occurrences of bivalves, ammonites and belemnites. However, there are three exceptions in terms of lithology and fossil content. Firstly, sandy limestone beds occur in the upper half of the Opalinus Clay. They are enriched in biodebris. Secondly, conglomeratic layers, often associated with hardgrounds, contain bioclasts and fragments of bivalves, echinoids, crinoids and belemnites. The conglomeratic layers also concentrate in the upper half of the Opalinus Clay. Thirdly, from 912.95 m to 919.00 m, ammonites have occasionally been found.

The *upper boundary* is set at 816.42 m. There, the grey limestone (iron-oolitic) of the overlying «Murchisonae-Oolith Formation» overlies the characteristic dark grey claystone of the Opalinus Clay. This sharp boundary is also very striking in both the petrophysical logs and the geochemical analyses (*cf.* Dossier IV).

The *lower boundary* is set at 927.91 m. The Opalinus Clay terminates downwards with a gradual increase in the carbonate content within some 0.35 m above its base, clearly visible on the cores by a colour change from the typical dark grey of the Opalinus Clay towards the brighter greyish colour of the Staffelegg Formation below. The surface at 927.91 m is the top of the uppermost calcareous marl of the Staffelegg Formation. This transition is accompanied by a significant increase in occurrences of belemnites, ammonites and bivalves which are characteristic of the uppermost member of the Staffelegg Formation.

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 subunits. They apply to the present section as follows:

816.42 – 846.88 m	«Subunit with silty calcareous beds» (30.46 m)
846.88 – 860.24 m	«Upper silty subunit» (13.36 m)
860.24 – 912.95 m	«Mixed clay-silt-carbonate subunit» (52.71 m)
912.95 – 927.91 m	«Clay-rich subunit» (14.96 m)

Lithology

«Subunit with silty calcareous beds», 816.42 – 846.88 m (30.46 m)

816.42 – 824.14 m	Claystone (silty), dark grey to black, micaceous and pyritic; with laminae of siltstone to sandstone (calcareous), beige grey and medium grey; a few siderite nodules around 820 m A hardground at the base (from 824.06 m to 824.14 m) consists of a conglomerate, calcareous (polymict) with lithoclasts (max. 1 cm) and bioclasts of bivalves as well as of belemnites in a matrix of silty claystone
824.14 – 826.00 m	Mainly a silty claystone (calcareous), dark grey, lenticular-bedded by lenses (< 1 cm) of siltstone (calcareous), medium grey
826.00 – 831.73 m	Recurrence of the silty claystone (calcareous) A hardground at the top (from 826.00 m to 826.05 m) consists of a thin conglomerate, calcareous (polymict), with rounded lithoclasts of sandy limestone (max. 8 cm), smaller bioclasts of belemnites and of crinoids as well as clasts of iron-oolite (thin section TRU1-1-826.03), all in a matrix of silty claystone. The clasts are bored, the borings are filled with pyrite. Siderite nodules cluster in the upper half of the interval from 826.60 m to 828.30 m
831.73 – 833.03 m	Interval dominated by limestone beds and several hardgrounds, separated by an interval of silty claystone (from 831.93 m to 832.48 m) Upper limestone interval (from 831.73 m to 831.93 m): twofold repetition of silty limestone (argillaceous), passing gradually into claystone (calcareous), pyritic, at the base (from 831.73 m to 831.87 m and from 831.87 m to 831.93 m). The basal surfaces are bored hardgrounds with bioclasts, sideritic stromatolites (thin section TRU1-1-831.91) and coquina Lower limestone interval (from 832.48 m to 833.03 m): in the upper part (from 832.48 m to 832.78 m) silty limestone in transition to calcareous marl (silty; thin section TRU1-1-832.49), composed of coquina and intraclasts above the basal hardground at 832.78 m; in the lower part (from 832.78 m to 833.03 m) silty limestone without as many coquina as in the upper part. Iron-oolids concentrate above an internal hardground at 833.00 m (thin section TRU1-1-833.00)

- 833.03 – 837.04 m Silty claystone (calcareous, partly sandy [fine-grained]), dark grey, micaceous, lenticular-bedded with mm-thick layers of siltstone to sandstone (calcareous), medium grey
- Conspicuous features of the interval are lenses (max. 3 cm) of calcareous sandstone, light grey, rippled, from 834.20 m to 836.19 m
- A hardground at the base (837.04 m) contains some reworked sideritic intraclasts, bioclasts and fossil fragments of bivalves and echinoderms at the top (TRU1-1-836.84)
- 837.04 – 846.88 m Silty claystone (calcareous), dark grey, micaceous, lenticular-bedded with mm-thick layers of siltstone to sandstone (calcareous), medium grey
- Conspicuous features of the interval are frequent siderite nodules from 838.81 m to 842.61 m. An erosional surface at 843.32 m is covered with lithoclasts (silty claystone), fossil detritus (echinoids, crinoids) and siderite nodules (thin section TRU1-1-843.33)

«Upper silty sub-unit», 846.88 – 860.24 m (13.36 m)

- 846.88 – 860.24 m Interval dominated by silty claystone (calcareous), dark grey, very micaceous, lenticular-bedded by mm- to cm-thick layers of siltstone to sandstone (fine-grained) (calcareous), light grey
- The section from 857.03 m to 858.17 m is the sandiest of this interval with an alternation of argillaceous sandstone (calcareous), light grey, and sandy claystone (calcareous), dark grey, both intensely bioturbated. Further conspicuous features are the occurrence of abundant siderite nodules in the lower half (from 854.79 m to 858.17 m) and some lenses of sandstone (calcareous) as described above in the middle part (from 852.97 m to 855.55 m)

«Mixed clay-silt-carbonate sub-unit», 860.24 – 912.95 m (52.71 m)

- 860.24 – 873.45 m Three-part division: some 2.5 m of silty claystone (calcareous) at the top, some 8 m of sandy claystone (silty, calcareous), forming a major part of the interval, and some 2.5 m of silty to sandy claystone (calcareous) at the base. All lithologies are dark grey and micaceous. The ample occurrence of laminae and lenses of siltstone and sandstone fades away at 873.45 m for the remaining Opalinus Clay down to its base at 927.91 m
- There are some conspicuous features of the interval: The uppermost section (from 860.57 m to 862.38 m) contains many siderite nodules which are almost absent in the remaining section. The disappearance of the siderite nodules coincides with the appearance of lenses of calcareous sandstone (mostly fine-grained), light grey, mostly rippled. They cluster from 863.15 m to 865.30 m and from 871.24 m to 873.06 m. In between (from 865.30 m to 871.24 m), a few interbeds (max. 50 cm) of sandy marl, light grey, micaceous, occur

873.45 – 912.95 m Rather uniform succession (relative to the other intervals) composed of silty claystone (calcareous), dark grey, micaceous, with sparse occurrence of ammonites and bivalves. The ammonites were identified exclusively as *Leioceras opalinum*

Conspicuous features of the interval are two clusters of siderite nodules from 875.32 m to 877.94 m and from 898.19 m to 902.75 m as well as thin layer of calcareous sandstone (fine-grained) (argillaceous) from 896.59 m to 896.69 m. The sandstone is medium grey, rippled, moderately cemented by calcite and with a clayey matrix (thin section TRU1-1-896.67)

«Clay-rich sub-unit», 912.95 – 927.91 m (14.96 m)

912.95 – 919.00 m Silty claystone (calcareous), dark grey, micaceous, laminated, siderite nodules abundant

The interval has the highest content of macrofossils in the entire Opalinus Clay. Ammonites and fragments of ammonites are found throughout, and bivalves (up to 2 cm) are enriched in several sections. A layer (max. 7 cm) of calcareous nodules (septarian nodules) occurs close to the base (from 917.78 m to 917.88 m)

The ammonites were identified as *Leioceras opalinum*

919.00 – 927.91 m Claystone (silty, calcareous), dark to medium grey, micaceous; from some 0.35 m above the base a gradual increase in carbonate content downwards and final transition into argillaceous marl, dark grey, at the base. Siderite nodules are virtually missing. The content of macrofossils comprises only a few ammonites, all identified as *Leioceras opalinum*

3.7 Lias Group

3.7.1 Staffelegg Formation, 927.91 – 971.68 m (43.77 m)

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

The *upper boundary* is set at 927.91 m at the uppermost surface of a fossiliferous calcareous marl. The gradual increase in carbonate content already starts in the Opalinus Clay from 927.55 m to 927.91 m. This increase agrees with a marked drop in the GR log readings over the same distance. On a larger scale, the boundary between the Opalinus Clay above and the Staffelegg Formation is well reflected in both petrophysical logs and the carbonate content data (*cf.* Dossier IV).

The *lower boundary* is set at 971.68 m at the base of a characteristic limestone bed including fossils as echinoderms overlying a bituminous layer with presumed bivalves and no echinoderms.

3.7.1.1 Gross Wolf Member, 927.91 – 934.73 m (6.82 m)

The Gross Wolf Member is usually composed of argillaceous marl (silty to sandy) to calcareous marl (silty to sandy). It is interbedded by nodular limestone layers up to a few decimetres in thickness. The member is characterised by a higher carbonate content and, consequently, brighter grey shades than the neighbouring units. Further characteristics are the abundance of well-preserved belemnites, ammonites and benthic fauna, as well as the nodular shape of the limestone interbeds with mottled surfaces due to intense bioturbation (Jordan & Deplazes 2019).

In TRU1-1, the Gross Wolf Member matches the predicted thickness and facies. However, the Gipf Bed as defined by Reisdorf et al. (2011) as a regional marker horizon at the base of the member cannot be identified for certain. Lithologically, the Gross Wolf Member can be divided into three units. The upper part consists predominantly of calcareous marl. In the middle part, the carbonate content is the highest. There, calcareous marl in transition to limestone (argillaceous) prevails. The basal part of the member is composed of argillaceous marl.

The *upper boundary* is set at 927.91 m at the uppermost surface of a fossiliferous calcareous marl. The gradual increase in carbonate content already starts in the Opalinus Clay from 927.55 m to 927.91 m. This increase agrees with a marked drop in the GR log readings over the same distance. On a larger scale, the boundary between the Opalinus Clay above and the Staffelegg Formation is well reflected in both petrophysical logs and the carbonate content data (*cf.* Dossier IV).

The *lower boundary* is set at 934.73 m at the base of a horizon with large belemnites characteristic of the basal Gross Wolf Member. The boundary coincides with a change to darker colours, the onset of bitumen content and a significant decrease in belemnite abundance, all indicative for the underlying Rietheim Member. An omission horizon or a hardground, reported to mark the boundary at other places (*cf.* Jordan & Deplazes 2019), was not found.

Lithology

927.91 – 929.90 m	Calcareous marl (slightly silty), medium to dark grey, pyritic, very fossiliferous (ammonites, belemnites, echinoderms, bivalves); a few thin (< 10 cm) interbeds of nodular limestone (argillaceous) (mudstone, biomicrite), light to medium grey, with sparser content of the same fossils as in the calcareous marl
929.90 – 934.73 m	From 929.90 m to 934.30 m: Calcareous marl in transition to limestone (argillaceous) (mudstone, biomicrite), medium light grey to medium grey, pyritic, as fossiliferous as above and intensely burrowed. In contrast to above, the distinct interbeds of nodular limestone (argillaceous) (wackestone, biomicrite; thin section TRU1-1-930.13) are thicker and as fossiliferous as the calcareous marl. Some nodules contain phosphorous cores From 934.30 m to 934.73 m: Argillaceous marl, medium to dark grey, pyritic, abundant belemnites and some bivalves

3.7.1.2 Rietheim Member, 934.73 – 944.68 m (9.95 m)

The Rietheim Member is very distinctive due its bitumen content and its lamination by very fine biotritus (e.g. Kuhn & Etter 1994). Usually, the total organic content is highest in the lower part of the member, reflected by the presence of bituminous shale in this section (e.g. Röhl et al. 2001, cf. Dossier IV).

In TRU1-1, the Rietheim Member coincides in facies and thickness with the findings in adjacent boreholes and outcrops (e.g. Hofmann et al. 2000, Nagra 2001a). The Rietheim Member consists of argillaceous marl (silty, bituminous), passing into bituminous shale towards the base. The section contains some beds of calcareous marl and limestone, both also bituminous and laminated, which are known as transregional marker horizons (e.g. Dietl & Etzold 1977).

The upper boundary is set at 934.73 m. It is the base of the lowermost belemnite horizon typical of the overlying Gross Wolf Member and the uppermost occurrence of argillaceous marl (bituminous) of the Rietheim Member.

The lower boundary is set at 944.68 m at the lowermost cm-thick seam of bituminous shale. Beneath, the calcareous marl, dark grey, of the Rickenbach Member sets in.

Lithology

934.73 – 935.90 m	Argillaceous marl (silty), passing downwards gradually into calcareous marl (silty), both bituminous, dark grey to light grey, pyritic and with pyritised bivalves (primarily <i>Bositra buchi</i>), belemnites, echinoderms, laminated by ultrathin coquina (thin section TRU1-1-935.81)
935.90 – 940.95 m	Lithologically uniform interval of argillaceous marl (bituminous), dark grey, micaceous, pyritic, ubiquitous coquina layers of pyritised bivalves, scattered ammonites and belemnites, laminated by ultrathin coquina
940.95 – 943.73 m	Bituminous shale, dark grey to dark greyish brown, micaceous and pyritic, with pyritised bivalves; three interbeds (max. 34 cm) of calcareous marl to limestone (argillaceous, bituminous), beige grey, biotrititic. The lowermost bed from 942.48 m to 942.82 m represents the marker horizon Unterer Stein
943.73 – 944.68 m	Argillaceous marl, dark grey, fossiliferous (belemnites and bivalves and an ammonite at 943.83 m) with two strongly bioturbated intervals (from 944.21 m to 944.27 m and from 944.49 m to 944.57 m); at the base (from 944.65 m to 944.68 m) thin layer of bituminous shale, dark grey

3.7.1.3 Breitenmatt and Rickenbach Members, 944.68 – 949.15 m (4.47 m)

The Breitenmatt Member and the Rickenbach Member represent a strongly condensed section throughout Northern Switzerland. Jordan & Deplazes (2019) recommend describing the Breitenmatt and Rickenbach Members (together with the evenly thin underlying Grünschholz Member) as one informal stratigraphic unit, as the delimitation of the three thin and predominantly calcareous and fossiliferous members was not expected to be simple.

In TRU1-1, the Breitenmatt and Rickenbach Members are described together. However, the Grünschholz Member can be clearly delimited.

The *upper boundary* is set at 944.68 m at the base of the lowermost cm-thick seam of bituminous shale from the hanging Rietheim Member overlying a dark grey calcareous marl.

The *lower boundary* is a pronounced hardground at 949.15 m. It separates an argillaceous marl (silty), pyritic and glauconitic, from the fossiliferous limestone with phosphoritic concretions of the Grünschoholz Member below.

Lithology

944.68 – 946.27 m	From 944.68 m to 945.15 m: Calcareous marl, dark grey, micaceous, very fossiliferous (belemnites and bivalves, ammonites) From 945.15 m to 946.27 m: Four beds (9 – 13 cm) of nodular limestone (mudstone, biomicrite), light grey, separated by calcareous marl (silty), medium light grey, micaceous, fossiliferous but less than above (belemnites, bivalves, crinoids) The uppermost limestone bed is biomicritic with ubiquitous burrows at the top (945.15 m)
946.27 – 949.15 m	Argillaceous marl (silty), medium grey, micaceous and pyritic, close to the base (949.15 m) glauconitic, very fossiliferous (belemnites abundant, bivalves, crinoids, ammonites). The interval contains limestone (mudstone, micrite), very light grey, as solitary nodules and beds which, again, are partly to completely disintegrated into nodules. The two lowermost limestone beds are intensely burrowed and bored

3.7.1.4 Grünschoholz Member, 949.15 – 949.90 m (0.75 m)

The Grünschoholz Member is the lowermost member of the highly condensed, calcareous and phosphoritic section framed by the more argillaceous and thicker Rietheim and Frick Members. Due to the presence of *Gryphaea obliqua* it can be distinguished from the likewise condensed beds of overlying sediment succession.

The *upper boundary* is set at 949.15 m at a hardground overlain by an argillaceous marl (silty), pyritic and glauconitic, of the Breitenmatt and Rickenbach Members.

The *lower boundary* is set at 949.90 m at an erosional surface separating the glauconitic limestone rich in fossils, including *Gryphaea obliqua*, and a macrofossil-poor sandy claystone of the uppermost Frick Member.

Lithology

949.15 – 949.90 m	Laminated to nodular beds of limestone (argillaceous) (packstone and boundstone, intramicrite), variegated from medium grey to dark grey and dark greyish brown, micaceous and glauconitic, extremely fossiliferous with belemnites, echinoderms and bivalves Hardgrounds at the top (949.15 m), at 949.24 m and at 949.55 m. Phosphoritic concretions occur down to 949.55 m. The base of the succession is covered with <i>Gryphaea obliqua</i> and pyrite
-------------------	--

3.7.1.5 Frick Member, 949.90 – 962.09 m (12.19 m)

The Frick Member is known as a uniform succession of micaceous and silty claystone in various shades of dark grey. Macrofossils are virtually absent (Reisdorf et al. 2011).

In TRU1-1, the core records and XRD data revealed an argillaceous sandstone close to the top (950.28 m) and a continuous decrease in sand content from the top to the base.

The *upper boundary* is set at 949.90 m at an erosional surface. It separates the glauconitic and extremely fossiliferous limestone of the overlying Grünschholz Member from the dark terrigenous sediments below.

The *lower boundary* is set at 962.09 m above a fossiliferous calcareous marl developed between 962.09 m and 962.19 m. Its brighter colour and the fossil content clearly separate it from the overlying Frick Member. The typical «Arietenkalk» facies of the Beggingen Member sets in just beneath a hardground at 962.19 m.

Lithology

949.90 – 962.09 m	Sandy claystone in transition to argillaceous sandstone close to the top, passing gradually into silty claystone (calcareous) in the lower part, both lithologies medium grey to dark grey, micaceous and pyritic; macrofossils almost absent apart from a few bivalves
-------------------	---

3.7.1.6 Beggingen Member, 962.09 – 965.83 m (3.74 m)

In north-eastern Switzerland, the Beggingen Member comprise two successions of thin- to medium-bedded fossiliferous limestone (iron-oolitic), partly limonitic, with thin marl interbeds (e.g. Reisdorf et al. 2011). The limestone successions are separated by a silty claystone interval becoming more prominent in the ZNO area (e.g. Nagra 2001a). The upper limestone succession is characterised by the occurrence of *Gryphaea arcuata*, an index fossil which is missing in the lower succession. This limestone succession is known as "Arietenkalk" (e.g. Hofmann et al. 2000). The base of the lower succession is marked by the Schleithem Bed as a regional stratigraphic marker with an erosional surface at its base (Reisdorf et al. 2011).

In TRU1-1, the Beggingen Member shows close similarities to adjacent boreholes in facies and thickness (e.g. Nagra 2001a). Coarse-grained sandstone input (informal «Herdern Member»; Jordan & Deplazes 2019), known from boreholes farther east to replace partly the Beggingen Member (e.g. Kiefer et al. 2015), could not be found in TRU1-1.

The *upper boundary* is set at 962.09 m at the top of a fossiliferous calcareous marl which contrasts with the overlying Frick Member by fossil abundance and brighter colour. The typical «Arietenkalk» of the Beggingen Member sets in just beneath a hardground at 962.19 m. This overlying interval, also known from the Klettgau and Wutach area (e.g. Hahn 1971, Schlatter 1976, Hofmann et al. 2000), is included in the Beggingen Member in agreement with Reisdorf et al. (2011).

The *lower boundary* is set at 965.83 m at a hardground. The hardground is overlain by reworked clasts of iron-oolite, limestone and bioclasts, accompanied by numerous macrofossils which is characteristic for the basal Beggingen Member (Schleithem Bed). The Schambelen Member below the hardground starts with densely packed nodules of a biotrititic limestone (argillaceous) passing downwards rapidly into silty claystone (calcareous) below.

As mentioned above, the Beggingen Member can be divided into several lithologically very different intervals:

962.09 – 962.19 m	Marly bed
962.19 – 963.27 m	Upper limestone succession («Arietenkalk»)
963.27 – 965.64 m	Claystone interval
965.64 – 965.83 m	Lower limestone succession; corresponds to the Schleithem Bed

Lithology

962.09 – 963.27 m From 962.09 m to 962.19 m: Calcareous marl, medium (light) grey, micaceous, biotrititic, hardground at the base (962.19 m) covered by belemnites and gryphid oysters

From 962.19 m to 962.67 m: Alternation of bioclastic limestone (grainstone, biosparite), light grey, and limestone (argillaceous) (packstone, biomicrite; thin section TRU1-1-962.44), medium grey, both lithologies interspersed with *Gryphaea arcuata*, bivalves, gastropods, echinoderms and phosphoritic concretions

From 962.67 m to 963.08 m: Succession of hardgrounds (962.67 m, 962.76 m, 962.90 m) with limestone (iron-oolitic) (grainstone, oospa-rite), dark greyish brown, and bioclastic limestone (grainstone, dominantly intrasparite), light to medium grey, both micaceous, pyritic and fossiliferous (record as above) with an ammonite at 963.00 m; phosphoritic concretions from 962.90 m to 963.08 m

From 963.08 m to 963.27 m: Hardground at the top, beneath beds of limestone (mudstone, micrite), light grey, interbedded by limestone (silty to sandy [up to medium-grained], argillaceous), micaceous

963.27 – 965.83 m From 963.27 m to 965.01 m: Silty claystone, dark grey, micaceous, with thin (about 1 cm) layers of siltstone, micaceous, pyritic, as well as single nodules and nodular layers (< 3 cm) of calcareous marl and dolomitic marl, both light grey

From 965.01 m to 965.64 m: Silty claystone and nodular calcareous / dolomitic marl as above but the marl interbeds are continuous and thicker (some 10 cm)

From 965.64 m to 965.83 m: Conglomerate, calcareous (polymict), with clasts of iron-oolite, encrusted and bored nodules of limestone (argillaceous), coquina layers of limonitised bivalves and echinoderms (thin section TRU1-1-965.78), all embedded in a matrix of argillaceous marl (silty to sandy), medium grey, with very small iron-oids, micaceous and pyritic, biotrititic; hardground bored at the base

This interval corresponds to the Schleithem Bed

3.7.1.7 Schambelen Member, 965.83 – 971.68 m (5.85 m)

The Schambelen Member is dominated by dark silty to sandy claystone with a sparse fossil content. However, the member shows many subtle changes in both lithology and facies throughout Northern Switzerland (e.g. Nagra 1992a, Nagra 1992b, Nagra 2001a, Albert et al. 2012, Jordan & Deplazes 2019). In north-eastern Switzerland, a fossiliferous limestone bed (Hallau Bed) is reported from the lowest part or the base of the Schambelen Member (Reisdorf et al. 2011).

In TRU1-1, the Schambelen Member consists almost exclusively of silty to sandy claystone. The lower part of this interval also contains thin beds and lenses of siltstone and sandstone. The main body is divided by a conspicuous layer of nodular bioclastic limestone. The characteristic Hallau Bed (971.31 m to 971.68 m) is found at the base of the member. Coarse-grained sandstone input (informal «Herdern Member»; Jordan & Deplazes 2019), known from boreholes farther east to replace the Schambelen Member (e.g. Kiefer et al. 2015), could not be found at TRU1-1.

The *upper boundary* is set at a hardground at 965.83 m. It marks the onset of bioclastic marl with iron-oids of the Beggingen Member above. The thin limestone layer just below the hardground is devoid of iron-oids and lacks the fossils which are typical of the Beggingen Member. It is thus already part of the Schambelen Member.

The *lower boundary* is set at 971.68 m, at the base of a 5 cm thick virtually macrofossil-free limestone (argillaceous, bituminous). It separates an overlying fossiliferous limestone from an underlying fossiliferous claystone (bituminous). The heterogeneous fossil record of the limestone comprises abundant echinoderms and thus documents normal marine conditions typical of the Early Jurassic. The fossil record of the underlying claystone is rather monotonous and is dominated by *Avicula*-type bivalves (interpreted as *Rhaetavicula* sp.) and probably typical of the estuarine facies of the Belchen Member. Limiting the Staffelegg Formation at the base of the lowest echinoderm-bearing layer was also proposed by Kiefer et al. (2015). The assignment of the "transitional" layer between 971.63 m and 971.68 m is open to discussion.

Lithology

965.83 – 968.37 m	Silty claystone, dark grey, micaceous, sparsely biotrititic, with thin (max. 2 cm) interbeds of siltstone (argillaceous), light grey, micaceous; at the top nodules of limestone (argillaceous) (mudstone, micrite), partly with a limonitic crust, pyritic
968.37 – 971.68 m	From 968.37 m to 968.50 m: Nodular bed of bioclastic limestone (grainstone, biosparite), medium grey, very fossiliferous (bivalves, echinoderms) From 968.50 m to 970.76 m: Silty claystone as above but lenticular-bedded with thin interbeds of siltstone and sandstone (fine-grained), very light grey to light grey, rippled From 970.76 m to 971.31 m: Claystone (silty, calcareous), dark grey From 971.31 m to 971.48 m: Limestone (argillaceous) (wackestone, biomicrite), medium grey, fossiliferous (biotrititic, echinoderms), at the top limestone (wackestone, oosparite) with clasts of iron-oolite and bioclasts of bivalves (thin section TRU1-1-971.35)

From 971.48 m to 971.63 m: Limestone (packstone, biomicrite), medium grey to dark greyish brown, very fossiliferous (coquina of bivalves, echi-noderms)

From 971.63 m to 971.68 m: Limestone (argillaceous) (mudstone, micrite), medium to dark grey, no macrofossils

3.8 Keuper Group

3.8.1 Klettgau Formation, 971.68 – 1'027.22 m (55.54 m)

The Klettgau Formation is a heterogeneous succession dominated by variegated playa sediments with mostly argillaceous marl (silty) and dolocretes. Fine-grained to coarse-grained calcareous or siliciclastic sediments are found in channels and overspill layers. In TRU1-1, the Belchen Member, which is missing in some surrounding boreholes (see Fig. 5 in Reisdorf et al. 2011 for the borehole locations) is present. The Gruhalde Member is separated by the Seebi Member as expected.

The *upper boundary* is set at 971.68 m. This is the base of a regional marker bed composed of limestone with stenohaline fossils of Jurassic age. The bed is underlain by fossiliferous claystones (bituminous) which are prevalent in the Belchen Member of the Klettgau Formation.

The *lower boundary* is set at 1'027.22 m at the top of the uppermost anhydrite bed of the Bänkerjoch Formation below.

3.8.1.1 Belchen Member, 971.68 – 973.09 m (1.41 m)

The Belchen Member usually consists of mostly carbonate-free quartz sandstone, dark marl and claystone (bituminous) with thin layers of silt- to sandstone (Etzold et al. 2010, Jordan & Deplazes 2019). Due to pre-Jurassic erosion, the Belchen Member is generally very thin or even missing (Jordan et al. 2016).

In TRU1-1, the claystone was encountered but no sandstone. Instead, a bioclastic limestone bed was drilled. The erosional surface at its base is covered by lithoclasts and pyritised bioclasts of bivalves. This horizon may be interpreted as a bone bed.

The *upper boundary* corresponds to the upper limit of the Klettgau Formation and is set at 971.68 m.

The *lower boundary* is set at 973.09 m at an erosional surface. It is at the base of a thin (9 cm) conglomerate above the uppermost of the greyish green and homogeneous dolomitic marls typical of the upper part of the Gruhalde Member.

Lithology

971.68 – 971.90 m	Claystone (silty), dark grey, bituminous, very fossiliferous (bivalves abundant, probably <i>Rhaetavicula sp.</i>)
971.90 – 972.10 m	Bioclastic limestone (sandy) (wackestone and packstone, biomicrite; thin section TRU1-1-972.00), light grey, very fossiliferous (bivalves, gastropods)
972.10 – 973.00 m	Claystone similar to that at the top but additionally flaser-bedded with laminae of siltstone (argillaceous), white
973.00 – 973.09 m	Conglomerate, calcareous (polymict), with lithoclasts of dolostone and limestone with abundant pyrite, above abundant pyritised bioclasts of bivalves

3.8.1.2 Gruhalde Member (upper part), 973.09 – 989.64 m (16.55 m)

The upper part of the Gruhalde Member is characterised by non-laminated dolomitic marl of a grey to reddish and brown colour (Jordan et al. 2016). These overbank sediments can be interrupted by channels often filled with dolomitic marl or dolostone.

In TRU1-1, non-laminated dolomitic marl shows grey and green shades in contact with the other lithologies of the members above and below. In between, the unit is mainly dark reddish brown.

The *upper boundary* is set at 973.09 m at an erosional surface. The basal conglomerate of the Belchen Member is underlain by the greyish green and homogeneous dolomitic marls of the Gruhalde Member.

The *lower boundary* is set at 989.64 m at an erosional surface. It separates the greenish grey dolomitic marl from the breccia (dolomitic), of the Seebi Member below. The transition is well evidenced by petrophysical logs, e.g. by a significant drop in the GR log readings.

Lithology (cuttings section from 973.34 – 978.00 m)

973.09 – 978.00 m	From 973.09 m to 973.34 m: Dolomitic marl to dolostone (argillaceous), medium grey to greyish green From 973.34 m to 978.00 m: Cuttings section; dolomitic marl, the colour changes gradually downwards from grey shades to predominantly dark reddish brown
978.00 – 987.53 m	Dolomitic marl (slightly silty to silty), dark reddish brown. Dolomite nodules and conglomeratic layers of subangular to rounded clasts of dolomitic marl are found at different levels, the latter possibly as synsedimentary or early diagenetic collapse breccia
987.53 – 989.64 m	Dolomitic marl (silty to sandy; thin section TRU1-1-988.32), light greenish grey, very pyritic, with lenses and some laminae (max. 2 mm) of dolostone (silty to sandy). The base is covered with angular dolostone clasts

3.8.1.3 Seebi Member, 989.64 – 1'003.95 m (14.31 m)

The Seebi Member was deposited on an alluvial plain and covers a wide range of lithofacies types from overbank fines and lacustrine carbonates to fluvial bed-load sediments (Hornung & Aigner 2002). The sediments are often organised in shallowing-upward cycles with coarse sandstone as channel infills at the base and lacustrine dolostone at the top (e.g. Etzold et al. 2010).

In TRU1-1, the Seebi Member consists lithologically of two parts. The upper part comprises a succession of dolostone, which is mainly developed either as *rauhwacke* or as breccia, suggesting a rock of evaporitic origin. Dolomitic sandstone with interbedded dolostone prevail in the lower part, pointing to sedimentation in a fluvial environment.

The *upper boundary* is set at 989.64 m at an erosional surface. The sharp boundary separates the greenish grey dolomitic marl of the Gruhalde Member (upper part) from brecciated dolostone. The transition is reflected by sharp changes in the petrophysical logs.

The *lower boundary* is set at 1'003.95 m at an erosional surface. It separates the succession of greenish grey dolomitic sandstone of the basal Seebi Member from the variegated argillaceous marl (silty) of the lower part of the Gruhalde Member. This transition, again, causes significant changes in the readings of the petrophysical logs.

Lithology

989.64 – 991.01 m	Intraformational breccia, dolomitic (monomict), with reworked dolocrete nodules in a matrix of dolomitic marl, light greenish grey, at the base interbedded with dolostone with many vugs
991.01 – 997.00 m	<i>Rauhwaacke</i> with breccia-like texture and frequent large vugs (max. 10 cm), rarely laminated; variegated from dark grey to pale pink due to abundant clasts of laminated dolostone (thin section TRU1-1-992.67), less commonly of sandstone and limestone (packstone, micrite) in a matrix of dolomitic marl
997.00 – 999.20 m	Dolostone (predominantly sandy), light beige to beige, massive
999.20 – 1'001.00 m	Alternation of predominantly sandstone and dolostone: • sandstone: sandstone (medium- to coarse-grained) (dolomitic), light greenish grey, quartz, rounded lithoclasts of claystone and intraclasts of dolostone (thin section TRU1-1-999.87), poorly sorted and moderately cemented • dolostone: dolostone (sandy), beige
1'001.00 – 1'003.95 m	Succession of sandstone (slightly dolomitic to dolomitic), in the lower part interbedded by thin (max. 3 cm) layers of claystone, variegated: • sandstone: sandstone (coarse-grained to pebbly), pale pink to light greenish grey, quartz abundant, feldspar sparse and rounded lithic fragments of claystone (thin section TRU1-1-1003.02), very poorly to poorly sorted, medium bedded, well cemented (quartz)

3.8.1.4 Gruhalde Member (lower part), 1'003.95 – 1'013.39 m (9.44 m)

The lower part of the Gruhalde Member does not usually show major differences to its upper part. The colours of the dolomitic marl vary considerably, but it often contains an interval with mainly reddish shades in the lower part (Jordan et al. 2016). Sparse interbeds of dolostone, partly with a large variety of components, can interrupt the uniform succession.

In TRU1-1, the lithology is fairly uniform. The interval is mainly composed of argillaceous marl (silty), in contrast to the Gruhalde Member (upper part) which consists of dolomitic marl. The succession predominantly shows a dark reddish-brown colour. It may correlate with the «Rote Wand», an important regional marker throughout north-eastern Switzerland and southern Germany.

The *upper boundary* is set at 1'003.95 m at an erosional surface underneath the sandstone (dolomitic) of the Seebi Member. Beneath, the argillaceous marl (silty) of the Gruhalde Member (lower part) sets in.

The *lower boundary* is set at 1'013.39 m at an erosional surface. This is the top surface of the massive anhydrite bed of the underlying Gansingen Member.

Lithology

1'003.95 – 1'013.39 m The main lithology is a non-laminated argillaceous marl (silty). In contact with other lithologies, it is light greenish grey to greyish blue green, otherwise dark reddish brown. The interval is interspersed by dolostone beds which are mostly of the same colour as the argillaceous marl. The dolostone is arranged in thin (< 10 cm) layers of nodules which are partly silicified to cherts. Towards the base, the dolostone nodules are coalesced into a few continuous beds of thicknesses greater than 10 cm

The uniform succession is interrupted by a conspicuous conglomerate from 1'006.52 m to 1'006.91 m with an erosional surface at its base. It is dolomitic (polymict), variegated and rippled. It consists of rounded clasts of dolostone and claystone (thin section TRU1-1-1006.80). The clasts are serrated into each other

3.8.1.5 Gansingen Member, 1'013.39 – 1'015.49 m (2.10 m)

The Gansingen Member is one of the most prominent lithostratigraphic marker beds of the Klettgau Formation. It testifies to a marine ingression from the west with a strong lateral variation of lithofacies in an E-W direction (Jordan et al. 2016). For the ZNO region, the member was predicted to be thin and evaporitic. Despite its lithological heterogeneity, the member is also conspicuous in the petrophysical logs by distinctive peaks and notches of the readings.

TRU1-1 drilled a massive anhydrite bed as the Gansingen Member. The marker bed is bounded by erosional contacts both at the top and at the base. It is also visible in the petrophysical logs.

The *upper boundary* is set at 1'013.39 m at an erosional surface. This is the top surface of the massive anhydrite bed of the Gansingen Member. It is overlain by the argillaceous marl (silty) of the Gruhalde Member (lower part).

The *lower boundary* is set at 1'015.49 m at an erosional surface. It is the base of the lowermost thick anhydrite bed of the Gansingen Member. Beneath, the variegated argillaceous marl of the Ergolz Member prevails with thin interbeds of anhydrite.

Lithology

1'013.39 – 1'014.74 m Anhydrite (alabastrine), very light grey and white, with mm-sized seams of anhydrite (not alabastrine), beige, laminated in the upper part, laminated to crenulated and nodular in the lower part

1'014.74 – 1'015.49 m Claystone (dolomitic), reddish brown to pale green, in laminated alternation with anhydrite, very light grey to white; boundaries between both lithologies partly crenulated

3.8.1.6 Ergolz Member, 1'015.49 – 1'027.22 m (11.73 m)

The Ergolz Member comprises a wide variety of lithologies. It reflects sedimentation in a fluvial to lacustrine depositional environment (e.g. Jordan et al. 2016). If fully developed, the sedimentary column of the Ergolz Member preserves the threefold repetition of erosion and accumulation (Hagdorn & Nitsch 2009).

In TRU1-1, the Ergolz Member is composed of sandstone, argillaceous marl, claystone and thin interbeds of anhydrite close to the top as well as sandy marl at the base.

The *upper boundary* is an erosional surface at 1'015.49 m. The variegated argillaceous marl of the Ergolz Member below is superseded by the lowermost anhydrite bed of the Gansingen Member above. The observed thin interbeds of anhydrite in the uppermost Ergolz Member of TRU1-1 are also quite common elsewhere.

The *lower boundary* is an erosional surface at 1'027.22 m. It is the top of the uppermost anhydrite bed of the Bänkerjoch Formation below. The upper part of the Bänkerjoch Formation often comprises claystone, dolostone and marls with a considerable silt content. The occurrence of sandy marl above the erosional surface clearly signals its affiliation to the Ergolz Member of the Klettgau Formation.

The sediments are organised vertically in a repetitive way. This allows the drilled lithology to be organised into three informal units, each with an erosional surface at the base. These informal units may correspond to sedimentary cycles, each with a fining-upward trend.

1'015.49 – 1'020.31 m Upper sandstone to marl succession, with interbeds of anhydrite close to the top

1'020.31 – 1'025.50 m Lower sandstone to marl succession

1'025.50 – 1'027.22 m Basal layer of sandy marl

Lithology

- 1'015.49 – 1'017.83 m Argillaceous marl (dolomitic), variegated (dark brown to dark reddish brown, greyish green and white). The argillaceous marl is interbedded by nodular layers of anhydrite, white
- 1'017.83 – 1'020.31 m Sandstone (fine-grained), fining upward from silty and crossbedded to argillaceous and laminated, mainly light greenish grey, quartz and claystone clasts, clayey matrix, well sorted, micaceous, moderately cemented, at the base cemented by anhydrite (thin section TRU1-1-1'020.30), with plant rootlets.
- The base is erosional with load casts
- 1'020.31 – 1'024.45 m Predominantly argillaceous marl (silty, dolomitic), light greenish grey and reddish brown, partly micaceous, burrowed; close to the base a rippled sandstone bed (fine-grained) (argillaceous), light grey, cross-bedded, moderately cemented (dolomite?)
- 1'024.45 – 1'025.50 m Sandstone (fine-grained) (argillaceous), light grey, well sorted, rippled, moderately cemented; in laminated to flaser-bedded alternation with claystone (silty), both lithologies micaceous
- The base is erosional
- 1'025.50 – 1'027.22 m Sandy marl (silty), greyish blue green, increasingly micaceous towards the base
- The top and the base are erosional

3.8.2 Bänkerjoch Formation, 1'027.22 – 1'084.01 m (56.79 m)

The Bänkerjoch Formation is a cyclic succession of sulphate sediments, interbedded by dolomitic marls, dolostones and sandstones, which partly hold the rank of regional marker beds (Jordan et al. 2016).

The *upper boundary* is set at 1'027.22 m at the top of the uppermost important, i.e. rock (co-)forming, occurrence of anhydrite.

The *lower boundary* is set 1'084.01 m at the base of the last significantly anhydritic rock coinciding with the top of the uppermost massive dolostone of the Asp Member of the Schinznach Formation.

Lithostratigraphic subdivision

There is as yet no formal subdivision of the Bänkerjoch Formation. The informal subdivision based on earlier core records of Nagra (Dronkert et al. 1990, Nagra 2001a) is proposed by Jordan & Deplazes (2019) to be used for the current campaign. The upper four of a total of five subunits could be recognised in TRU1-1. The lowermost part of the formation does not fit into the subunit «Dolomite and anhydrite». The abundance of anhydrite in the lowermost part of the formation indicates that the fourth subunit «Banded massive anhydrite» extends as far as the base of the Bänkerjoch Formation.

- 1'027.22 – 1'040.30 m «Claystone with anhydrite nodules» (13.08 m) including «Marker Horizon I» («Quarzitische Bank») from 1'039.86 m to 1'040.30 m
- 1'040.30 – 1'062.24 m «Cyclic sequence» (21.94 m)
- 1'062.24 – 1'077.33 m «Thin-layered anhydrite and claystone sequence» (15.09 m) including the possible «Marker Horizon II» from 1'071.94 m to 1'073.63 m
- 1'077.33 – 1'084.01 m «Banded massive anhydrite» (6.68 m)

Lithology

«Claystone with anhydrite nodules», 1'027.22 – 1'040.30 m (13.08 m)

This unit is lithologically the most heterogeneous of the formation. It consists mainly of silty claystone (anhydritic or dolomitic) of grey shades, less commonly of pale green and pale pink colour. Interbeds of anhydrite and dolostone (anhydritic) to dolomitic marl occur with decreasing frequency.

The anhydrite is formed as single nodules of varying sizes (mm to larger than core diameter), veins and as layers of densely packed nodules with bed thicknesses up to several dm. The several cm wide veins exhibit sharp boundaries to the claystone. They form a dense mesh when occurring in large numbers.

The beds of dolostone (anhydritic), medium grey to greenish grey, are concentrated in the middle part of the unit. The beds of dolomitic marl (silty), light grey, are interbedded at the base of the unit. The lowermost dolomitic marl layer may correspond to the «Marker Horizon I» («Quarzitische Bank») of Jordan et al. (2016).

«Cyclic sequence», 1'040.30 – 1'062.24 m (21.94 m)

The unit consists mainly of anhydrite with varying fabrics and bedding: beds of densely packed nodules, laminated anhydrites with thin claystone intervals, massive anhydrite that lacks internal structures and anhydrite nodules organised in a chickenwire structure. Solitary nodules such as in «Claystone with anhydrite nodules» are much less abundant. Veins of anhydrite are exclusively developed in thicker interbeds of claystone (anhydritic). «Cyclic sequence» can be subdivided as follows (from top to base):

- 1'040.30 – 1'044.25 m Interval dominated by an alternation of beds consisting of densely packed anhydrite nodules with beds of claystone (anhydritic)
- 1'044.25 – 1'047.87 m Section where anhydrite increasingly prevails over the claystone (anhydritic). The anhydrite forms both nodular and laminated beds. The laminae and the contacts to thicker interbeds of claystone (anhydritic) are often crenulated to intensely deformed
- 1'047.87 – 1'062.24 m The interval displays complete and incomplete cycles. If complete, a cycle reaches a thickness of a few dm. Complete cycles include (from top to base):
- claystone (anhydritic), dark grey, with pink to white anhydrite veins, partly intersecting each other, some folded; very few solitary anhydrite nodules

- nodular to laminated beds of anhydrite, white, alternating with interbeds of claystone, dark grey, very subordinate with dolomitic marl, dark greyish brown (thin section TRU1-1-1055.52). The interbeds commonly reach thicknesses of some 0.5 m
- chickenwire anhydrite, white, consisting mostly of mm – cm sized anhydrite nodules, in a matrix of claystone (anhydritic), dark grey, to claystone, black

«Thin-layered anhydrite and claystone sequence», 1'062.24 – 1'077.33 m (15.09 m)

This unit comprises four intervals which differ in lithology and textures:

1'062.24 – 1'068.03 m Predominance of anhydrite over claystone as above, but less cyclic, comprising:

- anhydrite (argillaceous), white to light grey, laminated by thin interbeds of claystone, dark grey
- claystone, dark grey, with anhydrite veins and laminated by thin layers of anhydrite (argillaceous), white to light grey
- anhydrite, white to light grey, partly bedded as densely packed nodules or in chickenwire structure

The base (1'068.03 m) is an erosional surface covered with intraclasts of claystone. It coincides with a sharp change in colour from dark grey and white above to shades of generally pale violet below the erosional surface

1'068.03 – 1'071.94 m Predominantly argillaceous marl (dolomitic), originally pale violet, in the upper part characteristically bleached to pale green, with intercalations of:

- from 1'068.03 m to 1'068.14 m, 1'070.19 m to 1'070.42 m and from 1'071.07 m to 1'071.68 m: three interbeds of dolomitic marl, pale green and pale violet, with nodules of anhydrite, white. The lowermost (thickest) interbed of dolomitic marl is interbedded with thin (max. 7 cm) layers of anhydrite, white
- from 1'068.57 m to 1'068.70 m, 1'069.02 m to 1'069.10 m and from 1'069.37 m to 1'070.14 m: three layers of breccia, dolomitic (monomict), consisting of clasts of argillaceous marl (dolomitic)

1'071.94 – 1'073.63 m Cyclic alternation (three-fold) of normally graded units of dolostone to dolomitic marl at the top, passing downwards gradually into sandy claystone and partly to sandstone (fine- to medium-grained) (argillaceous), with sub-rounded grains, poorly sorted, poorly cemented

Each cycle starts atop the dolostone or dolomitic marl with a thin layer of breccia, dolomitic (polymict), with clasts from all lithologies

The base is an erosional surface. It coincides with a sharp change in colour from the variegated succession above to white anhydrite below. The bedding is considerably inclined below the erosional surface but horizontal above

The interval could correspond to the «Marker Horizon II» in the classification scheme of Jordan et al. (2016)

1'073.63 – 1'077.33 m Inclined succession of anhydrite (argillaceous), white, laminated or interbedded by claystone (anhydritic), dark reddish brown and greyish green. The anhydrite beds are nodular close to the top. In turn, the thicker (max. 50 cm) interbeds of claystone (anhydritic) contain thin (< 10 cm) layers of anhydrite (argillaceous)

«Banded massive anhydrite», 1'077.33 – 1'084.01 m (6.68 m)

This unit shows by far the highest amount of anhydrite in the entire Bänkerjoch Formation. It contains the thickest beds of massive (i.e. featureless) anhydrite. Two specific features are a 65 cm-thick dolostone bed (brecciated at the base) in the upper part (from 1'078.01 m to 1'078.67 m) and a 2.5 m-thick breccia in the middle part (from 1'079.50 m to 1'082.00 m). This breccia blurs the integration of this interval into the classification scheme of Dronkert et al. (1990). Besides, it prevents an unequivocal recognition of an additional marker bed. Due to the occurrence of the breccia, the unit is best described by three intervals:

- 1'077.33 – 1'079.50 m Two massive beds of anhydrite, white, separated by a 50 cm-thick bed of dolostone (argillaceous), beige grey. The massive anhydrite contains rare streaks of anhydrite (argillaceous). The dolostone bed is underlain by a thin breccia of dolostone clasts
- 1'079.50 – 1'082.00 m Breccia, anhydritic (polymict), consisting of clasts of massive and laminated anhydrite, white, and dolostone, beige grey, laminated. Both clast types are frequently larger than the core diameter
- 1'082.00 – 1'084.01 m Predominantly beds of anhydrite, white, and anhydrite (argillaceous), light beige to beige, the latter partly dolomitised. The beds are partly convoluted. Both lithologies occur as folded laminae in the other lithology and together with folded laminae of claystone (dolomitic). In the lower part, dispersed clasts of dolostone, white, and of claystone (dolomitic), dark grey, are found

The beds above the breccia are still inclined. Below the breccia, the beds are subhorizontal. Thus, the inclined beds reach across the «Thin-layered anhydrite and claystone sequence» and «Banded massive anhydrite» from the erosional surface at 1'073.63 m to the top of the breccia at 1'079.50 m.

3.9 Muschelkalk Group

3.9.1 Schinznach Formation, 1'084.01 – 1'154.25 m (70.24 m)

The Schinznach Formation shows some divergences from the various older stratigraphic schemes applied when recording boreholes in earlier Nagra and Nagra-accompanied campaigns. The following record follows the recent formal scheme. Pietsch et al. (2016) and Jordan & Deplazes (2019) give a correlation with older records.

The *upper boundary* is set at the base of the lowermost significantly anhydritic bed of the Bänkerjoch Formation at 1'084.01 m, coinciding with the top of the uppermost massive dolostone of the Schinznach Formation.

The *lower boundary* is set, according to Jordan (2016) at 1'154.25 m, at the base of the lowermost limestone bed.

3.9.1.1 Asp Member, 1'084.01 – 1'090.46 m (6.45 m)

The Asp Member consists mainly of dolostone with intervals of *rauhwacke* in the upper half and fossiliferous bituminous shales with thin dolostone interbeds in the lower half (Pietsch et al. 2016).

TRU1-1 drilled through the twofold composition. The topmost layer of the Asp Member is brecciated, as often observed in outcrops and boreholes (e.g. Merki 1961).

The *upper boundary* is set (in accordance with the upper boundary of the Schinznach Formation) at the base of the lowermost significantly anhydritic bed of the Bänkerjoch Formation at 1'084.01 m. It coincides with the top of the uppermost massive dolostone bed of the Asp Member.

The *lower boundary* is set, following Pietsch et al. (2016), at 1'090.46 m at the erosional base of the lowest (thin) bituminous shale layer.

Lithology

- | | |
|-----------------------|---|
| 1'084.01 – 1'085.14 m | Breccia, dolomitic (monomict), pyritic, poorly sorted, with dolostone clasts, white, matrix supported by dolomitic marl, dark grey |
| 1'085.14 – 1'087.61 m | Dolostone, dark beige to beige, mainly massive (i.e. without internal texture), in sections anhydrite nodules, white, in varying frequency from sparse to abundant and, close to the base, two brecciated layers with clasts of dolostone and claystone, the upper one with mudcracks filled with anhydrite |
| 1'087.61 – 1'090.46 m | <p>From 1'087.61 m to 1'089.94 m: Bituminous shale, dark grey, pyritic, in the lower part laminated by abundant coquina (bivalves, fish remains, plant remains), white, overall light grey; close to the top dolostone bed (15 cm), beige grey</p> <p>From 1'089.94 m to 1'090.46 m: Bituminous shale, dark grey, pyritic, in alternation with dolostone beds, very light grey, pyritic, partly bioturbated; lowermost dolostone bed bioturbated and the uppermost part of this bed as breccia, dolomitic (polymict), with intraclasts and flakes and seams of claystone; top of each dolostone bed and the base of the whole interval as erosional surface</p> |

3.9.1.2 Stamberg Member, 1'090.46 – 1'119.16 m (28.70 m)

The Stamberg Member is a thick succession of dolostone in the upper part of the Schinznach Formation (Pietsch et al. 2016). In the past, the lower boundary of the unit was defined in different ways. The concept for the delineation of the Stamberg Member applied here is a purely petrographic approach. It is defined by the lower boundary of post-sedimentary, persistent and complete dolomitisation (commonly of an initially at least partly marine limestone).

The Stamberg Member in TRU1-1 shows a rather uniform succession of dolostone but a vertical variation in texture. In the upper part there is a medium- to thick-bedded alternation of massive (i.e. featureless) dolostone with its laminated equivalents. Vugs (partly filled with anhydrite) occur more often in the massive dolostone, which can lend a breccia-like appearance to the rock. Farther down, the uniform dolostone succession is terminated by oolitic beds (Eptingen Bed). Slightly deeper down, there is a change to bedded dolostone and dolomitic marl with seams of claystone which lend a platy texture to the rock. This interval is almost devoid of vugs. Macro-fossils are virtually absent except in the oolitic interbeds.

The *upper boundary* is set, following Pietsch et al. (2016), at 1'090.46 m, at the base of the lowest (thin) bituminous shale layer.

The *lower boundary* is set at 1'119.16 m at the lower boundary of the persistent and complete (secondary) dolomitisation. It coincides with a sharp change in colour from medium grey above to the beige colour of the Liedertswil Member below. The very sharp boundary is also visible in the FMI and the density-neutron readings.

In the formal stratigraphic scheme, two oolitic intervals may be included in the Stamberg Member (Pietsch et al. 2016): the Kaisten Bed in the upper part and the Eptingen Bed in the lower part. In the present section, the Kaisten Bed was not recognised. The interval from 1'101.21 m to 1'107.12 m, however, may correspond to the Eptingen Bed.

Lithology

- | | |
|-----------------------|---|
| 1'090.46 – 1'096.84 m | Dolostone, beige grey to light grey, internally featureless, medium-bedded by stylolites, open vugs abundant (max. 3 cm), at the top slightly brecciated with bituminous clay drapes |
| 1'096.84 – 1'101.21 m | Dolostone as above but internally laminated, abundant vugs (max. 5 cm) partly filled with anhydrite, white |
| 1'101.21 – 1'107.12 m | Dolostone as in the top interval but with interbeds of oolitic dolostone, fossiliferous (bivalves, gastropods; thin section TRU1-1-1103.66), very light grey to medium light grey, solitary to abundant peloids, bivalves in the lowermost bed of oolitic dolostone; vugs frequent, concentrated in layers (max. 1 cm) filled with anhydrite, white

The occurrence of ooids points to the Eptingen Bed |
| 1'107.12 – 1'109.20 m | Dolostone, beige grey, abundant peloids, irregularly wavy-bedded by mm- to cm-thick layers of claystone and argillaceous marl; with smaller (max. 1 cm) and less frequent vugs than above, filled with anhydrite, white |

- 1'109.20 – 1'116.89 m Dolostone, beige grey, towards the base (1'116.89 m) transition to medium grey, pyritic, thin- to medium-bedded, partly nodular texture due to bioturbation from weak to moderate, vugs still decreasing in size and number downwards, finally disappearing at about 1'115.00 m; with mm-thick layers of claystone, black, and of dolomitic marl, dark grey, layers increasing in number towards the base (1'116.89 m); with thin layers of breccia, dolomitic (polymict), with clasts (several mm) of dolostone and claystone
- 1'116.89 – 1'119.16 m Dolostone in transition to dolomitic marl, medium grey with nodular patches of grey beige, bioturbated

3.9.1.3 Liedertswil Member, 1'119.16 – 1'131.33 m (12.17 m)

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

In TRU1-1, the Liedertswil Member is a succession of micritic limestone with a repetitive variation of abiogenic components, especially peloids. The fossil content is restricted to bivalves, both solitary and concentrated in a few layers. The succession is well-bedded in contrast to the dolomitised equivalents above (Stamberg Member).

The *upper boundary* is set at 1'119.16 m at the base of a fully dolomitised rock. This coincides with a sharp change in colour. The medium grey dolostone of the Stamberg Member above is underlain by beige limestone. The boundary is also detectable in the readings of the FMI and density-neutron log combination.

The *lower boundary* is set at 1'131.33 m according to the formal stratigraphic scheme (Pietsch et al. 2016) at the uppermost bed consisting of more than 10% crinoids. In the present core, this bed is found from 1'131.33 m to 1'131.71 m. The uppermost occurrence of crinoids in the Schinznach Formation is observed from 1'123.23 m to 1'123.29 m.

Lithology

- 1'119.16 – 1'125.88 m Limestone, beige, irregularly thin- to medium-bedded, representing an alternation of:
- limestone (mudstone, micrite)
 - limestone (mudstone and wackestone, pelmicrite)
 - limestone (wackestone and packstone, intramicrite)
- Some basal surfaces of the alternation are erosional. Towards the base of the interval (1'125.88 m), the thicknesses of the wackestone and packstone are less than 10 cm
- 1'125.88 – 1'131.33 m Limestone, beige, irregularly thin- to medium-bedded by clustered seams and layers (mm – cm) of claystone, dark grey, representing an alternation as in the interval above but the wackestone and packstone (biomicrite) is less persistent

3.9.1.4 Kienberg and Leutschenberg Members, 1'131.33 – 1'154.25 m (22.92 m)

According to Jordan & Deplazes (2019), the upper Kienberg and the lower Leutschenberg Members should be combined because separation is often difficult. Generally, both members consist of limestone with very little clay content and a varying content of biogenic components. However, the Kienberg Member is particularly enriched in crinoids and shell debris, both concentrated in bioclastic limestone.

The *upper boundary* is set at 1'131.33 m at the top of the uppermost bed which consists of more than 10% crinoids (Pietsch et al. 2016).

The *lower boundary* is set at 1'154.25 m at the base of the lowermost limestone bed according to Jordan (2016). Beneath, the succession of laminated dolostone beds with the typical beige grey colour and chert nodules sets in, which is typical of the underlying Zeglingen Formation. The dolostones were deposited in an upper tidal to supratidal environment. A similar bed of dolostone already occurs above the lowermost limestone. However, this dolostone contains ooids (thin section TRU1-1-1153.72) which point to deposition at the shoreface.

Lithology

1'131.33 – 1'141.09 m Alternation of:

- limestone (mudstone, biopelmicrite), very light grey to light grey, laminated, partly bioturbated
- limestone (argillaceous) (mudstone, micrite), beige grey, bioturbated; with wavy clay drapes between the beds
- bioclastic limestone (wackestone and packstone, biosparite to biomicrite), beige grey, fine-grained with white biogenic components (mainly crinoids ["Echinodermenbrekzie"], brachiopods, bivalves). The fossils are normally graded both in size and content
- bioclastic limestone as above but coarse-grained

The bioclastic limestone is generally the thinnest limestone type (max. 15 cm) of all those mentioned above. The basal surface of a bioclastic limestone bed is often bored

1'141.09 – 1'146.22 m In contrast to the interval above, a more uniform succession of limestone (argillaceous) (mudstone, micrite), beige grey, laminated to irregularly wavy-bedded by mm-thick layers of claystone, dark grey.

At the top (from 1'141.09 m to 1'141.32 m), a biomicritic limestone bed with a bored upper surface contains bivalves and brachiopods but no crinoids or any other echinoderms. As there is an intermission of bioclastic limestone beds with crinoids below 1'141.09 m over a depth interval of several metres, the bed may correspond to the Saalhof Bed

1'146.22 – 1'151.38 m Succession of limestone beds (mudstone and wackestone, biopelmicrite), light grey to beige grey, with a varying content of peloids and fossils (mostly crinoids, less biotritus), fossils inversely graded in both size and number, bioturbated

Conspicuous features are two beds (10 cm, 15 cm) of bioclastic limestone (packstone, biosparite to biomicrite), light grey, as the lowermost occurrences of crinoid-rich layers ("Echinodermenbrekzie")

- 1'151.38 – 1'152.63 m From 1'151.38 m to 1'152.05 m: Oncolitic limestone, beige grey, microbial-encrusted lithoclasts or fossils.
- From 1'152.05 m to 1'152.63 m: Limestone (mudstone and packstone, oncomicrite) with oncoids, crinoids and bivalves, oncoids and crinoids increasing in number from top (1'152.05 m) to base (1'152.63 m) but oncoids are less abundant than in the overlying section
- At the base, the lowermost occurrence of single crinoids within the Schinznach Formation is found
- 1'152.63 – 1'154.25 m From 1'152.63 m to 1'153.67 m: Limestone (wackestone and packstone, oncomicrite), dark greyish brown, oncoids inversely graded (from a maximum at the top [1'152.63 m], vanishing rapidly towards the base), with ooids at the base (thin section TRU1-1-1153.62), fossiliferous (bivalves, gastropods); open vugs abundant, interpreted as dissolved anhydrite nodules
- Due to the occurrence of ooids, the limestone bed may correspond to the Fützen Bed
- From 1'153.67 m to 1'154.05 m: Dolostone bed (calcareous), beige grey, with ooids and peloids in a micritic matrix but partly cemented by sparite (thin section TRU1-1-1153.72), laminated microbial mats
- From 1'154.05 m to 1'154.25 m: Limestone bed (mudstone, micrite), light grey, open vugs frequent

3.9.2 Zeglingen Formation, 1'154.25 – 1'204.5 m (about 50.25 m)

The Zeglingen Formation (Jordan 2016) is an evaporate sequence. In TRU1-1, there was a change from core to destructive drilling at 1'160.99 m. A rock salt layer («Salzlager») is missing in the borehole. The anhydrite-dominated succession («Sulfatzone») shows an exemplary cyclic sedimentation which fits well with the observations in adjacent boreholes (e.g. Nagra 2001a). A cycle starts with a claystone at its base and passes gradually into an anhydrite at the top which is often brecciated or covered by teepees.

The *upper boundary* is set at 1'154.25 m at the base of the lowermost limestone bed of the overlying Schinznach Formation. Beneath, the beige and laminated dolostone of the upper Zeglingen Formation sets in.

The *lower boundary* is set at 1'204.5 m based on FMI where the lowermost thick succession of massive and white anhydrite quite sharply overlies the dolomitic marl and dolostone showing various shades of grey and marking the top of the Kaiseraugst Formation.

Lithostratigraphic subdivision

There is no formal subdivision of the Zeglingen Formation. The traditional subdivision into four informal units (*cf.* Jordan & Deplazes 2019) relies on the occurrence of salt. It separates the succession of anhydrite into an upper unit above the salt («Obere Sulfatzone») and a lower unit below the salt («Untere Sulfatzone»). As rock salt is missing, both units are unified to a single «Sulfatzone»:

1'154.25 – 1'164.0 m «Dolomitzone» (9.75 m)

1'164.0 – 1'204.5 m «Sulfatzone» (40.5 m)

The boundary between the two subunits is drawn at the top of the uppermost thick (1.30 m) anhydrite bed of the «Sulfatzone».

The lithological composition of the «Sulfatzone» reflects its cyclic sedimentation. Intervals of massive anhydrite alternate with intervals which are composed of an internal alternation of anhydrite and claystone. The succession is interrupted by a characteristic interval of dolomitic marl and dolostone below the massive anhydrite bed at the top (1'164.0 m).

Lithology

«Dolomitzone», 1'154.25 – 1'164.0 m (about 9.75 m), cuttings section 1'161.03 – 1'164.0 m

1'154.25 – 1'160.99 m Characteristically uniform succession of dolostone (calcareous), beige grey, laminated by microbial mats, with chert nodules dispersed or densely concentrated in intervals; close to the base a bed (15 cm) of anhydrite, white, massive (i.e. featureless); dolostone bed above the anhydrite bed with vugs

1'160.99 – 1'164.0 m Dolostone, beige grey, laminated; subordinate anhydrite (dolomitic), white, massive (i.e. featureless)

«Sulfatzone», 1'164.0 – 1'204.5 m (about 40.5 m), cuttings section

1'164.0 – 1'165.3 m Anhydrite in transition to anhydrite (argillaceous), very light grey to medium grey, massive (i.e. featureless)

1'165.3 – 1'168.0 m Characteristic interval of dolomitic marl, medium light grey, in the upper part with beds of dolostone (partly argillaceous), beige grey and medium grey; both lithologies bedded by thin layers of claystone (dolomitic), dark grey

1'168.0 – 1'174.7 m Anhydrite, white, massive (i.e. featureless); with two interbeds (50 cm and 60 cm) of anhydrite (argillaceous), very light grey to medium grey, rarely beige grey, laminated by claystone (anhydritic)

1'174.7 – 1'178.9 m At the top and at the base predominantly claystone (anhydritic), dark grey, with laminae of anhydrite, white, separated by an interval in between with anhydrite, white and anhydrite (argillaceous), very light grey to medium grey

1'178.9 – 1'186.8 m	Alternation of anhydrite (argillaceous, partly dolomitic), very light grey to medium grey, beige grey and anhydrite, white; some thin streaks of claystone (anhydritic), dark grey and of dolomitic marl, medium light grey
1'186.8 – 1'192.0 m	Anhydrite, white, massive (i.e. featureless); only sparse laminae of anhydrite (argillaceous), very light grey to medium grey, rarely beige grey
1'192.0 – 1'200.1 m	Interval mostly dominated by anhydrite (argillaceous), very light grey to medium grey; three minor intervals (max. 90 cm) dominated by claystone (anhydritic), dark grey and one by anhydrite, white, massive (i.e. featureless)
1'200.1 – 1'204.5 m	Anhydrite, white, massive (i.e. featureless); an interbed (40 cm) of anhydrite (argillaceous), very light grey to medium grey

3.9.3 Kaiseraugst Formation, 1'204.5 – 1'233.2 m (about 28.7 m)

The Kaiseraugst Formation is a succession of claystone (calcareous, silty) to argillaceous marl (silty) in the upper part and dolomitic marl in the lower part (Jordan 2016). Interbeds of limestone, dolostone and sandstone can occur throughout the unit, the latter two particularly in the lowermost part of the formation. Some of the interbeds are lithostratigraphic marker horizons.

In TRU1-1, one observation worth mentioning specifically is an interval of calcareous marl which cuts the subunit «Wellenmergel» (s. lithostratigraphic subdivision below) approximately in half. The upper half of the «Wellenmergel» is more calcareous than the lower one. Furthermore, the «Wellendolomit» subunit shows approximately half of the thickness compared to surrounding boreholes.

The *upper boundary* is set at 1'204.50 m at the base of the lowermost massive anhydrite bed of the Zeglingen Formation. The dolomitic marl beneath is part of the Kaiseraugst Formation.

The *lower boundary* is set at 1'233.2 m at the transition from the calcareous sediments of the Kaiseraugst Formation above to the siliciclastic sediments of the Dinkelberg Formation below. The siliciclastic sediments are devoid of fossils and well cemented by quartz, which clearly identifies them as part of the Dinkelberg Formation.

Lithostratigraphic subdivision

There is no formal subdivision of the Kaiseraugst Formation. The traditional subdivision into three informal units and traditional informal marker beds (*cf.* Jordan & Deplazes 2019) can be applied to the present core:

1'204.5 – 1'210.3 m	«Orbicularismergel» (5.8 m) including «Geislingen Bed» from 1'208.5 m to 1'210.3 m
1'210.3 – 1'230.2 m	«Wellenmergel» (19.9 m), within the «Wellenmergel», most of the frequent lithostratigraphic marker beds could not be detected either in the cuttings or in the FMI
1'230.2 – 1'233.2 m	«Wellendolomit» (3.0 m)

The boundary between the «Orbicularismergel» and the «Wellenmergel» is drawn at the base of the massive anhydrite bed (in Germany known as the «Geislingen-Bed»). This delineation differs from the boundary definitions of other boreholes with cores in this stratigraphic interval (e.g. Becker et al. 1997, Nagra 2001a).

The boundary between the «Wellenmergel» and the «Wellendolomit» is fixed arbitrarily at the top surface of the uppermost dolomitic limestone bed of the «Wellendolomit».

Lithology (cuttings section)

«Orbicularismergel», 1'204.5 – 1'210.3 m (about 5.8 m)

1'204.5 – 1'206.8 m	Dolostone in transition to dolostone (argillaceous) and finally dolomitic marl (bituminous), medium light grey to medium grey
1'206.8 – 1'208.5 m	Argillaceous marl, medium grey, close to the base occurrence of anhydrite, white, possibly as nodules and fine layers in the argillaceous marl
1'208.5 – 1'210.3 m	Anhydrite, white («Geislingen-Bed»)

«Wellenmergel», 1'210.3 – 1'230.2 m (about 19.9 m)

1'210.3 – 1'212.1 m	Argillaceous marl, medium grey, with a few thin (< 10 cm) interbeds of calcareous marl, medium light grey
1'212.1 – 1'218.3 m	Argillaceous marl (silty), predominantly medium grey, micaceous, with thin (< 10 cm) layers of calcareous marl (silty), medium grey, micaceous and in the lower part two interbeds (10 cm, 20 cm) of limestone (micrite and sparite), white to very light grey
1'218.3 – 1'219.3 m	Calcareous marl (silty), medium light grey, micaceous, with thin (< 10 cm) layers of limestone (sparite), very light grey
1'219.3 – 1'230.2 m	Claystone (often calcareous, silty), medium to dark grey; close to the base laminae of sandstone (fine-grained) (calcareous), light grey, quartz well rounded, well sorted, moderately cemented

«Wellendolomit», 1'230.2 – 1'233.2 m (about 3.0 m)

1'230.2 – 1'233.2 m	Limestone (dolomitic) (sparite), beige grey and white, both at the top and at the base, separated by an interval of argillaceous marl in transition to calcareous marl, medium light grey to medium grey, micaceous
---------------------	---

3.10 Buntsandstein Group

3.10.1 Dinkelberg Formation, 1'233.2 – 1'246.1 m (about 12.9 m)

The Dinkelberg Formation consists of siliciclastics with a preponderance of sandstones. The sandstones display a high degree of compositional as well as textural maturity. Intervals dominated by claystone and conglomerates / breccias can also occur. In combination with the lithofacies, they are used to separate subunits of the formation. However, there is as yet no formal subdivision of the Dinkelberg Formation. Jordan (2016) suggests provisionally maintaining the traditional subdivision (from top): «Rötton», «Plattensandstein», «Vogesensandstein».

The cuttings of TRU1-1 document a succession of sandstone beds with a basal conglomerate. The lack of both stratigraphic marker horizons and of the characteristic vertical arrangement of certain lithofacies types prevents a lithostratigraphic subdivision of the unit. At least, the Dinkelberg Formation can be divided lithologically into three units for the description hereafter (from top to base).

1'233.2 – 1'239.7 m	Alternation of sandstone beds with varying grain sizes from fine- to coarse-grained, accompanied by a decreasing degree of cementation as the grain size increases
1'239.7 – 1'244.7 m	Sandstone with a more uniform grain size (fine- to medium-grained) and a moderate degree of cementation
1'244.7 – 1'246.1 m	Basal conglomerate

Remarkably, all sandstone beds show a white to light grey colour, probably due to bleaching of former reddish sandstone. The grey shades are typical of the siliciclastic sediments of the Wiesental Formation which is intermediate between the Dinkelberg Formation and the Weitenau Formation. However, the high degree of both structural and compositional maturity also contradicts the occurrence of the Wiesental Formation.

The *upper boundary* is set at 1'233.2 m at the top of the uppermost sandstone layer. The complete lack of fossils and the cementation by quartz in the sandstone identifies it as part of the Dinkelberg Formation.

The *lower boundary* is set at 1'246.1 m at an erosional surface below a conglomerate interpreted as the base of the Dinkelberg Formation. The sandstone of the Dinkelberg Formation shows a higher compositional and textural maturity than the siliciclastic sediments found below this erosional surface. The siliciclastic sediments of the Weitenau Formation are (sub)arkosic, with angular components of quartz and feldspar, poorly sorted, and cemented by different minerals (quartz, calcite) combined with a frequent clayey matrix. Above, the sandstone of the Dinkelberg Formation consists of rounded quartz, sparse mica and feldspar, respectively (e.g. Nitsch et al. 2017).

Most characteristic for the transition between the Dinkelberg Formation and the Weitenau Formation is the sharp increase from the low GR log rates in the Triassic Dinkelberg Formation to very high ones in the Permian Weitenau Formation. This change is caused by the abundant occurrence of feldspar in the Weitenau Formation.

Lithology (cuttings section)

1'233.2 – 1'236.7 m	Alternation of: • Sandstone (predominantly fine-grained) (calcareous), white to very light grey, subrounded quartz, well sorted, micaceous, well cemented (quartz) • Sandstone (predominantly medium-grained) (calcareous, argillaceous), white to very light grey, (sub)rounded quartz, well sorted, micaceous, poorly to moderately cemented • Sandstone (predominantly coarse-grained), white to medium light grey, (sub)angular quartz, moderately sorted, micaceous, poorly cemented
1'236.7 – 1'239.7 m	Alternation of: • Sandstone (predominantly coarse-grained), white to medium light grey, (sub)angular quartz, moderately to well sorted, micaceous, moderately cemented (quartz) • Sandstone (predominantly medium-grained, subordinate fine-grained), white to very light grey, (sub)rounded in the medium-grained fraction, well rounded in the fine-grained fraction, moderately to well sorted, micaceous, well cemented (quartz) • very subordinate in both lithologies lithic fragments of claystone, black
1'239.7 – 1'244.7 m	Sandstone (fine- to medium-grained) (partly argillaceous), white to medium light grey, subrounded quartz, moderately sorted, moderately cemented
1'244.7 – 1'246.1 m	Breccia, crystalline basement (polymict), white and red orange, abundantly subangular to subrounded fine pebbles (max. 1 cm) of altered granite, white, rare pebbles of gneiss, dark grey to black (a few mm)

3.11 Permo-Carboniferous sediments

3.11.1 Weitenau Formation, 1'246.1 – 1'259.7 m (about 13.6 m)

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

TRU1-1 drilled a sedimentary column of about 13.6 m between the overlying Dinkelberg Formation and the basement, which is categorised as the Weitenau Formation. It contains subarkosic to arkosic sandstones with a breccia interval in between.

The *upper boundary* is set at 1'246.1 m at an erosional surface overlain by the basal conglomerate of the Dinkelberg Formation. The boundary is also visible in the petrophysical logs as well as in the differences in the sandstone maturity, both compositional and textural.

The *lower boundary* is set at 1'259.7 m at the top of the leucosome. The boundary is sharp, i.e. a zone of weathered leucosome does not exist.

Lithology (cuttings section)

1'246.1 – 1'251.4 m	Sandstone (very fine- to coarse-grained) (argillaceous), arkosic, dark reddish brown, with angular plagioclase and prismatic hornblende (?), (sub)angular quartz, very poorly sorted, thick-bedded with thin layers of fine pebbles of altered granite at the base of a bed, poorly cemented
1'251.4 – 1'256.8 m	Breccia, crystalline basement (polymict), white close to the top, towards the base more red orange and dark reddish brown, mostly pebbles of granite with alteration of feldspar and mica to a varying degree, rarely gneiss as pebbles, smaller than the granite pebbles, very poorly cemented
1'256.8 – 1'259.7 m	Sandstone as from 1'246.1 m to 1'251.4 m

3.12 Crystalline Basement, 1'259.7 – 1'310.0 m (> 50.3 m)

The crystalline rocks consist of a granite migmatite. Advanced melting led to a layered alternation of:

- Mesosome ("Biotite-Plagioclase-Gneiss")
- Leucosome
- Melanosome consisting mainly of biotite.

The drilled section is composed mainly of the leucosome and melanosome. The boundaries between the different rock types are sharp.

1'259.7 – 1'265.9 m	Leucosome
1'265.9 – 1'276.4 m	Melanosome
1'276.4 – 1'279.6 m	Mesosome ("Biotite-Plagioclase-Gneiss")
1'279.6 – 1'284.2 m	Melanosome
1'284.2 – 1'285.2 m	Leucosome
1'285.2 – 1'286.2 m	Melanosome
1'286.2 – 1'295.8 m	Leucosome
1'295.8 – 1'306.9 m	Alternation of leucosome, melanosome and mesosome ("Biotite-Plagioclase-Gneiss")
1'306.9 – 1'310.0 m	Mesosome ("Biotite-Plagioclase-Gneiss")

Petrography

The different rock types do not show major differences in terms of composition and texture with depth.

Leucosome

Overall variegated from reddish to pink and grey, coarse-grained (partly larger than cuttings [max. 1 cm]), non-foliated, equigranular and non-porphyritic unaltered. Minerals in decreasing occurrence:

- quartz, xenomorphic, variegated
- plagioclase, xenomorphic, white
- alkali feldspar, xenomorphic to hypidiomorphic, reddish orange
- biotite, (hyp)idiomorphic (platy), black
- sparse muscovite, (hyp)idiomorphic (platy), transparent
- very sparse hornblende, (hyp)idiomorphic (prismatic), black

In the interval from 1'295.8 m to 1'306.9 m, the leucosome is slightly foliated.

Melanosome

Overall dark grey to black, mainly fine-grained (max. 1 mm), less medium-grained, banded, unaltered:

- predominantly biotite, hornblende, other minerals, all black, strongly foliated, mm-thick banded
- subordinate alkali feldspar with seams of biotite and sparse quartz, slightly foliated, mm-thick banded

The melanosome in the interval from 1'279.6 m to 1'286.2 m is completely disintegrated into mineral components.

Mesosome ("Biotite-Plagioclase-Gneiss")

Overall medium to dark grey, fine- to medium-grained, slightly banded, unaltered:

- both biotite and plagioclase abundant, slightly foliated, mm-thick banded
- sparse quartz and alkali feldspar in layers up to more than 1 cm in thickness, non-foliated to slightly foliated

4 Comparison with the forecast profile

Generally, there are only minor differences between the findings of TRU1-1 and the forecast profile (Nagra 2016; *cf.* Fig. 4-1). The latter is mainly based on the record of the nearby Benken borehole (Nagra 2001a):

- The Upper Marine Molasse Group (OMM) is thinner than expected. Its base was already reached at 50 m. As the base of loose rocks was deeper than predicted (24 m instead of 10 m), the total thickness of the OMM encountered was only 26 m and not 65 m.
- Within the «Brauner Dogger» succession (Dogger Group without Opalinus Clay), the 36 m thick «Parkinsoni-Württembergica-Schichten» are the dominant unit. Their relative thickness is greater than in the Benken borehole.
- Both evaporite successions, the Bänkerjoch and the Zeglingen Formations, are significantly thinner than expected (57 m and 50 m, respectively, instead of 90 m each).
- Below the Triassic Dinkelberg Formation, some 14 m of Weitenau Formation have been found. The Crystalline Basement was encountered some 50 m higher than expected.

The Upper Marine Molasse Group (OMM) was predicted to be glauconitic. This argument, the presence of glauconite, was used to delimit it from the underlying USM.

The lithofacies encountered within the Lower Freshwater Molasse Group (USM) are in line with expectations as far as it can be assessed by the analysis of the cuttings samples. There are no indications regarding the chronostratigraphic age of the encountered sediments. There are also no further arguments to distinguish a younger (Aquitanian) USM I from an older (Chattian) USM II.

The existence and the possible thickness of stratiform sediments of the Siderolithic Group was difficult to forecast. The actual thickness is about 4 m.

In the forecast profile, the upper limestone succession of the Malm Group is subdivided into «Bankkalke» + «Massenkalk» and «Felsenkalke» + «Massenkalk». Later it was proposed (Jordan & Deplazes 2019) to summarise all these rocks as «Felsenkalke» + «Massenkalk» and only to distinguish, within this informal unit, between «Felsenkalke» facies and «Massenkalk» facies. Facies and overall thickness of the now recorded «Felsenkalke» + «Massenkalk» correspond quite well with the predicted «Bankkalke» + «Massenkalk» and «Felsenkalke» + «Massenkalk». This also applies to the Schwarzbach Formation.

In the ZNO siting area, the Villigen Formation is expected to be dividable into the Wangental, Küssaburg and Hornbuck Members. In the absence of the separating «Knollen Bed», a glauconitic and nodular marker interval, the Wangental and Küssaburg Members could not be distinguished in TRU1-1. On the other hand, the Hornbuck Member could be clearly identified and delineated.

The Wildeggen Formation proved to be thinner (about 11 m) than expected. The largely condensed Birnenstorf Member and the underlying «Glaukonitsandmergel Bed» *sensu* Gygi (1977, 2000) are 2.7 m thick.

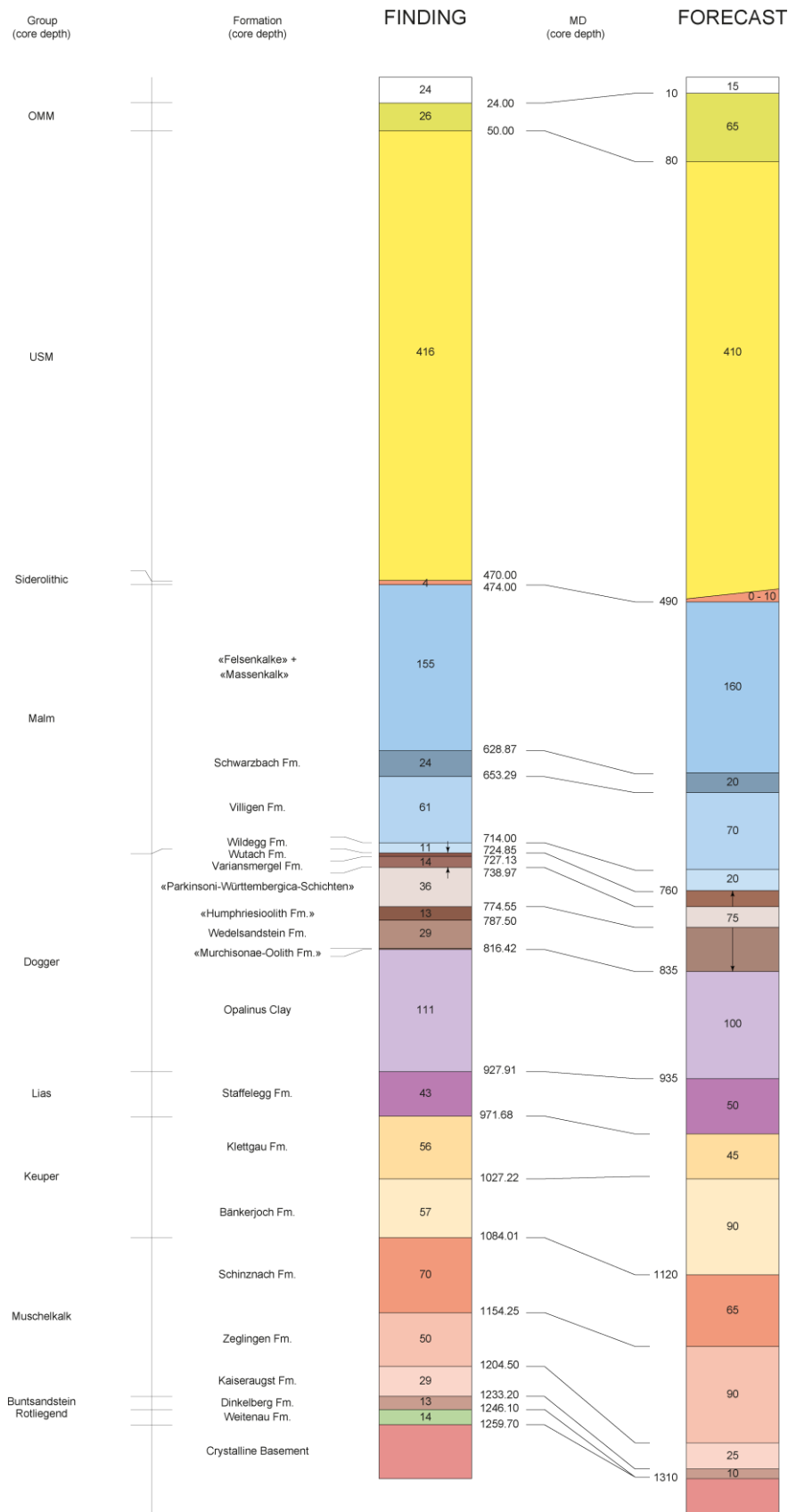


Fig. 4-1: Comparison of the forecast with the actual findings of TRU1-1

The thin Wutach Formation and the Variansmergel Formation correspond to expectations in terms of thickness and facies. As outlined above, the «Parkinsoni-Württembergica-Schichten» are much thicker than expected. The «Humphriesioolith Formation» shows the same configuration with two iron-oolitic horizons separated by a thicker marl layer as in the nearby Benken borehole. The Wedelsandstein Formation and the «Murchisonae-Oolith Formation» were also found in expected thickness and facies. The latter consists, as in the Benken borehole, of a single, few cm-thick iron-oolitic bed and a somewhat thicker silty clay layer, which separates it from the basal iron-oolite of the Wedelsandstein Formation.

Although the Opalinus Clay is thicker than expected (111 m instead of 100 m), the facies is in good agreement with the forecast and the Benken borehole. The four subunits recently proposed by Mazurek & Aschwanden (2020) could be identified.

Thickness and facies of the Staffelegg Formation correspond to a large extent to the findings of the Benken borehole. The forecast assumed a slightly larger thickness (50 m instead of 43 m). The reverse applies to the Klettgau Formation: According to the Benken borehole, about 45 m were expected in the forecast, 56 m were found. The largest difference compared to the Benken borehole, however, is found in the Ergolz Member (about 11.7 m instead of 6.1 m). The reduced thickness of the Bänkerjoch Formation (57 m) relative to forecast (90 m) was already mentioned above.

Overall thickness and facies of the Schinznach Formation match the prognosis. In detail, the Asp Member is thicker (6.5 m) than in the Benken borehole (4.2 m). The secondary dolomitisation is less in TRU1-1, resulting in a thinner Stamberg Member (28.7 m compared to 37.1 m in the Benken borehole) and, consequently, a relatively thick Liedertswil Member. The thickness of the crinoidal limestone-dominated Kienberg and Leutschenberg Members corresponds almost exactly to the findings in the Benken borehole.

The Zeglingen Formation (about 50.5 m) proved to be much thinner than predicted (90 m) but also thinner than recorded in the Benken borehole (about 67.7 m).

The Kaiseraugst and Dinkelberg Formations, on the other hand, again meet expectations, although both are slightly thicker than predicted. Below, 14 m of Permian Weitenau Formation were found before the Crystalline Basement was reached.

5 References

- Albert, W., Bläsi, H.R., Madritsch H., Vogt, T. & Weber, H.P. (2012): Geologie, Stratigraphie, Strukturgeologie, bohrlochgeophysikalisches Logging und Wasserproben der Geothermiebohrung Schlattingen SLA-1 (Rohdaten). Nagra Project Report NPB (restricted).
- Becker, F., Lutz, M., Hoppe, A. & Etzold, A. (1997): Der Untere Muschelkalk am Südostrand des Schwarzwaldes – Lithostratigraphie und Gammastrahl-Log-Korrelation. Jber. Mitt. oberrhein. geol. Ver. 79, 91-109.
- Bläsi, H.R., Deplazes, G., Schnellmann, M. & Traber, D. (2013): Sedimentologie und Stratigraphie des 'Braunen Doggers' und seiner westlichen Äquivalente. Nagra Arbeitsbericht NAB 12-51.
- Blüm, W. (1989): Faciesanalyse im Rotliegenden des Nordschweizer Permokarbon-Trogs (Hochrhein-Region zwischen Basel und Laufenburg). Eclogae geol. Helv. 82/2, 455-489.
- Deplazes, G., Bläsi, H.R., Schnellmann, M. & Traber, D. (2013): Sedimentologie und Stratigraphie der Effinger Schichten. Nagra Arbeitsbericht NAB 13-16.
- Dietl, G. (2010): Die Wutach-Formation (clw) des südwestdeutschen Juras – Beschreibung und Gliederung. Jh. Ges. Naturkde. Württemberg, Stuttgart 166, 5-21.
- Dietl, G. & Etzold, A. (1977): The Aalenian at the Type Locality. Stuttgarter Beiträge zur Naturkunde Serie B, p. 13.
- Dronkert, H., Bläsi, H.R. & Matter, A. (1990): Facies and origin of Triassic evaporites from the Nagra boreholes, Northern Switzerland. Nagra Technical Report NTB 87-02.
- Etzold, A., Franz, M. & Heunisch, C. (2010): Die Forschungsbohrung Trossingen (Baden-Württemberg und Ausführungen zum Knollenmergel und Oberkeuper der Umgebung. LGRB-Informationen 25, 105-142.
- Flügel, E. (1982): Microfacies analysis of limestones. Springer-Verlag Berlin, 633 p.
- Folk, R.L. (1959): Practical petrographic classification of limestones. AAPG Bull. 43/1, 1-38.
- Folk, R.L. (1962): Spectral subdivision of limestone types. In: Ham, W.E. (ed.): Classification of Carbonate Rocks – A Symposium. Am. Assoc. Pet. Geol. Mem. 1, 62-84.
- Frank, M., Groschopf, P., Sauer, K., Simon, P. & Wild, H. (1975): Die marin-sedimentären Eisen-erze des Dogger in Baden-Württemberg. Geol. Jb. Reihe D10, 23-128.
- Franz, M., Rohn, J., Finger, P. & Grimm, B. (2004): Erläuterungen zum Blatt Blumberg. Geologische Karte von Baden-Württemberg 1:25000. LGRB Baden-Württemberg, Freiburg, p. 196.
- Fritz, P. (1966): Zur Genese von Dolomit und zuckerkörnigem Kalk im weißen Jura der Schwäbischen Alb. Dissertation, University Stuttgart, p. 99.
- Füchtbauer, H. (ed.) (1988): Sedimente und Sedimentgesteine. 4. Ed., Schweizerbart, Stuttgart, p. 1141.

- Geyer, M., Nitsch, E. & Simon, T. (2011): *Geologie von Baden-Württemberg*. 5. Ed., Schweizerbart, Stuttgart, p. 627.
- Geyer, O.F. & Gwinner, M.P. (1991): *Geologie von Baden-Württemberg*. 4. Ed., Schweizerbart, Stuttgart, p. 482.
- Gygi, R.A. (1969): Zur Stratigraphie der Oxford-Stufe (oberes Jura-System) der Nordschweiz und des süddeutschen Grenzgebietes. Beiträge zur Geologischen Karte der Schweiz, Schweiz. Geol. Komm., Bern, 136, p. 123.
- Gygi, R.A. (1977): Revision der Ammonitengattung *Gregoryceras* (Aspidoceratidae) aus dem Oxfordian (Oberer Jura) der Nordschweiz und von Süddeutschland. Taxonomie. Phylogenie. Stratigraphie. *Eclogae geol. Helv.* 70/2, 435- 542.
- Gygi, R.A. (2000): Annotated index of lithostratigraphic units currently used in the Upper Jurassic of northern Switzerland. *Eclogae geol. Helv.* 93/1, 125-146.
- Gygi, R.A. (2012): Quantitative geology of late Jurassic epicontinental sediments in the Jura Mountains of Switzerland. Springer, Basel, Heidelberg etc. p. 216.
- Hagdorn, H. & Nitsch, E. (2009): Triassic of Southwest Germany. 6th International Triassic Field Workshop, Tübingen, p. 72.
- Hahn, W. (1971): Der Jura. In: Sauer, K.F.J. & Schnetter, M. (ed.): *Die Wutach. Naturkundliche Monographie einer Flußlandschaft*. Bad. Landesver. f. Naturkde. u. Naturschutz 6, 117-133.
- Hofmann, F. & Hantke, R. (1964): Erläuterungen zu Blatt 1032 Diessenhofen mit Anhängsel von Blatt 1031 Neunkirch des Geologischen Atlas der Schweiz 1:25'000. Schweizerische Geologische Kommission, Bern.
- Hofmann, F. (1967): Erläuterungen zu Blatt 1052 Andelfingen des Geologischen Atlas der Schweiz 1:25'000. Schweizerische Geologische Kommission, Bern.
- Hofmann, F., Schlatter, R. & Weh, M. (2000): Erläuterungen zu Blatt 97: Beggingen (LK 1011) des Geologischen Atlas der Schweiz 1:25'000. Bundesamt für Wasser und Geologie, Bern.
- Hornung, J. & Aigner T. (2002): Reservoir Architecture in a Terminal Alluvial Plain: An Outcrop Analogue Study (Upper Triassic, Southern Germany), Part II: Cyclicity, Controls and Models. *J. Pet. Geol.* 25/2, 151-178.
- Isler, A., Pasquier, F. & Huber, M. (1984): Geologische Karte der zentralen Nordschweiz 1:100'000. Herausgegeben von der Nagra und der Schweiz. Geol. Komm.
- Jordan, P. & Deplazes, G. (2019): Lithostratigraphy of Consolidated Rocks expected in the Jura Ost, Nördlich Lägern and Zürich Nordost Regions. Nagra Arbeitsbericht NAB 19-14.
- Jordan, P. (2016): Reorganisation of the Triassic stratigraphic nomenclature of northern Switzerland: overview and the new Dinkelberg, Kaiseraugst and Zeglingen formations. *Swiss Journal of Geosciences*, 109/2, 241-255.

- Jordan, P., Pietsch, J.S., Bläsi, H.R., Furrer, H., Kündig, N., Looser, N., Wetzel, A. & Deplazes, G. (2016): The middle to late Triassic Bänkerjoch and Klettgau formations of northern Switzerland. *Swiss Journal of Geosciences* 109/2, 257-284.
- Kiefer, L., Deplazes, G. & Bläsi, H.R. (2015): Sedimentologie und Stratigraphie des Frühen Juras in der Nordschweiz: Staffelegg-Formation und sich nach Osten anschliessende Vorkommen. *Nagra Arbeitsbericht NAB 14-95*.
- Kuhn, O. & Etter, W. (1994): Der Posidonienschiefer der Nordschweiz: Lithostratigraphie, Biostratigraphie, Fazies. *Eclogae geol. Helv.* 87/1, 113-138.
- Lang, H.B. (1964): Dolomit und zuckerkörniger Kalk im Weißen Jura der mittleren Schwäbischen Alb (Württemberg). *N. Jb. Geol. Paläont. Abh.* 253-299.
- Lokier, S.W. & Al Junaibi, M. (2016): The petrographic description of carbonate facies: re we all speaking the same language? *Sedimentology* 63/7, 1843-1885.
- Logan, B.W. & Semeniuk V. (1976): Dynamic metamorphism: processes and products in Devonian carbonate rocks, Canning Basin, Western Australia. *Geol. Soc. Australia SP 6*, p. 138.
- Mazurek, M. & Aschwanden, L. (2020): Multi-scale Petrographic and Structural Characterisation of the Opalinus Clay. *Nagra Arbeitsbericht NAB 19-44*.
- Merki, P. (1961): Der Obere Muschelkalk im östlichen Schweizer Jura. *Eclogae geol. Helv.* 54/1, 137-219.
- Naef, H., Büchi, M., Bläsi, H.R., Deplazes, G. & Gysi, M. (2019): Lithology Manual – Lithological description of drill cores and cuttings in Northern Switzerland. *Nagra Arbeitsbericht NAB 19-11*.
- Nagra (1992a): Sondierbohrung Siblingen. Untersuchungsbericht. *Nagra Technischer Bericht NTB 90-34*.
- Nagra (1992b): Sondierbohrung Siblingen. Beilagenband. *Nagra Technischer Bericht NTB 90-34*.
- Nagra (2001a): Sondierbohrung Benken. Untersuchungsbericht. *Nagra Technischer Bericht NTB 00-01*.
- Nagra (2001b): Sondierbohrung Benken. Beilagenband. *Nagra Technischer Bericht NTB 00-01*.
- Nagra (2014): SGT Etappe 2: Vorschlag weiter zu untersuchender geologischer Standortgebiete mit zugehörigen Standortarealen für die Oberflächenanlage. Geologische Grundlagen. Dossier II: Sedimentologische und tektonische Verhältnisse. *Nagra Technischer Bericht NTB 14-02*.
- Nitsch, E., Kimmig, B. & Saussele, M. (2017): Die äußere Randfazies des Buntsandsteins in neuen Kernbohrungen bei Steinen im Wiesental (Schopfheimer Bucht, Baden-Württemberg). *Jber. Mitt. oberrhein. geol. Ver.* 99, 507-544.
- Pawellek, T. & Aigner, T. (2002): Fazies, Petrophysik und Rohstoffeigenschaften von Carbonatgesteinen des schwäbischen Oberjura – ein Atlas. *Jber. Mitt. oberrhein. geol. Ver.* 84, 257-321.

- Pietsch, J. & Jordan, P. (2014): Digitales Höhenmodell Basis Quartär der Nordschweiz – Version 2013 (SGT E2) und ausgewählte Auswertungen. Nagra Arbeitsbericht NAB 14-02.
- Pietsch, J., Wetzel, A. & Jordan, P. (2016): A new lithostratigraphic scheme for Schinznach Formation (Upper Muschelkalk of Northern Switzerland). *Swiss Journal of Geosciences* 109, 285-307.
- Reisdorf, A.G., Wetzel, A., Schlatter, R. & Jordan, P. (2011): The Staffelegg Formation: a new stratigraphic scheme for the Early Jurassic of northern Switzerland. *Swiss Journal of Geosciences* 104, 97-146.
- Röhl, H-J., Schmid-Röhl, A., Oschmann, W., Frimmel, A. & Schwark, L. (2001): Erratum to "the Posidonia Shale (Lower Toarcium) of SW-Germany: an oxygen-depleted ecosystem controlled by sea level and palaeoclimate" [*Palaeogeogr., Palaeoclimatol., Palaeoecol.* 165 (2001) 627-652]. *Palaeogeography, Palaeoclimatology, Palaeoecology* 169, 273-299.
- Schlatter, R. (1976): Die Stufe des Lotharingium im unteren Lias des Klettgau (Kanton Schaffhausen, Schweiz). *Stuttgarter Beiträge zur Naturkunde. Serie B*, 1-17.
- Wetzel, A. & Allia, V. (2003): Der Opalinuston in der Nordschweiz: Lithologie und Ablagerungsgeschichte. *Eclogae geol. Helv.* 96, 451-469.