INTERNATIONAL CONTINENTAL SCIENTIFIC DRILLING PROGRAM

ICDP Operational Report

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Drilling Overdeepened Alpine Valleys (DOVE) – Operational Report of Phase 1

DOVE-Phase 1 Scientific Team, Anselmetti, F. S., Beraus, S., Buechi, M. W., Buness, H., Burschil, T., Fiebig, M., Firla, G., Gabriel, G., Gegg, L., Grelle, T., Heeschen, K., Kroemer, E., Lehne, C., Lüthgens, C., Neuhuber, S., Preusser, F., Schaller, S., Schmalfuss, C., Schuster, B., Tanner, D. C., Thomas, C., Tomonaga, Y., Wieland-Schuster, U., and Wonik, T.

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Schaller, S., Buechi, M. W., Schuster, B. and Anselmetti, F. S. (2023). Drilling into a deep buried valley: A 252 m long sediment succession from a glacial overdeepening in northwestern Switzerland, Scientific Drilling, 32, https://doi.org/10.5194/sd-32-27-2023

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DOVE-Phase 1 Scientific Team, Anselmetti, F. S.*, Beraus, S., Buechi, M. W., Buness, H., Burschil, T., Fiebig, M., Firla, G., Gabriel, G., Gegg, L., Grelle, T., Heeschen, K. U., Kroemer, E., Lehne, C., Lüthgens, C., Neuhuber, S., Preusser, F., Schaller, S., Schmalfuss, C., Schuster, B., Tanner, D. C., Thomas, C., Tomonaga, Y., Wieland-Schuster, U., and Wonik, T.

* corresponding author

1. Introduction & site overview

1.1. Introduction

This report documents the drilling operations of the ICDP Project "Drilling Overdeepened Alpine Valleys" (DOVE) and includes information on the six different sites investigated during Phase 1 of the DOVE project. Two sites, site 5068_1 (Tannwald) and site 5068_2 (Basadingen) have been drilled in 2021 with the support of ICDP funding. The drilling operations at both sites are published in this operational report. In addition, the report includes summarized information on the four legacy sites, all drilled in the framework of earlier projects and cited before. The remnants of these legacy cores have been curated, described and re-sampled in the framework of the DOVE project.

All sites are investigating overdeepened troughs along the northern Alps and their foreland. The sedimentary infill of glacially overdeepened valleys (i.e. excavated structures below the fluvial base level) are, together with glacial geomorphology, the best-preserved direct archives of extents and ages of past glaciations in and around mountain ranges. The cores are investigated with regard to several aspects of environmental dynamics during the Quaternary, with focus on the glaciation, vegetation, and landscape history. Besides the scientific goals, DOVE also addresses a number of applied objectives such as groundwater resources, geothermal energy production, and seismic hazard assessment. Details on the scientific objectives and approach of the DOVE project are explained in Anselmetti et al. (2022).

The initial core description and interpretation of the cores from the Tannwald Area (5068_1_A, 5068_1_B, 5068_1_C; Schuster et al., in prep) and the Basadingen Trough (5068_2_A, Schaller et al., subm.) are presented in the scientific reports, which are intended to be published in Scientific Drilling in 2023. Table 1 lists all the sites of the Phase 1, their coordinates, IGSN and the first scientific report/publication on the respective site if applicable.

1.2. Objectives

For Details on the objectives of the project please see Anselmetti et al. (2022)

1) What was the timing and extent of past Alpine glaciations?
   Hypothesis: Glacier advances and related erosion and infilling of overdeepened troughs varied in timing and extent around the Alps during the Quaternary.

2) How did atmospheric circulation patterns control ice flow across the Alps?
   Hypothesis: Atmospheric circulation over the Alps varied during past glaciations so that moisture distribution became the pivotal control of ice build-up.

3) How were mountain ranges and their foreland shaped by repetitive glaciations?
   Hypothesis: The timing and amount of erosion and infill varied not only around the Alps, but also within one system.

Add-ons:

- Geophysical investigations
- Potential of overdeepened structures as groundwater resources
- Potential of the Quaternary valley fills for shallow geothermal applications
- Alpine vegetation history
- Microbial activity in the sediments,
- later: Modelling landscape response, glacial erosion, and climate.

1.3. Referencing articles

Schaller, S., Buechi, M. W., Schuster, B. and Anselmetti, F. S. (in press). Drilling into a deep buried valley: A 252 m long sediment succession from a glacial overdeepening in northwestern Switzerland, Scientific Drilling, 32, (2023) https://doi.org/10.5194/sd-32-27-2023.

1.4. Supplementary data

DOVE-Phase 1 Scientific Team et al. (2023c) Drilling Overdeepened Alpine Valleys (DOVE) – Explanatory Remarks, https://doi.org/10.48440/ICDP.5068.002

DOVE-Phase 1 Scientific Team et al. (2023b) Drilling Overdeepened Alpine Valleys (DOVE) - Operational Dataset of Phase 1, https://doi.org/10.5880/ICDP.5068.001

1.5. The locations of the drill sites DOVE Phase 1

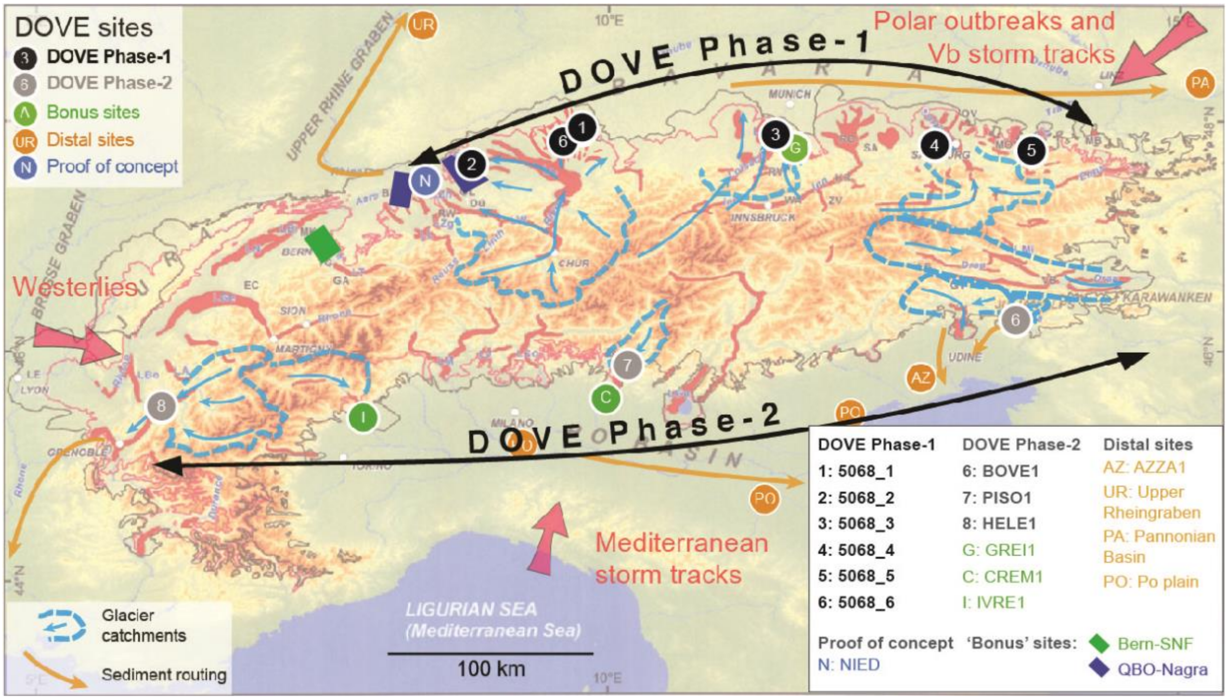

Figure 1 Map of the Alps and their forelands including the locations of the drill sites of the DOVE project (Anselmetti et al. 2022, updated). The sites of DOVE Phase-1 5086_1 to 5086_6 are covered by this report.

Table 1 Location and Identifiers of boreholes from DOVE Phase 1

Borehole Combined-ID	Borehole IGSN https://doi.org/10.60510/..	Latitude decimal WGS84	Longitude decimal WGS 84	Operational Phase in	First Scientific Reports
5068_1_A	ICDP5068EH50001	47.9998028	9.7486417	2021	Schuster et al., in prep
5068_1_B	ICDP5068EH60001	47.9995528	9.7486111	2021	Schuster et al., in prep
5068_1_C	ICDP5068EH70001	47.9995500	9.7490139	2021	Schuster et al., in prep
5068_2_A	ICDP5068EH40001	47.6480956	8.7532566	2021	Schaller et al., 2023
5068_3_A	ICDP5068EHC0001	47.9710190	11.460135	2017	Firla et al. in prep
5068_4_A	ICDP5068EHD0001	47.8628920	12.909791	2009	Fiebig et al. (2014)
5068_5_A	ICDP5068EHE0001	47.6069711	13.7741043	1998	Husen van & Mayr (2007)
5068_6_A	ICDP5068EHG0001	47.8880460	9.7112920	2016	Ellwanger, 2015; Schaaf, 2017; Rolf, 2021

1.6. DOVE-Phase 1 Scientific Team Members

(alphabetic order, see site reports for detailed responsibilities, **bold: PI**)

Anselmetti	**Flavio S.**	**Institute of Geological Sciences and Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland**
Beraus	Sarah	Leibniz Institute for Applied Geophysics, 30655 Hanover, Germany
Buechi	Marius W.	Institute of Geological Sciences and Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland
Buness	Hermann	Leibniz Institute for Applied Geophysics, 30655 Hanover, Germany
Burschil	Thomas	Federal Institute for Geosciences and Natural Resources, 30655 Hannover, Germany
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Firla	Gustav	Department of Civil Engineering and Natural Hazards, Institute of Applied Geology, University of Natural Resources and Life Sciences, Vienna (BOKU), 1190 Vienna, Austria
Gabriel	**Gerald**	**Leibniz Institute for Applied Geophysics, 30655 Hanover, Germany and Institute of Geology, Leibniz University Hanover, 30167 Hanover, Germany**
Gegg	Lukas	Institute of Earth and Environmental Sciences, University of Freiburg, 79104 Freiburg, Germany
Grelle	Thomas	Leibniz Institute for Applied Geophysics, 30655 Hanover, Germany
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Lüthgens	Christopher	Department of Civil Engineering and Natural Hazards, Institute of Applied Geology, University of Natural Resources and Life Sciences, Vienna (BOKU), 1190 Vienna, Austria
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Schmalfuss	Clemens	Department of Civil Engineering and Natural Hazards, Institute of Applied Geology, University of Natural Resources and Life Sciences, Vienna (BOKU), 1190 Vienna, Austria
Schuster	Bennet	Institute of Earth and Environmental Sciences, University of Freiburg, 79104 Freiburg, Germany
Tanner	David C.	Leibniz Institute for Applied Geophysics, 30655 Hanover, Germany
Thomas	Camille	Institute of Geological Sciences and Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland
Tomonaga	Yama	Eawag, Department of Water Resources and Drinking Water, 8600 Dübendorf, Switzerland
Wieland-Schuster	Ulrike	Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau, Referat 92 Landesgeologie, 79104 Freiburg i.Br., Germany
Wonik	Thomas	Leibniz Institute for Applied Geophysics, 30655 Hanover, Germany

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2. Site 5086_1

2.1. Site Introduction

The Tannwald Basin is located approximately 45 km northeast of Lake Constance in the central part of the Alpine foreland. Its overdeepened structure was incised into Tertiary Molasse sediments by subglacial erosion under the Rhine Glacier. Later it was filled by glacial, fluvial, and lacustrine deposits of up to 250 m thickness. As shown by Ellwanger et al. (2011), the Tannwald Basin site is characterised by two superimposed unconformities (Fig. 1; D2 and D3). The site therefore has the potential to characterize sedimentary sequences above both of these unconformities. The earlier interpretations are based, amongst other things, on the sediment succession found in a previously-drilled borehole (Schneidermartin research borehole; LGRB-ID: 8024-925; Burschil et al., 2018), about 1200 m southeast of the newly-drilled Tannwald site, ICDP 5068_1 (Figs. 2 and 3). The whole sequence apparently comprises the deposits of three glacial cycles. However, neither the sedimentary record nor the results of pollen analysis have been documented in detail. Furthermore, no geochronological data are available for the Schneidermartin borehole.

Three individual boreholes were drilled (ICDP 5068_1_A; 5068_1_B; 5068_1_C): The first two are flush drillings (ICDP 5068_1_A & 5068_1_B), with the main purpose of enabling post-drilling cross-borehole geophysical measurements, and the third one was a core drilling (ICDP 5068_1_C).

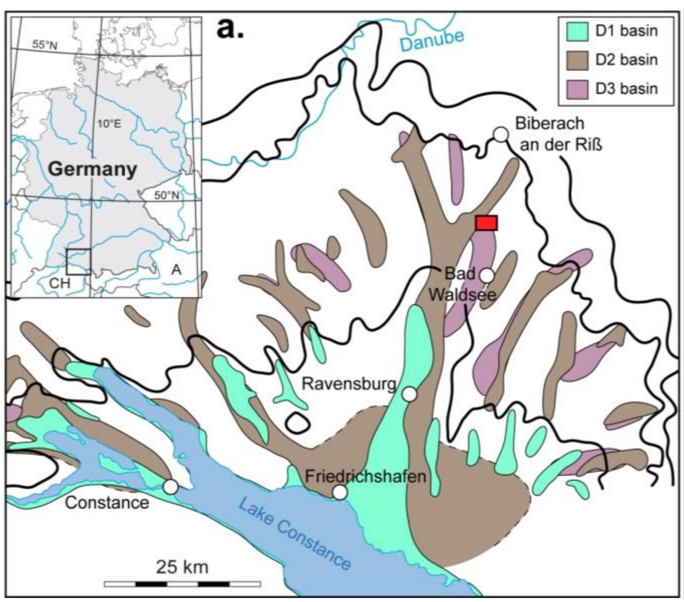

Figure 1: Map of basins of the Rhine Glacier, modified after Ellwanger et al. (2011). Three different generations of unconformities can be identified, known as D1–D3. These correspond to the advances of the Rhine glacier in the Würmian, Rissian and Hosskirchian glacial periods. The red box marks the area shown in Figure 3 including the current drilling location in the Tannwald Basin.

2.2. Personnel in the Operational Phase

Technical project management and supervision

David C. Tanner, Leibniz Institute for Applied Geophysics, Germany (responsible)

Project and on-site science coordination

David C. Tanner, Leibniz Institute for Applied Geophysics, Germany
Bennet Schuster, (Ph.D. student) University of Freiburg, Germany

Volunteers

Julia Silov-Tepic (1-month practical experience), University of Potsdam, Germany

Drilling advisors

Ulrike Wielandt-Schuster, Landesamt für Geologie, Rohstoffe und Bergbau, Germany
Marius W. Buechi, University of Bern, Switzerland

Downhole geophysical measurements (LIAG, Hanover)

Hermann Buness, Leibniz Institute for Applied Geophysics, Germany
Thomas Grelle, Leibniz Institute for Applied Geophysics, Germany
Carlos Lehne, Leibniz Institute for Applied Geophysics, Germany
Thomas Wonik, Leibniz Institute for Applied Geophysics, Germany

Drilling team (H. Anger's Söhne, Bohr- und Brunnenbaugesellschaft mbH)

Mirko Huber (company liaison)
Jürgen Pröhl (drilling manager, flush drilling)
Markus Schick (drilling manager, core drilling)
J. Achler, Mohammad Alhamad, Hsaan Alsasihl, Asabdi, Peter Goor, Frank Hapke, Zoltan Mihalti, Zoltan Olah, Jens Täubert, Lutz Tonne, Peter Toth

Off-site assistance & Data management

Katja Heeschen, ICDP, GFZ German Research Centre for Geosciences, Potsdam, Germany

2.3. Site Selection and Permits

To determine the optimal location for the drillsite (ICDP 5068_1), LIAG carried out a high-resolution reflection P-wave seismic campaign over the basin structure at this location in 2014 and 2015 (Fig. 2). The profiles concentrated on the deepest part of the Tannwald Basin, as known from seismic refraction surveys (Behnke and Bram 1998). The seismic grid was connected to the Schneidermartin borehole (Fig. 2). Details can be found in Burschil et al. (2018).

In consideration of groundwater safety regulations and drilling suitability, a site was located on the western flank of the basin structure, so that drillholes would have to drill 150-160 m to reach the base of the Quaternary glacial fill (Fig. 4).

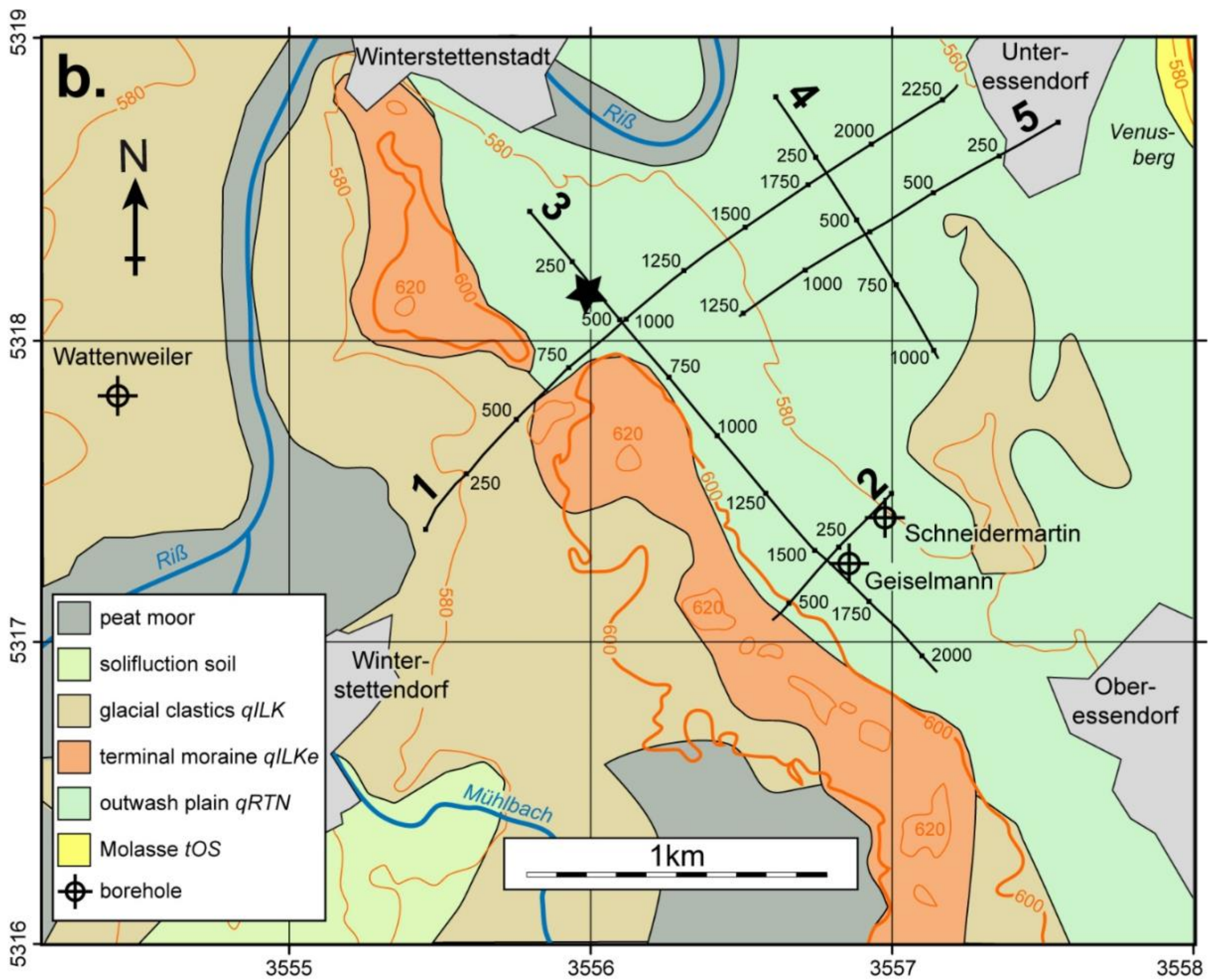

Figure 2: Geological map of the survey area of the Tannwald Basin, showing the location of seismic reflection profiles 1–5 and previous boreholes (from Burschil et al., 2018). The drillsite location is indicated by a star.

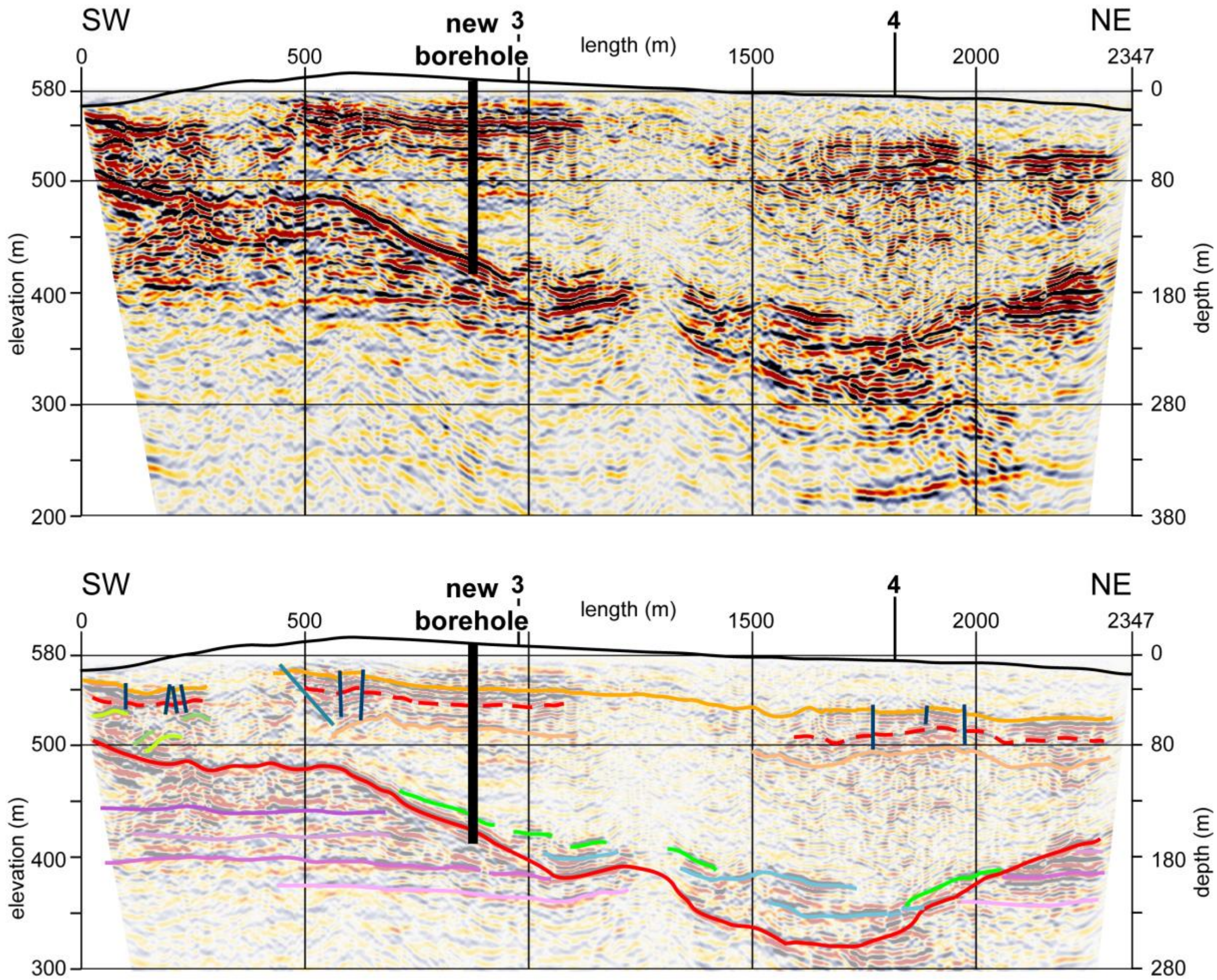

Figure 3: Seismic section 1, for location see Fig. 2. Above: seismic profile, below: interpreted structure and seismic facies. Vertical exaggeration, 2.5x. Profile intersections (black numbers), elevation (black line), faults with offsets >2 m (dark blue), and faults with unknown offsets (light blue). Dashed red line shows D2 unconformity, base of the overdeepened valley (D3) is solid red line. Green lines indicate top of a layer of waterlain till, blue lines show allochthonous blocks of Tertiary molasse. Purple lines represent bedding in the Tertiary molasse sediments (Burschil et al., 2018). The location of the three new boreholes is projected 100 m towards the south east.

2.4. Site Preparation and Infrastructure

1500 m^2 of land in the NE corner of an arable field (known from now on as the drillsite) was leased from a local farmer. It was agreed that the drillsite would be sown with clover, while the rest of the field was sown with sweet corn. The drillsite was directly next to an asphalted road. Therefore, no additional access road was required, at least to start with. Top soil was not removed, but large wooden plank mats were used to protect the ground around the drilling rig and containers.

On-site facilities included workshops for repairs to equipment, waste and drill-mud tanks around the drill rig, and containers for the drilling team and science crew (Figs. 4 and 5). LIAG set up an information tent to cater for casual tourists and arranged visits of schoolchildren and local geologists.

Electricity for the site was provided on-site by a generator. Water was obtained from the local authority and kept in a lorry-mounted, 9 m³ tank. Later, because of torrential rain, it became necessary to construct a small (ca. 25 m length) cambered road across the drillsite (27th-30th June 2021). The road was constructed by laying 25 cm of gravel and hogging on top of a geotextile sheet.

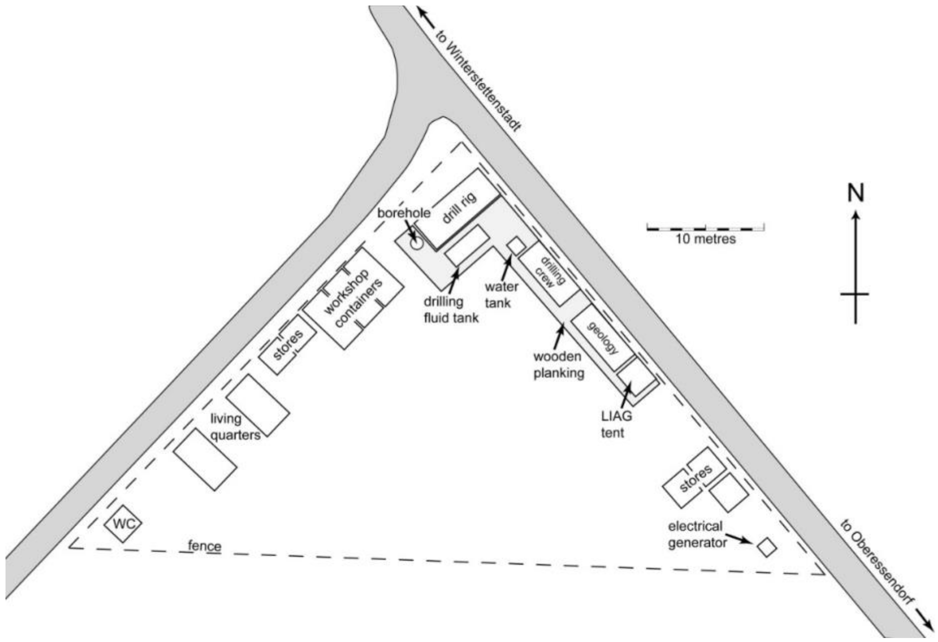

Figure 4: Layout of the drillsite (5068_1) for the borehole A. See Appendices for layouts of the other boreholes.

Figure 5: Aerial view of the drill site during the drilling of borehole 5068_1_C.

2.5. Technical Operations

2.5.1. Summary of drilling, coring and logging operations

The Leibniz Institute for Applied Geophysics (Hannover, Germany) coordinated technical operations. A German drilling company, H. Anger's Söhne, Bohr- und Brunnenbaugesellschaft mbH (known hereafter as Angers), was the drilling contractor. The drilling crew consisting of two/three persons (one drilling manager/controller, one to two drilling workers), nominally worked 12 hour shifts from Monday through Thursday. Occasionally, they worked Friday to complete various tasks.

Figure 2: The drill rig (MB Actros 3341A, UH2) used for all three boreholes, with the manual casing handling system.

Table 2: Technical details of the drill rig.

Hook nominal force/ max. force	240 kN / 360 kN
Hydraulic force (pull/push)	110 kN/50 kN
Drill winch ZHP 4.25-EG	120 kN
Cable coring winch ZHP 4.19-EG1	20 kN
Auxiliary winch ZHP 4.13	25 kN
Drill head Type UH2 -14000 torque	14 kNm
Roller block Type 240 kN	240 kN
Compressor Atlas Copoco XAHS 107 (pressure/flow rate)	12 bar/5.5 m³/min

Angers provided a lorry (MB Actros 3341A)-mounted drill rig, UH2, for the drilling (Fig. 6). It was last tested and found to be in working order on 7th May 2020. For details of the device, see Table 2. The timing of the drilling operations at DOVE Site 1 are summarised in Table 3.

Table 3. Site 5068_1 (Tannwald Basin) drilling operations by time

date (all 2021)	working days	task
6th – 13th April	6	Construction of site, mobilization
15th April – 5th May	15	Flush drilling 5068_1_A
10th – 11th May	1.5	Downhole geophysical logging (open hole) 5068_1_A
12th – 20th May	6	Completion of 5068_1_A
31st May – 21st June	13	Flush drilling 5068_1_B
28th June – 30th June	3	Construction of road across drillsite
28th June – 1st July	4	Completion of 5068_1_B
6th July – 8th July	3	VSP (zero-offset and walkaway) of 5068_1_A and B
12th July – 3rd Aug.	17	Changing drilling rig over
4th Aug. – 5th Aug.	2	Core drilling of 5068_1_C
9th Aug. – 20th Aug.	20	Holiday for the drilling team
23rd Aug. – 11th Nov.	48.5	Core drilling of 5068_1_C
11th – 12th Nov.	1.5	Downhole geophysical logging (open hole) of 5068_1_C
15th – 18th Nov.	3	Completion of 5068_1_C
22nd Nov. – 2nd Dec.	8	Demobilization
10th – 12th March 2022	3	Downhole geophysical logging (closed hole) of all boreholes 5068_1_A, B and C

Flush drilling procedure

ICDP 5068_1_A. The standpipe (318 mm inner diameter (ID)) was drilled dry using an auger down to 10 m. From then on, drilling mud was pumped through the drill stem. With a 273 mm rolling drill bit the borehole was advanced to a depth of 42 m, with casing. Because the borehole was stable and not leaking drilling mud, it was decided to continue drilling with a 241 mm rolling drill bit without casing. This was continued to a depth of 163 m, i.e. 10 metres in to the Tertiary Molasse sediments. Mud samples were taken and washed discontinuously after advancing 1 m.

ICDP 5068_1_B. The standpipe (318 mm ID) was drilled dry using an auger down to 11 m. From then on, drilling mud was pumped through the drill stem. With a 273 mm rolling drill bit the borehole was advanced to a depth of 47 m, with casing. Because the borehole was stable and not leaking drilling mud, it was decided to continue drilling with a 241 mm rolling drill bit, without casing. This was continued to a depth of 155 m, i.e. 1 m in to the Tertiary Molasse sediments. Mud samples were taken and washed discontinuously after advancing 1 m. The sediment material was accumulated on a sieve that was not cleaned after every metre. It became obvious that the sand fraction must have been completely removed during flush drilling. The flush fluid flux, fluid velocity and fluid pressure were not monitored and hence quite a large uncertainty also exists with regard to the sample depths.

Core drilling procedure

ICDP 5068_1_C. Two different coring systems were used for this borehole; 1/ a percussion drilling technique (Nordmeyer system) and 2/ a wireline rotational **SK6L** core system. The standpipe (318 mm ID) was drilled dry using an auger down to 14.6 m. Percussion coring with drilling mud began at the same time from a depth of 2 m, using 178 mm casing with a drill crown and a 101 mm coring tool. At a depth of 26.25 m, due to strong loss of drilling mud, a second casing (273 mm) was introduced and advanced to a depth of 25 m. Subsequently, this 273 mm casing was extended in line with the 178 mm casing down to a final depth of 47.7 m. On 20.10.2021, at a depth of 82.5 m, after drilling in to strongly-compacted sand, the decision was made to switch to a wireline rotational **SK6L** core system (146 mm) with 101 mm coring. Core drilling was carried out using the wireline rotational core system until the end of the borehole. Tertiary Molasse bedrock was reached at 155.35 m. We then drilled for another 10.85 m into the Molasse bedrock to exclude the possibility of drilling into an allochthonous block of Molasse, as the seismic survey and the Schneidermartin borehole (Fig. 2 &3) had predicted such blocks. A total length of 164.25 m of core was recovered, with an overall recovery of 95% (Fig. 7). Core lengths were mostly of 1 m.

Core loss mainly occurred in the top 45 m, where core runs of 1 m could often not be completed due to technical problems with the percussion drilling technique. At 82.5 m, after the coring method was changed to a wireline rotational core system, recovery speed picked up. Recovery speed decreased again in the basal coarser units because of a significant sand component, which is prone to outwashing by the rotational technique.

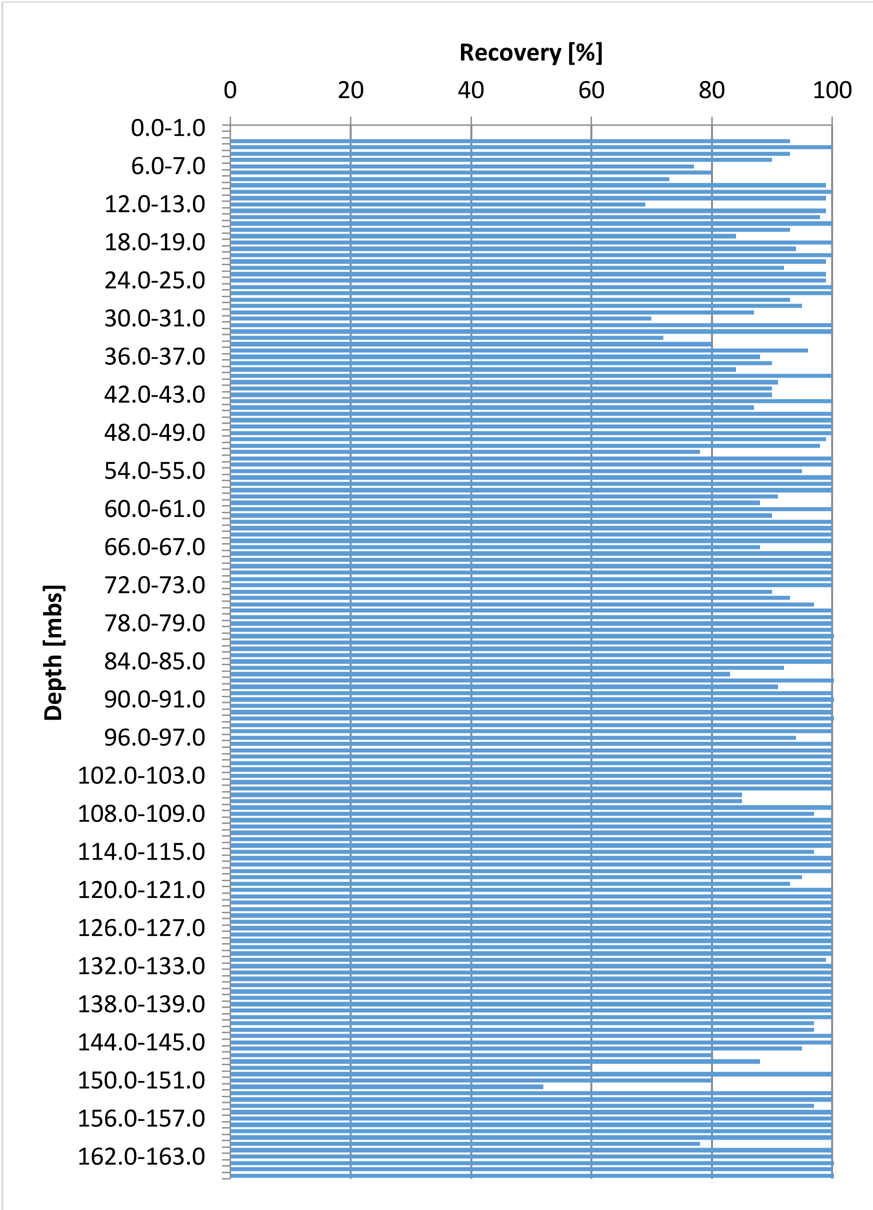

Figure 3: Recovery of the ICDP 5068_1_C drill core (total recovery 95%). Note that recovery was determined based on actual liner length. Therefore, expansion of the core due to pressure release could not be determined. Note also that possible unconsolidated re-core material falsifying the recovery could not be detected, because the cores were not opened and liners were opaque.

2.5.2. Detailed report of operations

For all boreholes, the drilling mud consisted of approximately 9 m^3 of water, mixed with Antisol and bentonite (1 part to 6 parts, respectively). The ratio of additives to water was approximately 1-1.2 kg/l (Table 4).

Table 4: Drilling mud parameters over time, for the three boreholes.

Daily report No.	Day (all in 2021)	Mixing ratio (Y)	Drain time (AZ)	Remaining drain time (RAZ)	Temperature	Conductivity (LF)	Water release time (WAZ)	pH
	5068_1_A	kg/l	sec	sec	°C	mS/cm	min	
10	21 April		44.0	29.0	11.5	1.268	13.8	9.0
12	23 April		48.3	37.9	9.8	1.096	17.8	11.0
14	27 April	1.2	50.2	41.5	10.3	1.068	18.1	10.8
16	29 April	1.2	50.0	41.0	11.0	1.200	19.0	10.8
	5068_1_B							
33	02 June		50.3	40.1	10.8	1.140	18.8	11.0
36	09 June	1.2	50.3	40.1	10.8	1.140	18.8	11.0
48	15 June	1.2	50.3	40.1	12.5	1.350	18.8	11.1
	5068_1_C							
67	08 September		39.0	36.0				
68	09 September	1.0	36.0	35.0				
69	13 September	1.1	43.0	49.0				
70	14 September	1.1	46.0	43.0	14.5	0.716	13.0	7.7
72	16 September	1.1	47.0	46.0	15.9	0.728	10.0	7.7
73	20 September	1.1	43.0	39.0	13.5	0.789		7.8
74	21 September	1.1	40.0	37.0	14.7	0.755		7.9
75	22 September	1.1	45.0	43.0	13.9	0.782		7.8
76	23 September	1.1	55.0	53.0	13.9	0.756		7.9
78	28 September	1.1	38.0	36.0				
79	29 September	1.1	39.0	36.0			10.0	
91	21 October						17.0	
92	25 October						31.0	
93	26 October	1.1	32.0	27.0			34.0	
95	28 October	1.1	33.0	27.0			38.0	
96	01 November	1.1	34.0	28.0			36.0	
97	02 November	1.1	35.0	28.0			40.0	
98	03 November	1.1	33.0	26.0			41.0	
100	05 November	1.1	33.0	26.0			48.0	
106	15 November	1.0	34.0	28.0			35.0	

Problems that occurred during drilling

Flush drilling ICDP 5068_1_A

- 22nd April – Breakdown of electrical generator. The generator was replaced.
- 4th May – Breakdown of the next electrical generator. New generator rented and then replaced.
- 17th May – The drill rig could not pull out the casing out of the first borehole. A hydraulic press was used to raise a bar that was temporally welded to the casing. Finally, the casing was raised after 2 days delay.

Flush drilling ICDP 5068_1_B

- 9th June – Strong loss of drill mud. Remedied by sinking the casing deeper and raising the viscosity of the drill mud.
- 9th June – High-pressure hydraulic pipe bursts. This was replaced in a few hours.
- 15th June – Strong loss of drill mud. Remedied by sinking the casing deeper.

6.3.3 Core drilling ICDP 5068_1_C

- 25th August – A large (metamorphic and calcareous) rocks in the top 10 m of the borehole cause the crown of the coring body to be damaged (bent). The same crowns are used until 30th August, until the firm creates a stronger, reinforced crown with spikes on the top edge. This is used from 31st August onwards.
- 1st September – Pump on the drill rig breaks down due to a fault in a solenoid valve. Electrical engineers are called out to fix the problem. Problem fixed by 6th September.
- 7th September – Piston rod of drill rig broken. Problem fixed by 8th September.
- 8th September – Drill crown worn out due to attrition. Replaced by 9th September.
- 13th September – Loss of flush drilling fluid is too large. Driller decides to add additional casing (273 mm). Done by 14th September.
- 15th September – Drill crown worn out due to attrition again. Replaced by 20th September.
- 23th September – Drill rig is out-of-balance. Repaired by 28th September.
- 29th September – Chuck head of drill rig broke. Repaired by 4th October.
- 6th October – Supply difficulties with new crown. Crown arrives at the same day.
- 14th October – Supply difficulties with crown. Crown arrives at 19th October.

Summary of progress

Figure 8 shows the depth of the three boreholes over time. ICDP 5068_1_B was quicker than ICDP 5068_1_A because the geology and its physical properties were better known after the first borehole had been drilled. From Fig. 8 it is also clear that drilling became faster with depth in the flush boreholes; this is because the lower lithologies, being finer and more homogenous, were easier to drill. The obvious kink in the drilling progress at ca. 40 m in both wells is caused by the changing of the drill bit and casing at this level. By comparison, coring took twice as long. Ramming to depth of 82 m took over two months, coring then became easier using rotary core technique and also it was easier to core the lower lithologies. Thus, contrary to other drilling campaigns, we have the unusual situation that the drilling became faster with depth.

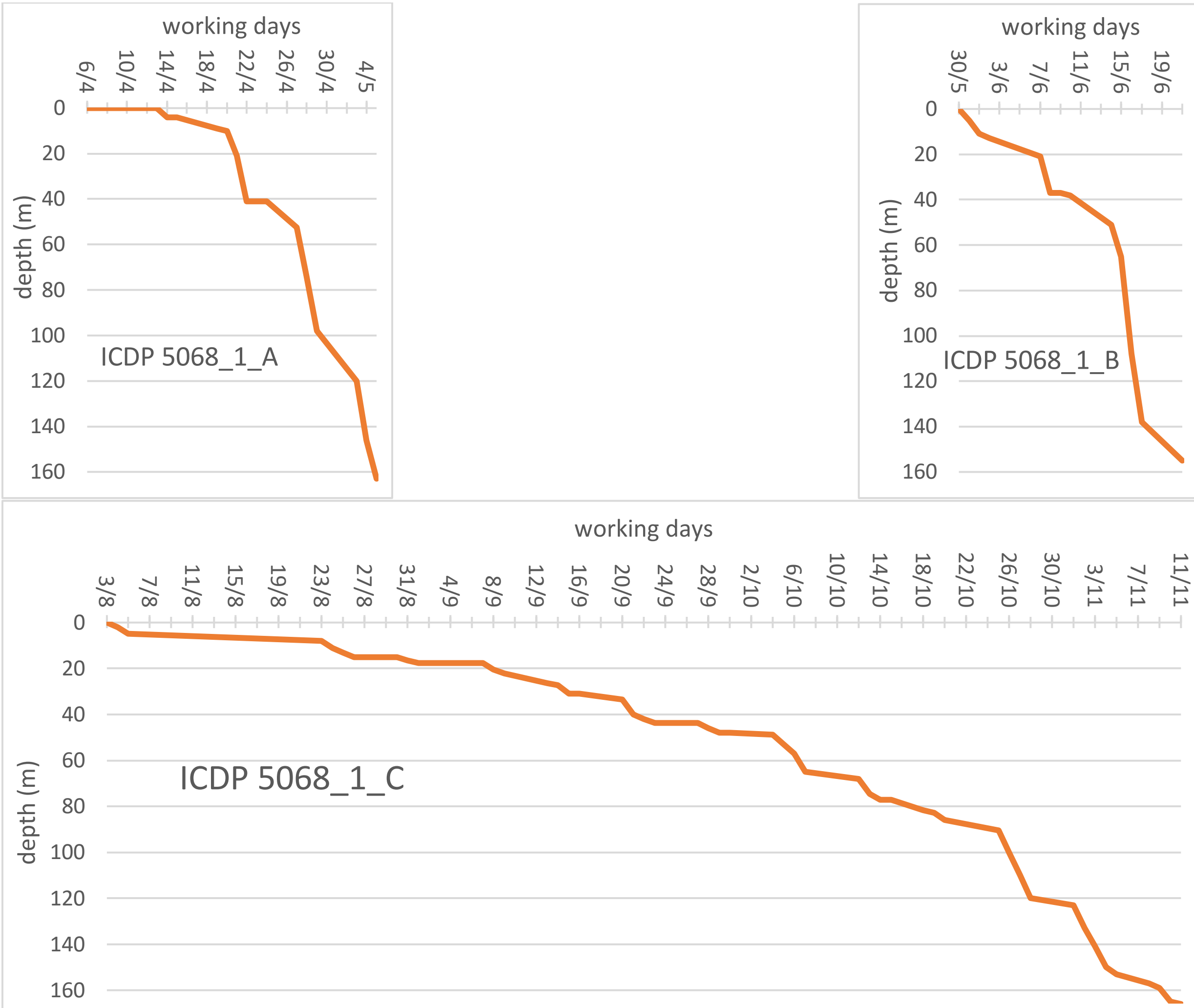

Figure 8: Depth/time plots for the three boreholes, at the same scale.

2.5.3. Borehole deviation

The borehole geophysics, run in ICDP 5068_1_A and ICDP 5068_1_C, also measured borehole deviation (Figs. 9 and 10). 5068_1_A first plunges south-eastwards for 0.5 m, before heading north and north-west to be 3.5 m due north of the origin. 5068_1_C is closer to vertical; it plunges near-straight north-westwards, northwards by 2 m and west by 1 m. This information is necessary to obtain true-vertical depth, especially for geophysical modelling.

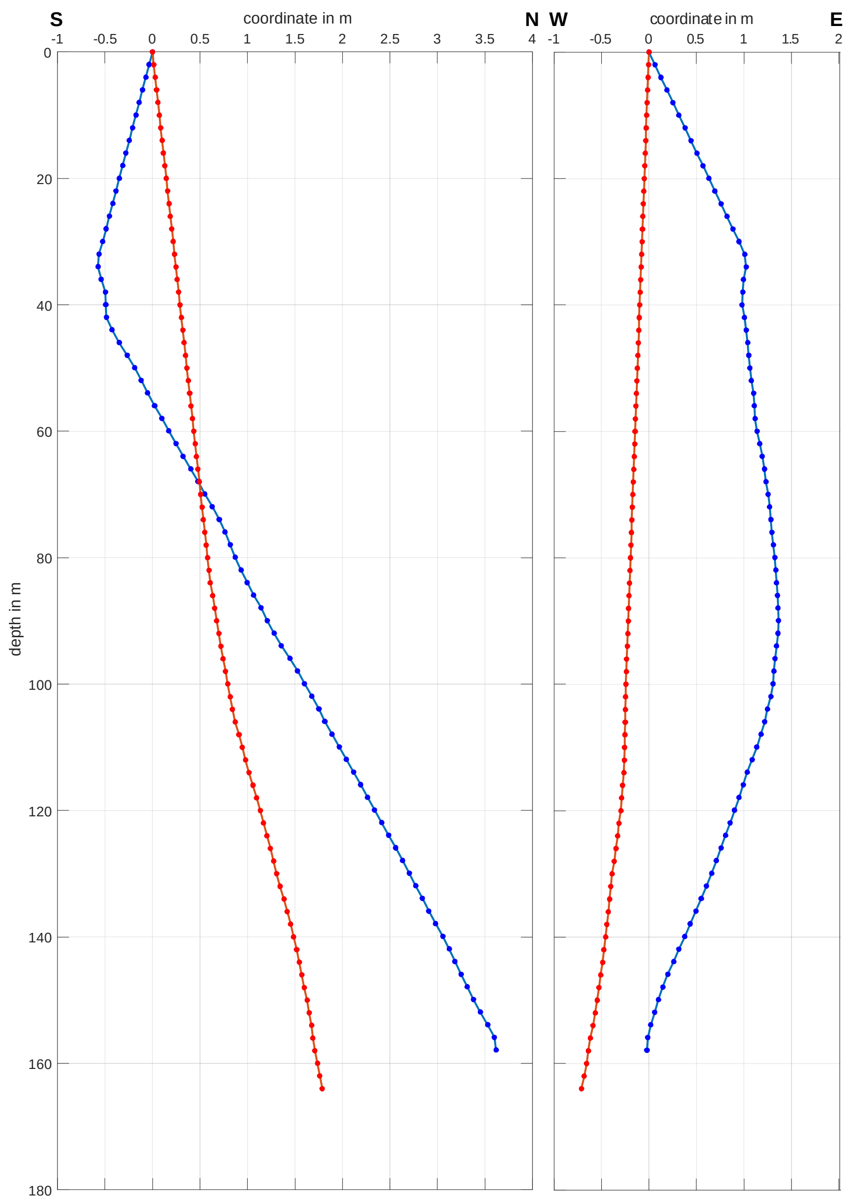

Figure 9: Deviation of ICDP 5068_1_A (blue) and ICDP 5068_1_C (red) in the S-N and E-W planes.

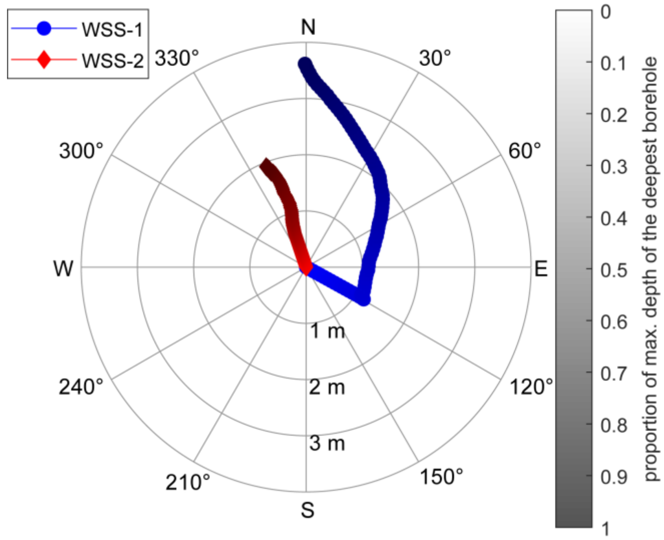

Figure 10: Deviation of ICDP 5068_1_A (blue) and ICDP 5068_1_C (red) in polar view.

2.5.4. Refilling and post-drilling finishing procedure

All three boreholes were finished by inserting a DN80mm plastic pipe, with a 1-metre filter (in ICDP 5068_1_C, 3 m) at a certain depth. In the first, second and third boreholes, filters were placed at depths of 153 m, 45 m, and 153 m, respectively. The annular spaces of the first and second drill holes were then backfilled with bentonite pellets, except for the depths of ca. 5 m around the filters, which were backfilled with fine gravel. Because the third drill hole was very narrow, it was decided to backfill its annular space to a depth of 82 m first with gravel, and from 82 m on to the surface with bentonite (Fig. 12).

At the surface, all three boreholes were closed using a lockable SEPA cap below the ground level (Fig. 11), and covered by a lockable manhole cover at ground level.

Figure 11: SEPA lockable borehole cap on top of a DN80 mm pipe.

2.5.5. Borehole geometry and preliminary lithology assessment

The final geometries of the boreholes 5068_1_A, B, C are shown in Figure 12A-C, respectively. A preliminary geological interpretation is shown on the left-hand side. Note the position of the filters, close to the base of the Quaternary basin at 153 m depth in 5086_1_A and C, and at the depth of 45 m in 5086_1_B.

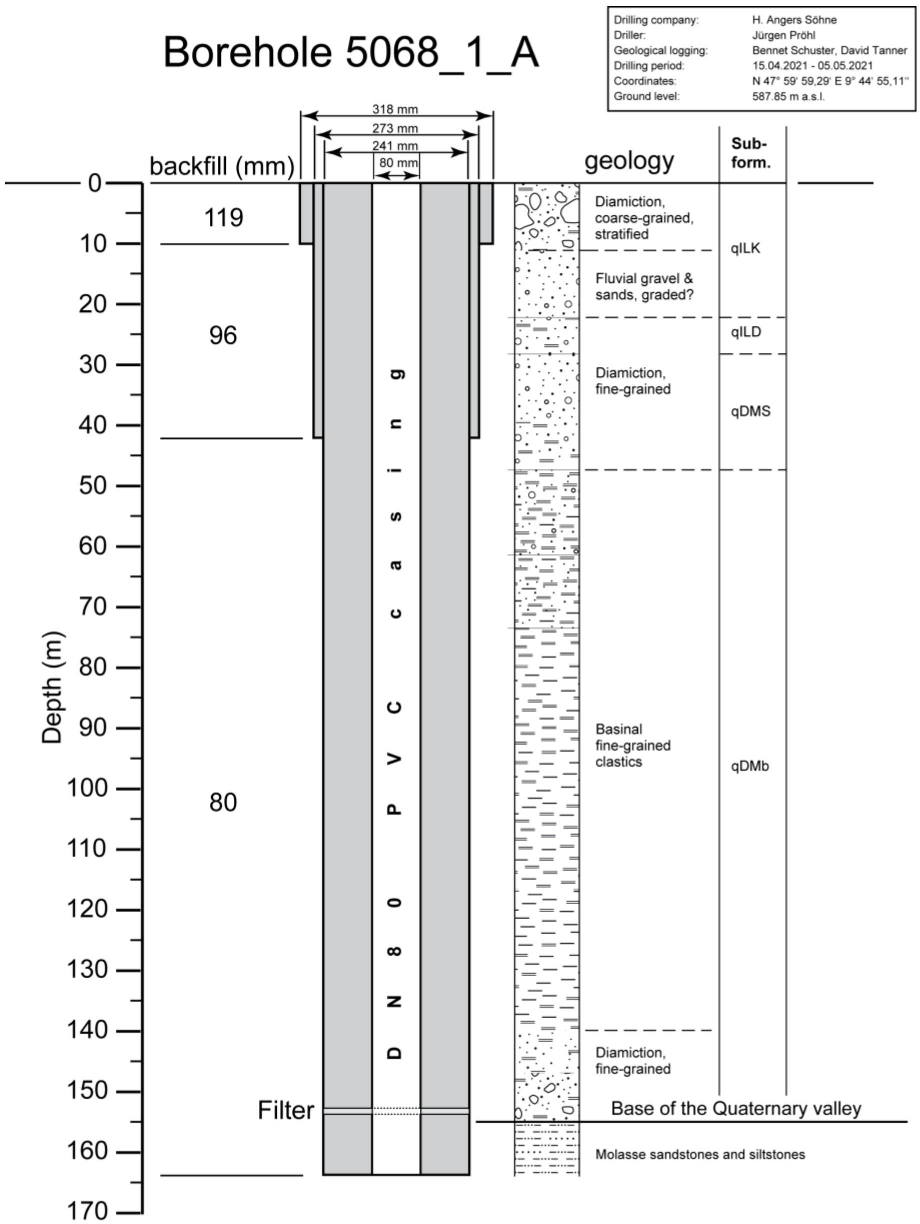

Figure 12A: Final geometry of the borehole 5068_1_A. Preliminary Quaternary subdivisions: gLK – Kisslegg Subformation (Wurmian); qILb – Illmensee basin sediment (Rissian – Wurmian), qDMS – Scholterhaus Subformation (Rissian), qDMb – Dietmanns basin sediments (Hosskirchian – Rissian). Molasse sandstones are Tertiary (Miocene) in age.

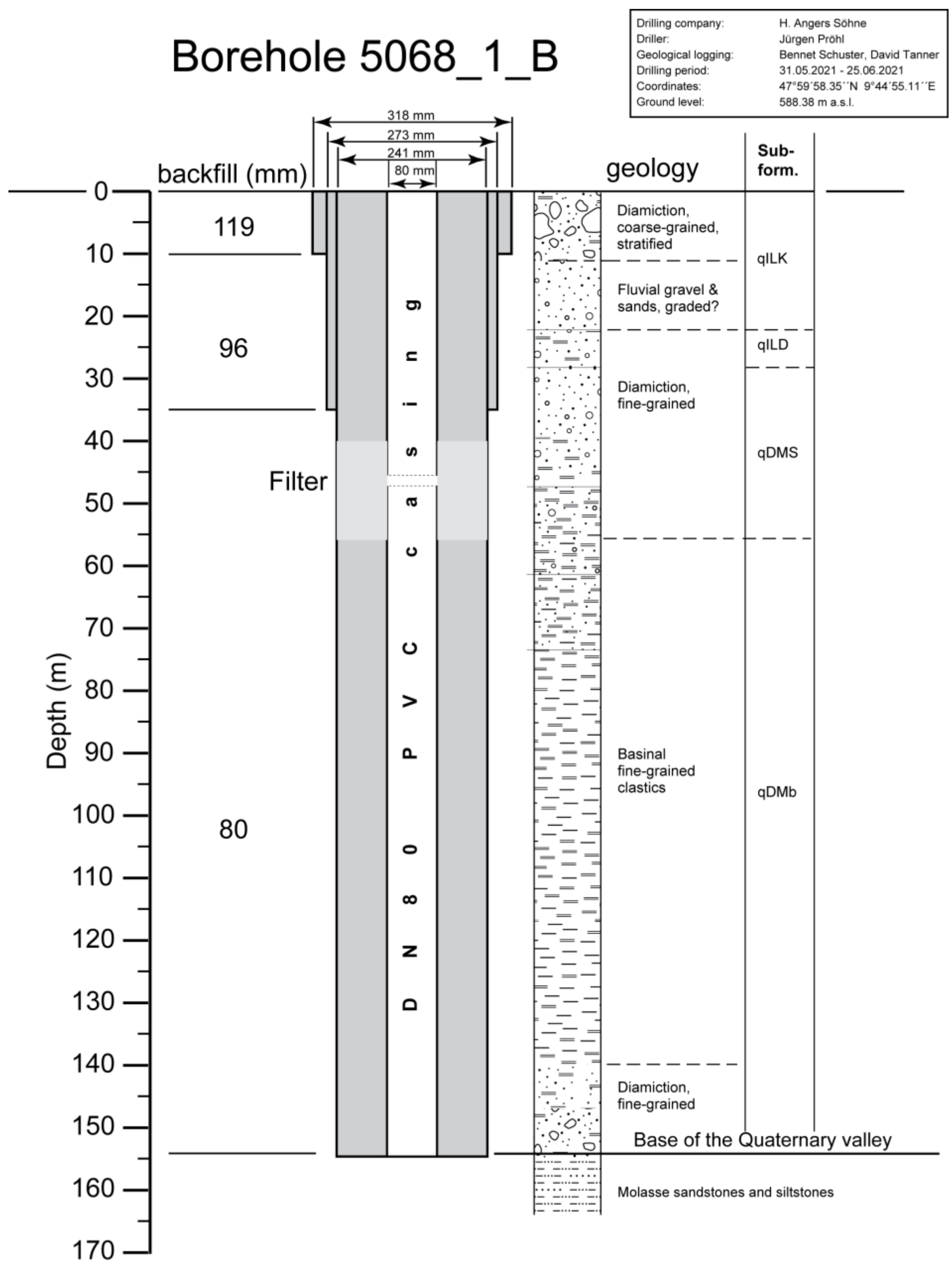

Figure 12B: Final geometry of the borehole 5068_1_B. Preliminary Quaternary subdivisions: gLK – Kisslegg Subformation (Wurmian); qILb – Illmensee basin sediment (Rissian – Wurmian), qDMS – Scholterhaus Subformation (Rissian), qDMb – Dietmanns basin sediments (Hosskirchian – Rissian). Molasse sandstones are Tertiary (Miocene) in age.

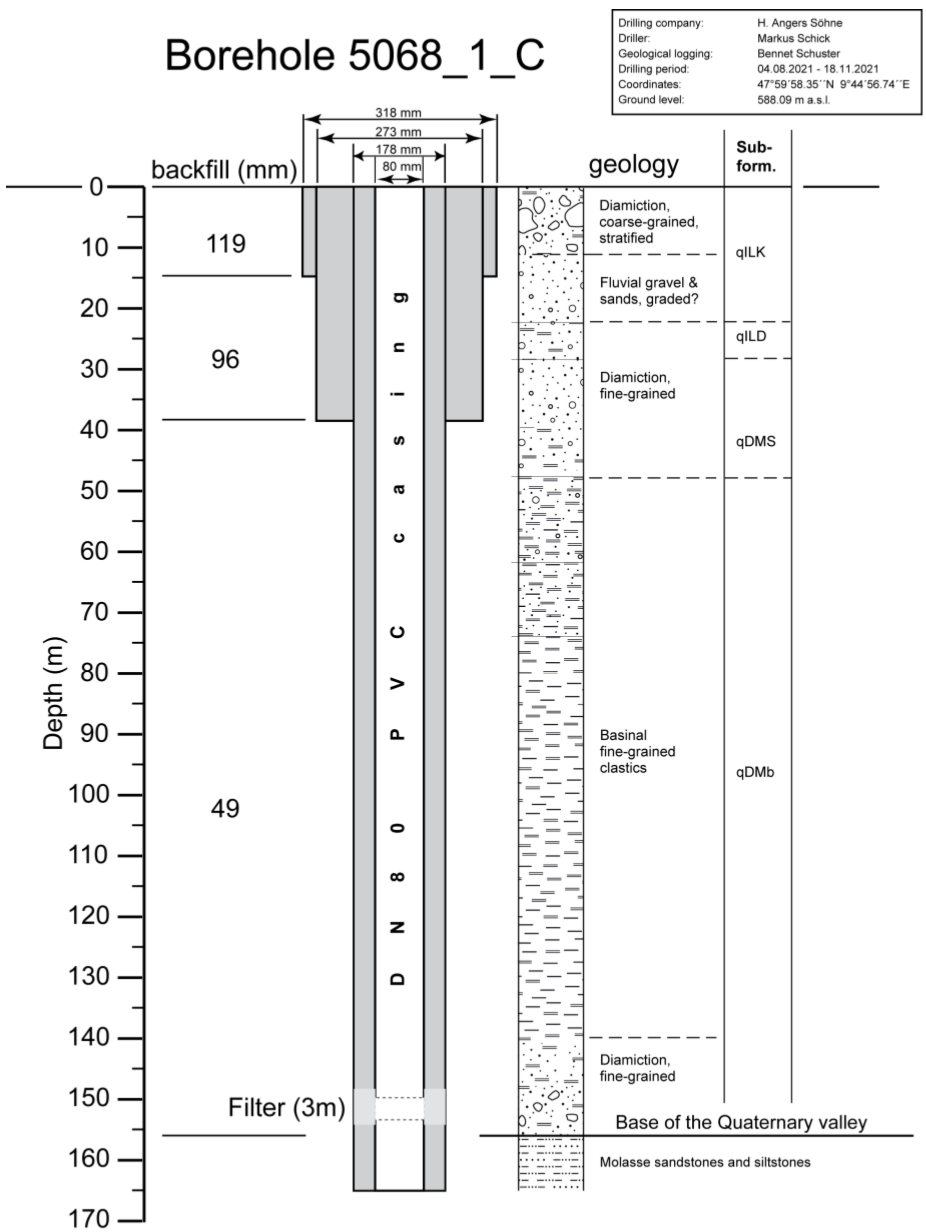

Figure 12C: Final geometry of the borehole 5068_1_C. Preliminary Quaternary subdivisions: gLK – Kisslegg Subformation (Wurmian); qILb – Illmensee basin sediment (Rissian – Wurmian), qDMS – Scholterhaus Subformation (Rissian), qDMb – Dietmanns basin sediments (Hosskirchian – Rissian). Molasse sandstones are Tertiary (Miocene) in age.

The ICDP 5068_1_C drill hole penetrated a succession of gravel-dominated, partly diamictic units (Fig. 12C). Below 38 m the sediments become finer, mostly silt dominated with varying clay content, occasionally interrupted by sand units (e.g., at 73–81 m and 99–104 m). In this section, rare outsized clasts were visible and indicate the presence of dropstones. At 136 m, the sediments become coarser and well-sorted sand units alternate with fine-grained diamicts, occasionally containing a significant amount of gravel. Sand becomes dominant at 149 m and the bedrock Tertiary Molasse deposits were encountered at 155 m. The bedrock is marly in appearance at the top (including macroscopically-observable fossil fragments), occasionally transsected by pure sandstone. The occurrence of sandstone increases towards the bottom and finally dominates from 164 m to the final depth of 166 m.

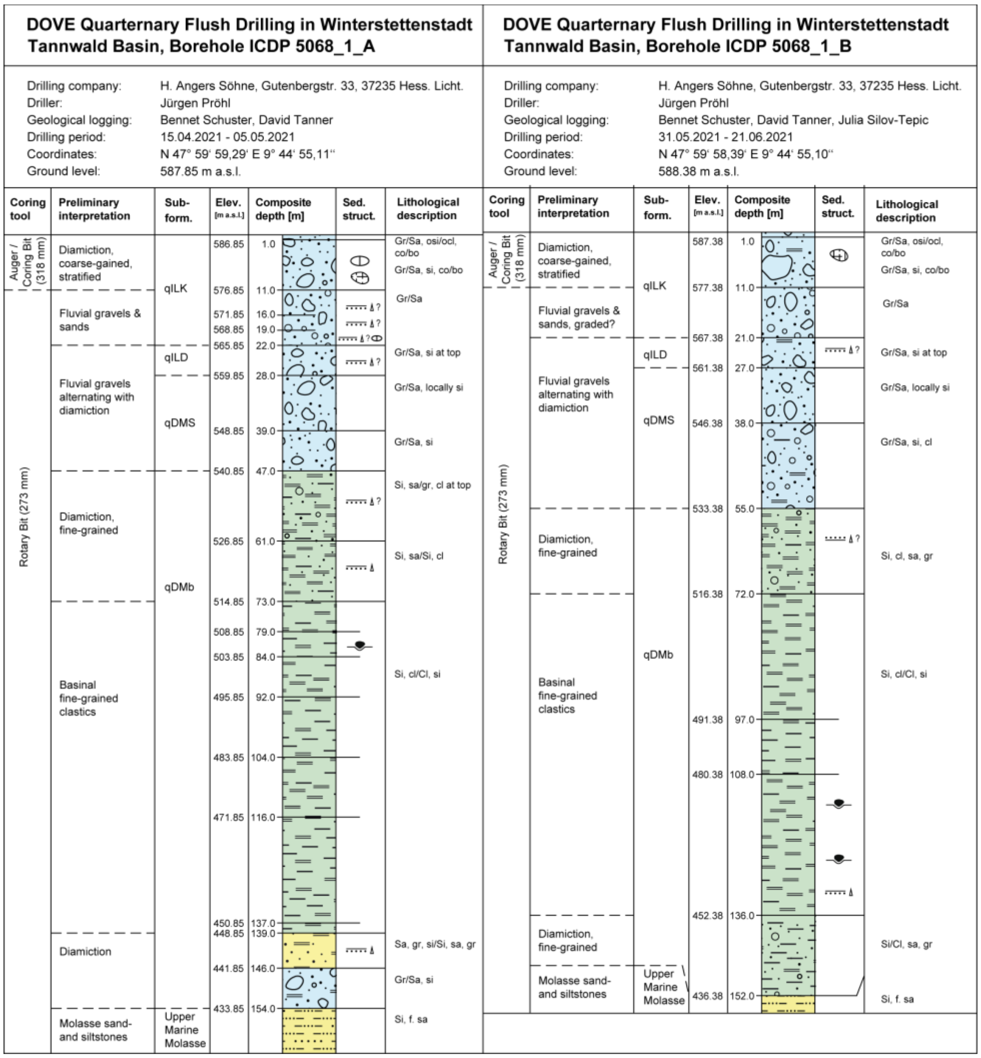

Figure 13: Preliminary profiles of the two flush boreholes ICDP 5068_1_A (left) and 5068_1_B (right). Larger stratigraphic units are linked to subformations found in the Schneidermartin research borehole (Fig. 2). Note that the lithological description uses the following abbreviations (capital letters for main components): boulders (Bo/bo), cobbles (Co/co), gravel (Gr/gr), sand (Sa/sa), silt (Si/si), clay (Cl/cl), organic silt (Osi/osi), organic clay (Ocl/ocl).

The flush drilling samples observed on-site have little potential to represent the lithologies encountered at depth, if not compared with existing information on the regional geology. However, the local geological setting is well documented based on extensive seismic p-wave survey (Burschil et al., 2018), geological maps, and the detailed description of an archived drilling (Schneidermartin borehole, see Figs. 2 and 3, and Buschil et al. 2018). Thus, with the help of this information, we were able to detect certain changes and connect them to units of the Dietmanns and Illmensee Formations. Two sedimentary profiles were constructed (see Fig. 13). Although these interpretations are preliminary and based on the flush boreholes, they still show the very local extent of known lithologies. Furthermore, they were useful for orientation during the core drilling, preparation for lithological changes while coring, and to enhance core quality.

Despite the limitations related to the interpretation of the cuttings from holes 5068_1_A and 5068_1_B, close monitoring of the lithologies during drilling in all three boreholes (by observing flush drilling samples, and surfaces at the top and the bottom of the drilled cores) allowed us to determine small-scale changes in the glacial-interglacial deposits between the three drilling locations. In only ca. 28 m distance between the two flush boreholes, the qDMS unit (Fig. 13) has a thickness difference of 9 m. Also surprising is the much thicker than expected uppermost qILK gravel layer (Fig. 13), despite its location on the western flank of the basin.

2.6. Scientific operations on-site

The scientific operations for the flush drillings were coordinated by the Leibniz Institute for Applied Geophysics, Germany, and the scientific operations for the core drilling were coordinated by the University of Freiburg, Germany. For the two flush drillings, two scientists were on-site all the time during the operational phase from the 12th April until the 1st July 2021. One scientist was on-site to accompany the core drilling from 4th August until the 11th November 2021 and was supported by a second scientist in the case of additional work, e.g. publicity.

2.6.1. Workflow flush drilling

At every metre of drilling, approx. 1 – 1.5 kg of drill cuttings from the drilling mud (known as cuttings in mDIS) was sampled using a large 0.5 mm mesh sieve. The sample was then carefully washed in water to remove most of the mud. At the geologist's table, a small portion (< 50 g) of the sample was placed on an aluminium tray. The rest of the sample was weighed and stored. The details, shown in Fig. 14, were noted, as applicable. For fine-grained material or grain characteristics, the sample was viewed with a hand lens or stereo, light-reflecting microscope. Finally, the sample in the aluminium tray was photographed for reference.

Each cuttings sample was stored in a clear plastic container with a lid. Each container was labelled with an ICDP label that contains a QR code and unique identifier of the sample. The details of each sample were then uploaded in to ICDP's database, the mDIS (mobile Drilling Information System).

Identifier and drillers information			
Project/Site		Curator	
Depth [m]		Day/Time	
Sieve [mm]		Comment by Driller	
Unwashed sample			
Sample weight [g]		Inferred Lithology	
Sorting		Colour	
Max grain size [mm]		Perc. Rock Clasts	
Perc. Mud clasts		Max diameter Mud clasts [mm]	
Comments			
Cuttings from rock clasts (> 2 mm)			
Petrography		Roundness	
Shape		Surface Texture	
Fossil		Plant remains	
Intact mud/matrix cuttings (> 2 mm)			
Internal Structures		Consistency	
Smear slide?			
Microscope analysis (< 0.2 mm)			
Petrography		Roundness	
Fossil		Plant remains	
Accessory Minerals			

Figure 14: The form used to document cutting samples from the flush drillholes.

2.6.2. Workflow drill-core handling

The on-site science team was present at the drill rig when each core was pulled on deck, noting timing and other details about the specific drilling procedure on the core run protocol. We inspected the bottom face of the core, conducted a first lithological assessment, and, when appropriate, sampled and/or photographed it. The drill team then pulled out the drill core in its plastic liner and transported it to a pipe handling rack, noting top and bottom depths. If the core was less than one metre long, the core liner was shortened accordingly to stop core material moving during transport. If excess material was present at the top of the core from drilling the casing after the last core run (re-core material), it was sampled in addition (cutting sample). If the quality of drilling was not satisfactory we discussed possibly reasons for core loss with the drilling team and were prepared to adjust drilling technology, bit type, or drilling fluid composition at any given time.

After the caps were taped on at each end of the liner, we received the closed liner from the drilling team and transported it to the geologist's core handling table. We then proceeded to label the liner, measure the total weight and length of the drill core/liner, and placed the drill core in a wooden box. The wooden core boxes were transferred to a cool storage room in the community centre of Winterstettenstadt the next evening, where the local authorities were kind enough to let us store the cores temporarily. We packed the core boxes on to pallets and transported them to the long-term cool storage at the Emmi Group AG, Bern, on the 3rd December 2021.

We continuously uploaded drill core metadata (number of core run, length of core run, time of core on deck, sections, length of sections, weight of sections, information on core loss, coring technology, onsite lithological description of core bottom, samples) to mDIS. Hole, Core, and any kind of sample were automatically assigned an IGSN (International Generic Sample Number). All samples were labelled.

2.6.3. On-site sampling

Biosphere sampling

We took samples to investigate microbial activity within the sediments at intervals of 3 m throughout the whole core. For this, preferably fine-grained sediment was sampled at the bottom of the core or the top of the removable core-catcher (85 cm in-section depth). Wearing gloves, we performed the sampling directly after the core was recovered in order to preserve the biological material and minimize contamination. The biosphere samples consist of two parts: The first part is the DNA sample. We used a sterile plastic syringe to punch out about 2 cm^3 of sediment and push it into a plastic tube (Fig. 15, left). The second part of the sample is the additional material sample. We used a conventional spatula that was sterilized with ethanol to fill about 20 cm^3 of sediment in a second plastic tube. This sample is reserved for optional additional measurements or as backup for the DNA sample. We stored the samples temporarily in a cool box, before freezing them the following evening. We took fifty-three samples and, after the drilling was completed, we send them to the University of Geneva for further investigation, planned to start in February 2022.

Figure 15: Left, taking a bio sample from the core. Right, vessel used to store samples for noble gas.

Noble-gas pore water sampling
We took bulk sediment samples of preferably fine-grained clastic materials with trapped pore water. We took the samples, similar to the biosphere samples, as early as possible after the core was recovered, just so as little volatiles as possible could escape the pore water. If possible (depending on type of sediment), we took cohesive chunks of material to capture and preserve as much pore-water as possible. The samples were stored in special containers, from which noble-gas concentrations will be measured directly (Fig. 15, right). We developed a sampling strategy in advance, based on findings from the nearby boreholes, existing geological mapping and the results from the first two flush drillings. Due to geological uncertainties, we often had to adjust the sampling distance, which is why the aspired sampling interval of about 13 m could not always be kept. We took a total of 14 samples. After drilling, we sent the samples to the Swiss Federal Institute of Aquatic Science and Technology on the 3rd December 2021 for further analysis. The samples will be used to date the glacial sediment succession using the ^{4}He/U-Th method on the pore water.

MSCL geophysical core logging
The following sensors were used: gamma attenuation, core diameter deviation, P-wave travel time and magnetic susceptibility. This resulted in processed data for: density (calculated from gamma attenuation and core diameter), P-wave velocity (calculated from an automatically picked P-wave travel time and core diameter), and corrected volume specific magnetic susceptibility (calculated from senor loop and core diameter). The MSCL dataset provides valuable data on rock/sediment density and magnetic susceptibility. However, P-wave velocity values are constantly low and of poor quality, therefore, they were not published. For details please see Explanatory Remarks.

2.6.4. Downhole geophysical measurements
Downhole geophysical measurements were conducted upon completion of the drilling operations of Hole 5068_1_A from 10.-11.05.2021 and Hole 5068_1_C from 11.-12.11.2021. After equipping the boreholes with PVC pipes all three holes 5068_1_A, 5068_1_B and 5068_1_C were logged from 09.-10.03.2022. Thomas Grelle and Carlos Lehne from LIAG carried out all the downhole geophysical measurements in the three campaigns.

In the first two campaigns, the first measurement was made using spectral gamma ray SGR (i.e., the instrument measures gamma ray (GR) plus K (wt%), Th (ppm), and U (ppm)) along the entire length of the borehole through the drill string. The drill string was then removed by the drill crew to a depth that precluded collapse of the borehole. The remaining probes were deployed in the open hole interval:

- CAL; Caliper (in perpendicular directions, in mm),
- DEV and DAZ; Deviation and deviation direction (in degrees from the horizontal and from north, respectively),
- DIP; Dipmeter (including CAL, DEV, DAZ plus the dip of geological strata)
- DLL; Resistivity (in Ωm, both near- and far-field),
- NN: Porosity (%),
- PE: Photoelectric absorption (barns/electron; b/e) and density (g/cm³ in Fig. 16),
- SALTEMP: Salinity (mS/cm) Temperature (°C) of the borehole fluid,
- SONIC; Seismic velocity (in m per second),
- SUSZ; Magnetic susceptibility (10^{-4} SI in Fig. 16).

In the third measurement campaign, in which LIAG surveyed the boreholes that had in the meantime been equipped with PVC pipes, only a limited measurement program could be carried out. In addition to the SGR, SONIC and SUSZ probes, it also includes our Array Induction Tool (AIND), which measures the electrical conductivity of the rock. However, it can only measure up to a few hundred Ωm. With our BHTV probe we tried to be able to see behind the PVC piping; however, this was not successful. The only information that can be obtained from this data is the location of the filter section and the borehole lining with the PVC pipes.

On 6th-8th July 2021, Jan Bayerle and Thomas Burschil from LIAG also carried out Vertical Seismic Profiling (VSP) measurements on boreholes 5068_1_A and 5068_1_B. Two types of VSP were acquired, i.e., zero offset and walk-away VSP measurements, in both boreholes. These measurements are still being processed.

Table 5: Wire-line logging overview. Tool abbreviations: AIND: Array Induction (electric conductivity), BHTV: Borehole Televiewer, CAL: Caliper, DIP: Dipmeter, DLL: Dual laterolog resistivity, GR: Gamma Ray, NN: Neutron porosity, PE: Density/Photoelectric factor, SGR: Spectral Gamma Ray, SONIC: Sonic log (seismic velocity), SUSZ: Magnetic susceptibility, TEMPSAL: Temperature and salinity of mud. Other Abbreviations: OH: measurements in open hole, CH: measurements in cased hole, OD: outer diameter.

Date/Hole	Run	Parameter	From [m]	To [m]	Hole Condition
10./11.05.2021 5068_1_A	1	CAL	160	43	OH
	1	DLL	160	43	OH
	1	NN	160	43	OH
	1	PE	160	43	OH
	1	SGR	143	0	CH
	1	SGR	160	130	OH
	1	SONIC	160	43	OH
	1	SUSZ+GR	160	43	OH
	1	TEMPSAL+GR	0	160	OH+CH
Remarks: Casing 0-43 m: 273 mm OD					
11./12.11.2021 5068_1_C	2	BHTV	164	85	OH
	2	DIP+GR	164	85	OH
	2	DLL	164	85	OH
	2	NN	164	20	OH+CH
	2	PE	164	10	OH+CH
	2	SGR	164	0	CH
	2	SONIC	164	85	OH
	2	SUSZ+GR	164	85	OH
	2	TEMPSAL+GR	0	164	OH+CH
Remarks: Drill string retracted 85 m					
09./10.03.2022 5068_1_A_3	3	AIND+GR	97	0	CH
	3	AIND+GR	155	95	CH
	3	BHTV	155	45	CH
	3	SGR	155	0	CH
	3	SONIC+GR	155	45	CH
	3	SUSZ+GR	120	105	CH

Remarks: -					
10.03.2022 5068_1_B_3	3	AIND+GR	145	40	CH
	3	BHTV	145	40	CH
	3	SGR	145	0	CH
	3	SONIC+GR	145	40	CH
	3	SUSZ+GR	145	0	CH
Remarks: -					
09./10.03.2022 5068_1_C_3	3	AIND+GR	165	0	CH
	3	BHTV	165	30	CH
	3	PE	165	0	CH
	3	SGR	165	0	CH
	3	SONIC+GR	165	50	CH
	3	SUSZ+GR	165	50	CH
Remarks: -					

2.7. Storage, initial core description and 1st sampling party

2.7.1. Sites 5068_1 and 5068_2

Prior to opening and initial core description and 1st sampling, the drill cores were stored in the cold-storage (4 °C) facility at the Institute of Geological Sciences, University of Bern and at Eawag Dübendorf. The sampling party and initial core description took place from 09/2022 to 02/2023. Each core section was cut, opened, and split lengthwise into an archive half for non-destructive analyses and a working half for physical sampling. The following work was conducted on each archive half: A high-resolution line scan was obtained, and each section was sedimentologically described and documented on a log sheet. The focus of these descriptions was: i) the dominant grain size; ii) type and thickness of bedding; iii) color; iv) contacts between different beds; v) secondary sedimentary structure; vi) quality of the core section; and vii) an overview of clast lithology and morphology. Furthermore, undrained shear strength (cu') and undrained uniaxial compressive strength (qu') were measured at 25, 50, and 75 cm section depth where applicable with a pocket vane-shear tester and a pocket penetrometer. Sedimentary lithotypes were defined and described based on the combined findings, and the whole sediment succession was assigned to the best-fit lithotype. X-ray computed tomography (CT) images of selected core sections were taken. Each working half was sampled for: i) grain-size distribution; ii) total inorganic and organic carbon (TIC and TOC); and iii) water content. Smear slides have been taken from interesting silt/clay-rich sections. Based on the line scans, samples were taken for a first screening of pollen content, luminescence dating, cosmogenic nuclide burial dating, and geotechnical analyses). After completing the description and the sampling campaign, the core halves were sealed in lightproof black foil, stored in standard-sized wooden boxes, and labelled according to the ICDP guidelines. After processing, the cores were sent to a large cool storage facility of the Emmi AG (Milchstrasse 9, 3012 Ostermundigen, Switzerland), where they are stored currently at the date of this report (August 2023). Till the end of the official moratorium (December 2024), access to samples/core is only possible by contacting Flavio Anselmetti or Gerald Gabriel.

2.7.2. Legacy sites 5068_3 through 5068_6

2.8. Site-specific preliminary scientific assessment

2.8.1. Geology

See Chapter 2.5.5 for the preliminary lithological assessment and Figures 12 A- C and 13 for a graphical overview of the lithological units.

2.8.2. Borehole Geophysics

The Explanatory Notes describe in detail how the pre-processing of the data of the three measurement campaigns was carried out. This includes, among other things, the matching of the depths of the individual measurements, the elimination of false measurement data, the splicing of measurement curves etc. With this knowledge it can be understood how to get from the raw data to the respective composite dataset, which is e.g. the basis for the presentation of the measurements in 5068_1_A (Fig. 16). At this stage of the project, the temperature values and gradient are disregard because the measurements were taken a few days after drilling, before the temperature in the borehole could re-equilibrate. The temperature profile will be remedied by later downhole logging.

Resistivity is high (>50 Ωm) around 50 m depth, gradually sinking with depth down to 95-105 m, where, in unison with the Spectral Gamma Ray (SGR), it irregularly rises to higher values, before returning to the background (clay) values of 10–20 Ωm until 137 m: Here similar to SGR, the basal units have a very high value (up to 100 Ωm) before returning to very low values in the Tertiary Molasse. Magnetic susceptibility shows very little change apart from a very large peak at 140 m (which must be considered an artefact, possibly caused by a piece of metal, perhaps from the drill bit) and slightly higher values in the Molasse. When this artefact is removed, the magnetic susceptibility may show more detail. Seismic velocity (Vp) is between 1700-1900 m/s at 50 m depth, peaking at 2200 m/s at the geophysical anomaly at 95-110 m depth. The sharp Quaternary base at 154 m is very clear in all measurements.

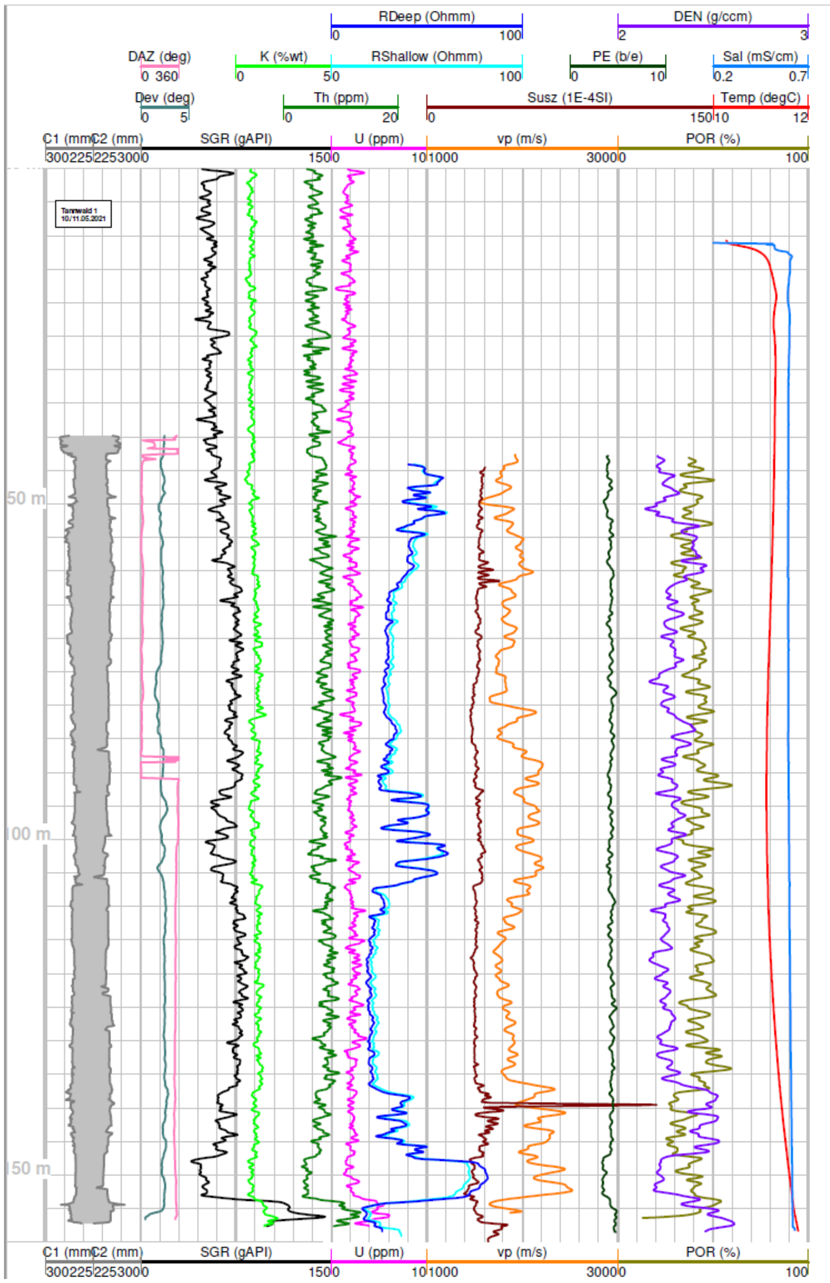

Figure 16: Results of the downhole geophysical measurements on the open hole of 5068_1_A.

3. Site 5086_2

3.1. Site Introduction

This section documents the drilling operations at ICDP Site 5086_2 that explored the sedimentary infill of the glacial overdeepening 'Basadingen Trough' located in the western Rhine-paleoglacier area (Müller, 2010). The scientific objectives and approach of the DOVE project are explained in detail in Anselmetti et al. (2022). The initial core description and interpretation of the cores from the Basadingen Trough (ICDP 5068_2_A) are presented in Schaller et al. (2023). For more details on the operations at the drill site also see Büchi et al. (2023).

3.2. Personnel in the Operational Phase

Technical project management and supervision

Marius W. Buechi, University of Bern, Switzerland
Flavio Anselmetti, University of Bern, Switzerland

Project and on-site science coordination

Sebastian Schaller (Ph.D. student), University of Bern, Switzerland
Bennet Schuster (Ph.D. student), University Freiburg, Germany
Marius W. Buechi, University of Bern, Switzerland
Flavio Anselmetti, University of Bern, Switzerland

Downhole geophysical measurements (LIAG, Hanover)

Hermann Buness, Leibniz Institute for Applied Geophysics, Hanover, Germany
Thomas Grelle, Leibniz Institute for Applied Geophysics, Hanover, Germany
Thomas Wonik, Leibniz Institute for Applied Geophysics, Hanover, Germany

External drilling advisor

Luka Seslak, Nagra, Hardstrasse 73, 5430 Wettingen, Switzerland

Drilling company (Fretus AG, Bad Zurzach)

Alex Küng (company liaison)
Lukas Seiler (company liaison)
Juan Gonzalez (driller)
Marek Bajcura (driller assistant)
Joaquim Teixeira (driller assistant)

Hydrogeological supervision

Lawrence Och, Dr. von Moos AG, Zurich, Switzerland

Off-site assistance & data management

Katja Heeschen, ICDP-OSG, GeoForschungsZentrum Potsdam, Germany

3.3. Site selection and permits

To determine the best location for the BASA drill site, LIAG (Leibniz Institute for Applied Geophysics, Hannover, Germany), in collaboration with ETH Zurich (Switzerland), acquired two high-resolution P-wave reflection seismic profiles across the Basadingen overdeepening in September 2019 (Fig. 17; Approval by Kanton Thurgau, Departement für Bau und Umwelt, 61.03). The resulting seismic sections revealed the general shape of the overdeepening as well as a potentially multiphase internal facies architecture, which was found in both profiles (Brandt, 2020). The central part of profile 2 (Fig. 18, ca. CDP 640-680) seemed most suited for drilling because all seismically mappable units could be cored by one vertical well.

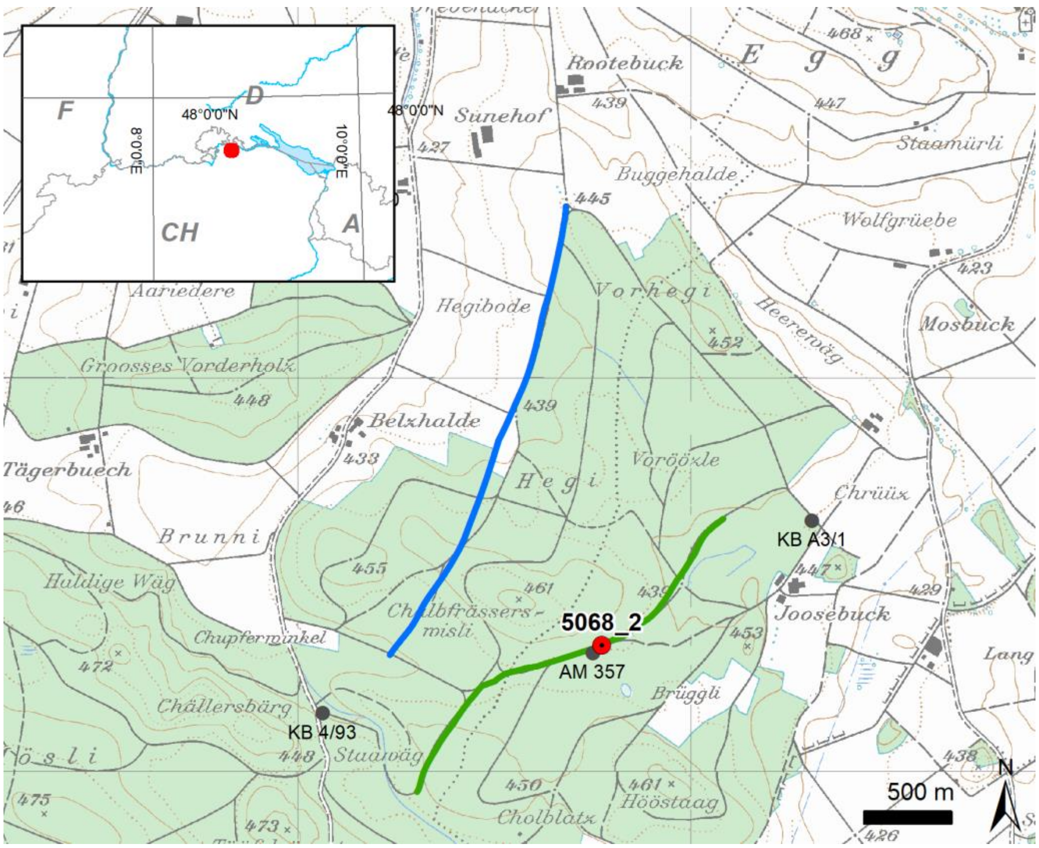

Figure 17: Location of the two high-resolution P-wave reflection seismic profiles acquired by LIAG in 2019. Profile 1 (blue) and profile 2 (green) run roughly perpendicular across the overdeepened basin. The red dot marks the position of the chosen drill site 5068_2. The grey dots indicate the location of flush drilling AM-357 and nearby shallow drill sites with archived logs.

In close discussions with the landowner and forester, a partially open area directly adjacent a forest road was selected to place the drill rig and all other installations. In total an area of 245 m^2 (plus additional spare areas of 39 and 29 m^2) was made available to DOVE from the landowner without charge. This arrangement was found to minimize the impact on the surrounding forest and allowed to keep the forest road open during the operations. The coordinates of 5068_2_A at the surface are given in Tab. 6.

At this site, located just N of the basin axis, the depth to bedrock was estimated to 240 m but considerable depth uncertainty was expected as only a simplified depth conversion had been applied (Brandt 2020). Minimal well control was provided from an archived description of a nearby flush drilling conducted in 1984 (AM-357, ca. 30 m WSW) with final depth of 201 m that did not reach bedrock (Müller, 2010).

The responsible authorities (mainly 'Politische Gemeinde Basadingen-Schlattingen' and 'Amt für Umwelt Kanton Thurgau) decided that the permission would be coordinated under the regular building permit procedure ('Baubewilligung'). The final building permit (No. 2021-0002 / 2021.01-122) was handed in on 11.01.2021, open for public consultation between 15.01. and 04.02.2021 and granted on 10.04.2021. The building permit included a permit for a temporary clearing of forest area around the drill site ('Rodungsbewilligung').

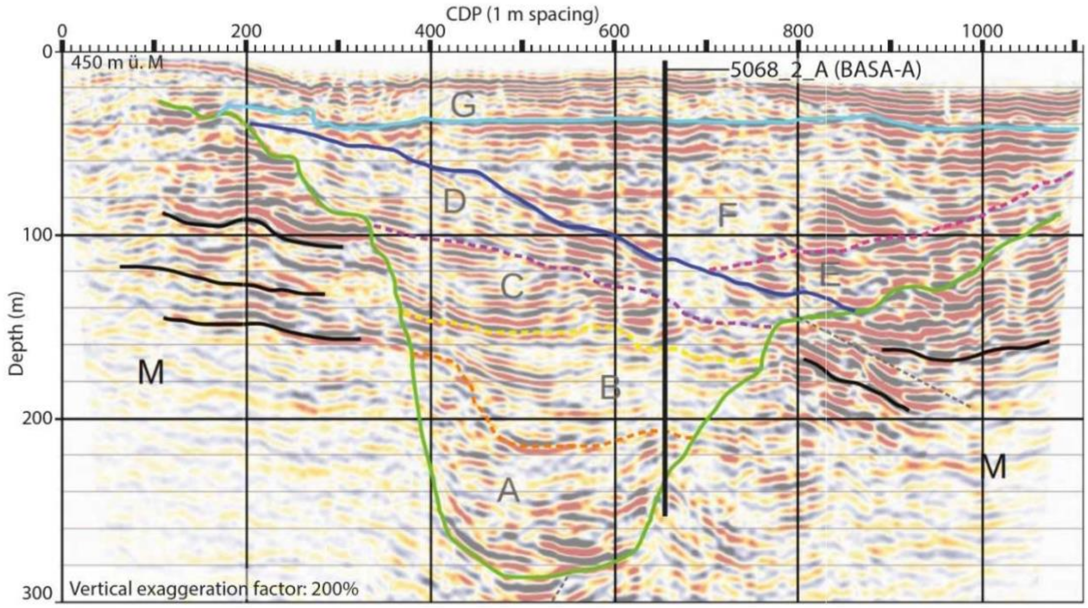

Figure 18: Pre-drilling interpretation of the seismic section 2 across the Basadingen Trough with the position of the final drill site (for location see Fig. 17, Brandt, 2020). M = bedrock (Molasse); green line = Base Quaternary; A-G = Seismic units; Black vertical line = drillhole 5068_2-A (BASA-A) with predicted bedrock at ~240 m depth. From Brandt 2020; see Schaller et al. (subm.).

3.4. Site preparation and infrastructure

After a joint visit of the drill site by representatives of the University of Bern, the drilling contractor (Fretus AG, Bad Zurzach) and the local authorities, landowner, forester and hunters on 21.4.2021, the final position of the drill point was marked (see Table 6) and the site was prepared for the operational phase. The forester moved wooden material to the backside of the open area and had to fell one tree close to the road. The remaining preparatory work was organized and installed by the drilling contractor (Fretus AG, Bad Zurzach) in accordance with the permit (Fig. 19).

Table 6: The coordinates of the final drill point at the surface.

Reference system	Coordinates	Ground elevation
CH1903+/LV95	2’698’774 / 1’278’321	445.1 m ü. M.
WGS84 *	47.648095564°N, 8.753256645°E	492.429 m

** Conversion according to NAVREF transformation service, www.swisstopo.admin.ch*

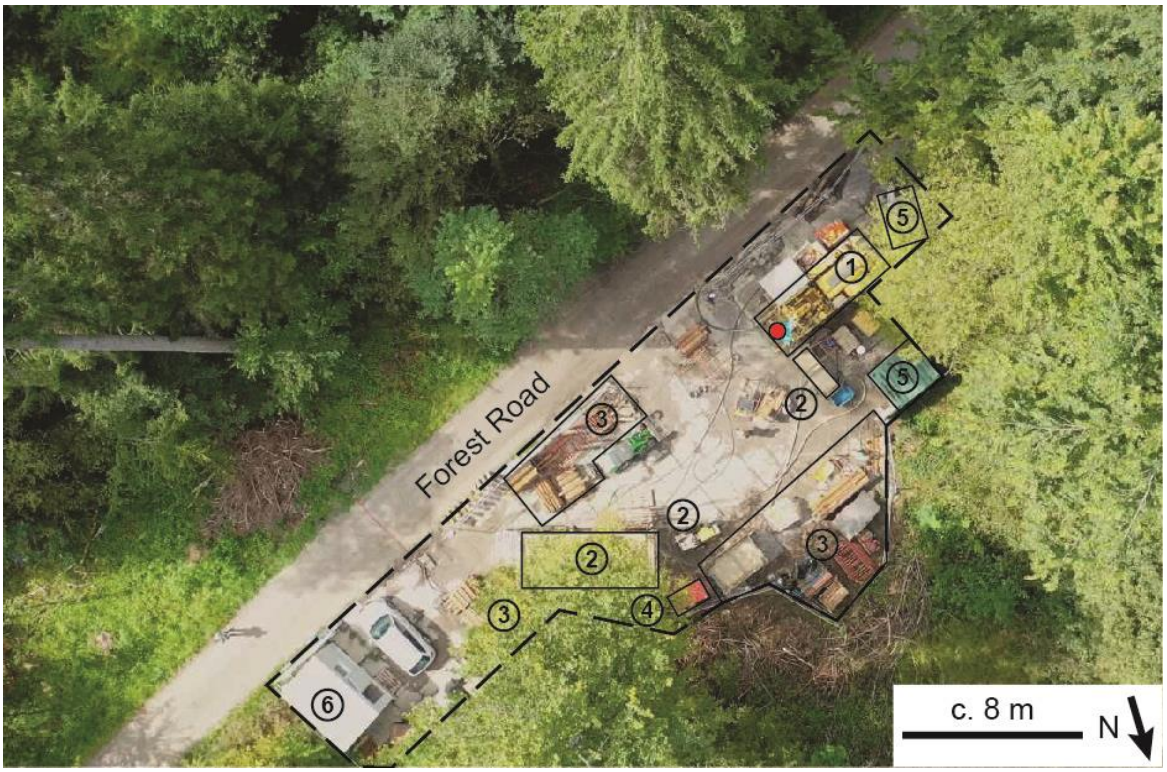

Figure 19: Aerial view of the installations at site 5068_2: 1) Drill rig, red dot marks the location of borehole 5068_2_A, 2) mud pump and tanks, 3) storage area of various components, 4) power generator, 5) tools and drill crew container, 6) science container.

The soil was protected by soil-protection mats extending from the existing forest road into the cleared areas. The drill rig was additionally supported by wooden planks. In addition, the ground beneath the drill rig was covered by a plastic tarp to protect the underground in the unlikely event of a leakage. Before the second drill rig (AGBO) was installed (see 5.2 detailed report of operations), a gravel bed was built to support the additional loads. Fretus AG installed a temporary water connection along the road from the next hydrant (Josenbuck) to the drill site. Electricity was supplied by a power generator on site.

For the scientific operations, a container was installed on the drill site for sampling and as a field office, while more space was available in a garage of a forestry repository at Josenbuck, where the cores were scanned for petrophysical properties using a Geotek MSCL scanner (owned by ICDP OSG) and temporarily stored before transport to the University of Bern.

3.5. Technical operations

3.5.1. Summary of drilling, coring and logging operations

After a public tender in late 2020, the University of Bern contracted the drilling company Fretus AG (Bad Zurzach, Switzerland) for the drilling operations, with the requirement to core in high-quality down to a depth of max. 300 m. The drilling crew consisted of two to three people (one drilling operator, one to two drilling workers). To achieve the scientific goals, the drilling company planned to work with different drill rigs depending on the depth and type of operations (Table 7).

Table 7: Drill rigs used during the operations.

Rig 1 - Nordmeyer DSB 1/6	0 - 228m depth drilling and coring
Rig 2 - AGBO G750	228 - 252 m depth, drilling and coring, (leased by Fretus from Groupe Grisoni)
Rig 3 - Comacchio MC15	Logging, refilling

Table 8 summarises the technical parameters of the drilling and coring operations in hole 5068_2_A. For coring of the first 58.0 m, a percussion coring system (Düsterloh-Hammer) was used. This system works without mud circulation ('dry coring') and was therefore very successful for the loose and, in parts, very permeable gravelly lithologies encountered in the upper part. Below 57.0 m the wireline triple tube core-barrel system CSK-146 was used. This method in combination with suited drill bits, core-catchers, and a fine-tuned mud-circulation yielded excellent core recovery and rapid progress in cohesive and sandy lithologies. In gravelly zones, repeated borehole collapses, and large drilling mud losses slowed down progress significantly (see 5.2 detailed report of operations). A total length of 252.0 m of core was recovered, with an overall recovery of 94 % (Fig. 20).

The time vs. depth plot shows the drilling processes for site 5068_2 (Fig. 21) and a weekly summary of the drilling operations (Table 8). Three longer periods without depth progress (marked with (1) to (3)) relate to technical challenges during the drilling process. (1) standstill was needed to deblock the casing (280 mm and 245 mm) and to stabilise the borehole walls, (2) is related to the change of the drill rig and unforeseen mechanical problems with drill rig 2, and (3) to deblocking the casing for before cementation.

At 252.0 m depth, drilling-mud losses and borehole collapses could not be managed (risk of blocking the drill string). It was therefore decided to stop the drilling even though the targeted bedrock had not been reached yet. After a return run down to 252 m, a successful geophysical downhole logging was performed by LIAG (see section 6.3). The lowest 2-3 m were blocked so that wire-line logging tools reached 249 m.

After completion of the coring and downhole geophysical logging, the borehole was refilled (see section 5.5) as there was no further use of the hole for further experiments. While retracting the casing after many months proved to be challenging, the refilling was conducted according to the plan and all casing was retracted. The drill site was fully cleaned up by the drilling contractor and returned to the landowner on 23.11.2021.

Table 8: Summary of the technical drilling and coring parameters for hole 5068_2_A.

	From [m]	To [m]	Diameter	Description
Drilling/Coring	0.0	57.0	133 mm	Düsterloh-Hammer (percussion drilling technique)
	57.0	252.0	146 mm	Wireline coring, CSK-146
	104.0	143.0	200 mm	Rolling cutter drill bit, for reopening & widening borehole
Casing (final state)	0.0	35.0	OD: 324 mm ID: 302 mm	Drill pipe, OD
	0.0	88.0	OD: 280 mm ID: 246 mm	Drill pipe
	0.0	105.0	OD: 245 mm ID: 224 mm	Drill pipe
Drilling mud	57.0	252.0	-	Polymer & bentonite
Liner	0.0	252.0	OD: 110 mm ID: 104 mm	PVC, dark orange, pre-cut to 1 m pieces

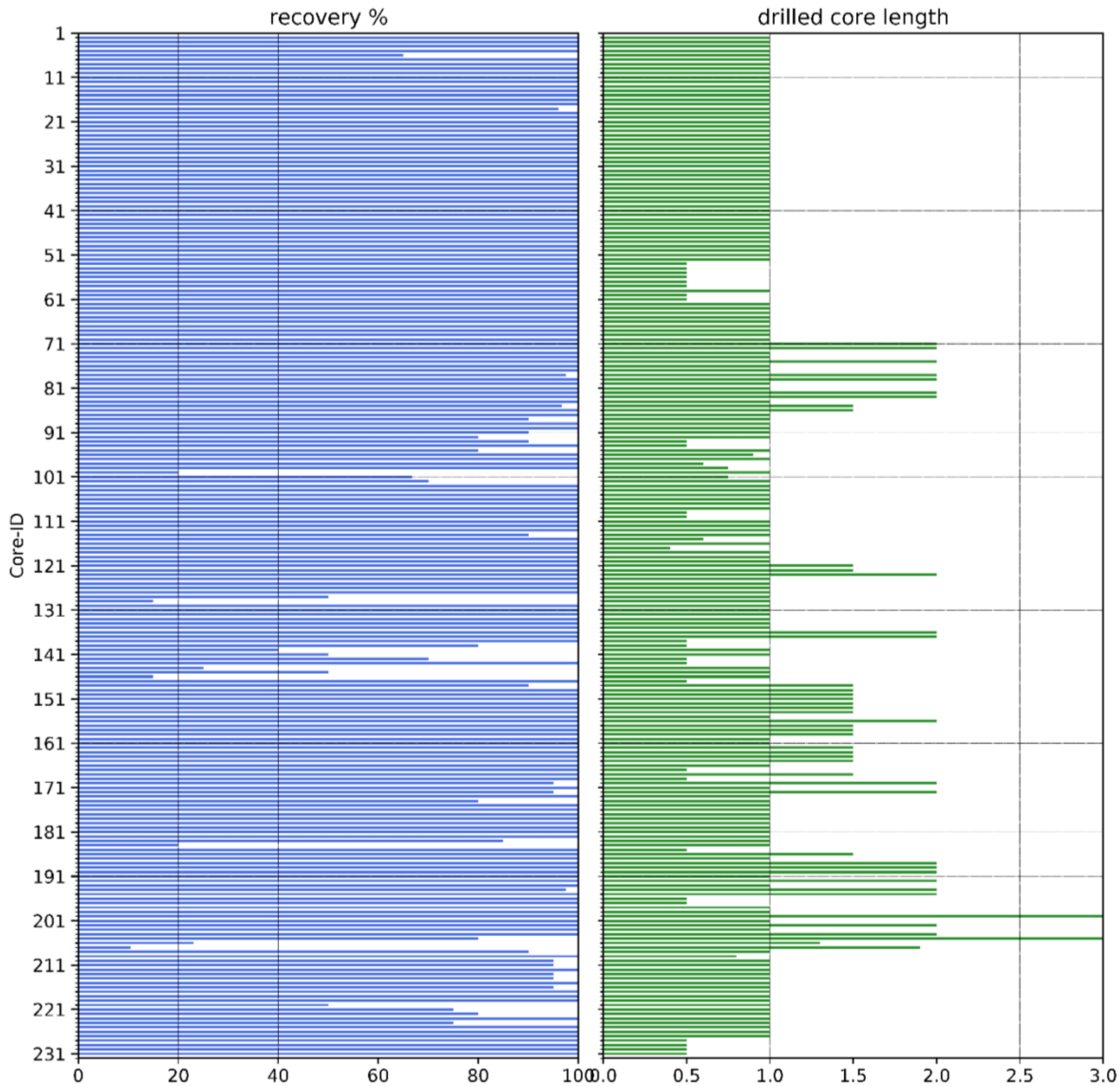

Figure 20: Recovery and core length for hole 5068_2_A. Recovery was determined based on the driller's information, which were transferred to mDIS.

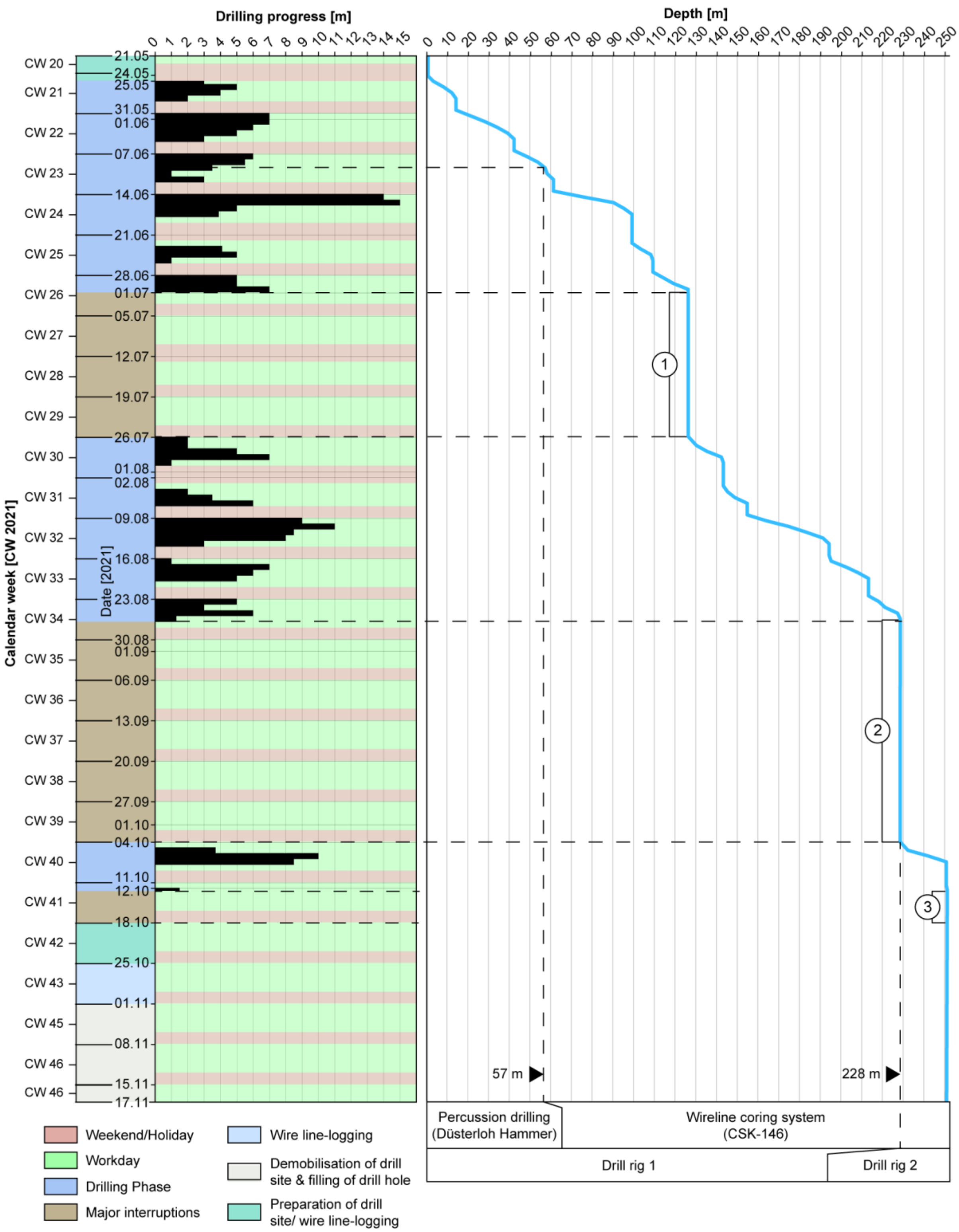

Figure 21: Depth vs. time plots for hole 5068_2_A.

3.5.2. Detailed report of operations

A detailed weekly summary of the drilling operations is given in Table 9.

Table 9: Detailed report of operations for site 5068_2.

Calendar week	Summary of technical operations and decisions
CW 20 **(17.5.-21.5.2021)**	• Transport and installation of drill rig (Nordmeyer DSB 1/6)
CW 21 **(24.5.-28.5.2021)**	• Inspection of drill site with external supervisor (L. Seslak), installations accepted • Drilling 0-15 m using Düsterloh Hammer (Ø 133 mm, core Ø 110 mm) • Continuous installation of casing (Ø 324 mm) down to 15 m • Ground water entering borehole 3-4 m and 10-11 m
CW 22 **(31.5-5.6.2021)**	• Drilling down to 35 m using Düsterloh Hammer (Ø 133 mm, core Ø 110 mm) • Continuous installation of casing Ø 324 mm • Ground water entering borehole 28-29 m, disturbed water table at 28.5 m • Installation of casing Ø 280 mm down to 35 m • Drilling down to 42 m using Düsterloh Hammer (Ø 133 mm, core Ø 110 mm) • Continuous installation of casing Ø 280 mm down to 42 m
CW 23 **(7.6.-11.6.2021)**	• Drilling down to 57 m using Düsterloh Hammer (Ø 133 mm, core Ø 110 mm) • Continuous installation of casing Ø 280 mm down to 58 m • Switching to wire-line coring (CSK 146), • Drilling down to 58 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Changing drill bit • Drilling down to 61 m using CSK 146 (Ø 146 mm, core Ø 110 mm)
CW 24 **(14.6.-18.6.2021)**	• Drilling down to 95 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Core loss (see recovery plot) • Loss of drill mud at 93.9-95 m • Drilling down to 95 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Continued core losses (see recovery plot) • Continued loss of drill mud at 95-98.9 m • Attempt to seal borehole wall with bentonite
CW 25 **(21.6.-25.6.2021)**	• Re-open borehole, sealing borehole wall, and changing drill bit • Continued loss of drill mud at 95-98.9 m • Drilling down to 109 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Continued core losses down to c. 103 m (see recovery plot) • Continued loss of drill mud at 98.9-103 m
CW 26	• Re-open borehole down to 109 m • Drilling down to 126 m using CSK 146 (Ø 146 mm, core Ø 110 mm)

(28.6.-2.7.2021)	• Installing casing Ø 245 mm down to 60 m
CW 27 **(5.7.-9.7.2021)**	• Installing casing Ø 245 mm down to 95 m • 6.7.2021: casing Ø 245 mm blocked, no rotation possible • To unblock casing Ø 245 mm: drill with casing Ø 280 mm over casing Ø 245 mm, down to 71 m
CW 28 **(12.7.-16.7.2021)**	• Continue workaround to unblock casing 245 mm: drill with casing Ø 280 mm over casing Ø 245 mm, continued in steps down to 89 m
CW 29 **(19.7.-23.7.2021)**	• Casing 245 mm Ø finally deblocked • Complete retraction and reinstallation casing Ø 245 mm • Re-opening borehole with CSK 146 down to 105 m • Changing drill bit • Re-opening borehole with CSK 146 down to 123 m • Continued borehole instability. • Installation of rolling cutter bit
CW 30 **(26.7-30.7.2021)**	• Re-opening borehole with rolling cutter drill bit (200 mm Ø) down to 126 m • Installation of CSK • Drilling down to 143 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Minor core and drilling mud losses
CW 31 **(2.8.-6.8.2021)**	• Re-opening borehole with rolling-cutter drill bit (Ø 200 mm) from 126-143 m • Installation of CSK • Drilling down to 154.5 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Continued bore-hole instability, core losses and drilling-mud losses
CW 32 **(9.8.-13.8.2021)**	• Drilling down to 194 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Minor drilling-mud losses
CW 33 **(16.8.-20.8.2021)**	• Changing drill bit, maintenance, mud curation • Drilling down to 213 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Minor drilling-mud losses
CW 34 **(23.8.-20.8.2021)**	• Drilling down to 228.3 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Performance limit of drill rig reached; decision to switch drill rig • Minor drilling mud losses
CW 35 **(30.8.-3.9.21)**	• Remove & transport drill rig (Nordmeyer DSB 1/6) • No drilling
CW 36 **(6.9.-10.9.21)**	• Laying of a stable gravel bed for heavier truck-mounted drill rig • Installation of new drill rig (AGBO G750) • Repair work on hydraulic pump • No drilling
CW 37 **(13.9.-17.9.21)**	• Continued repair work on hydraulic pump and other components • No drilling

CW 38 **(20.9.-24.9.21)**	• Continued repair work (various components), support by technician from manufacturer • No drilling
CW 39 **(27.9.-1.10.21)**	• Final preparatory work • Re-opening borehole and widening borehole rolling-cutter drill bit (Ø 152 mm) down to 228.3 m, replace drilling mud • Prepare installation of CSK
CW 40 **(1.10.-8.10.2021)**	• Installation of CSK • Flush and re-open borehole down to 228.3 m • Drilling down to 250 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Retract CSK 146 to changing drill bit
CW 41 **(11.10.-15.10.2021)**	• Retract CSK 146, changing drill bit and re-install CSK 146 • Drilling down to 252 m using CSK 146 (Ø 146 mm, core Ø 110 mm) • Core losses • Attempts to continue drilling but borehole cannot be sealed (drill mud is lost) and borehole collapses (with high risk of blocking the drill string). • Joint decision to stop drilling • Retract CSK 146
CW 42 **(18.10.-22.10.2021)**	• Remove & transport drill rig (AGBO G750) • Transport & installation of new drill rig (Comacchio MC15) for downhole logging and refilling
CW 43 **(25.10.-29.10.2021)**	• Install CSK 146 • Perform return run with CSK 146 down to 248 m and retract to 175.9 m to clean borehole in preparation to downhole logging of first stage • Downhole logging of first stage (see logging report) • Retract CSK 146 up to 118.9 m • Downhole logging of second stage (see logging report) • Fully retract CSK 146 • Attempt to retract Ø 245 mm casing fails (same for Ø 280 mm casing) • Downhole logging of third and final stage (see logging report) • Clean up and preparatory work for borehole cementation and re-filling
CW 44 **(1.11-5.11.2021)**	• Continued attempts to deblock Ø 245 mm and Ø 280 mm casing • Fully retract casing Ø 245 mm and Ø 280 mm casing • Clean up and preparatory work for borehole cementation and re-filling • Refilling borehole according to accepted refilling scheme • Cementation of first stage (248-200 m, 400 kg cement Küchler INJEKTHERM 110 HS) before weekend break
CW 45 **(8.11.-12.11.2021)**	• Continued refilling borehole according to refilling scheme • Cementation 200-80 m and 80-55 m in two stages (2000 and 1200 kg cement Küchler INJEKTHERM 110 HS) • Fill borehole with swelling clay 55-50 m (500 kg, Mikolit 300 M) • Fill borehole with gravel 50-12 m (3 m^3)

	• Fill borehole with swelling clay 12-5 m (1000 kg, Mikolit 300 M) • Fill borehole with earth/humus 5-0 m • Retracting Ø 323 mm casing parallel to refilling stages
CW 46 **(15.11.-19.11.2021)**	• De-installation of drill site • Disposal of gravel bed and recultivation of drill site • 17.11.2021 Fretus AG finished work on site
CW 47 **(22.11-26.11.2021)**	• 23.11.2021: Inspection of site with forester/representative of landowner (S. Pachera); site acceptance and returned • 23.11.2021: Inspection of forest road with responsible (P. Eicher); no damages found

3.5.3. Borehole deviation

The borehole deviation of 5068_2_A was measured as part of the downhole geophysical logging after completion of the drilling operations. The results indicate only a minor deviation of max. 0.77 m to the SSE (Fig. 22). The borehole can be considered essentially vertical. Note that due to the still existing drill pipe for the top 105 m, only the inclination of the borehole could be determined with accelerometers. The direction of the deviation is determined with fluxgate magnetometers. Therefore, the borehole direction in the cased area was assumed.

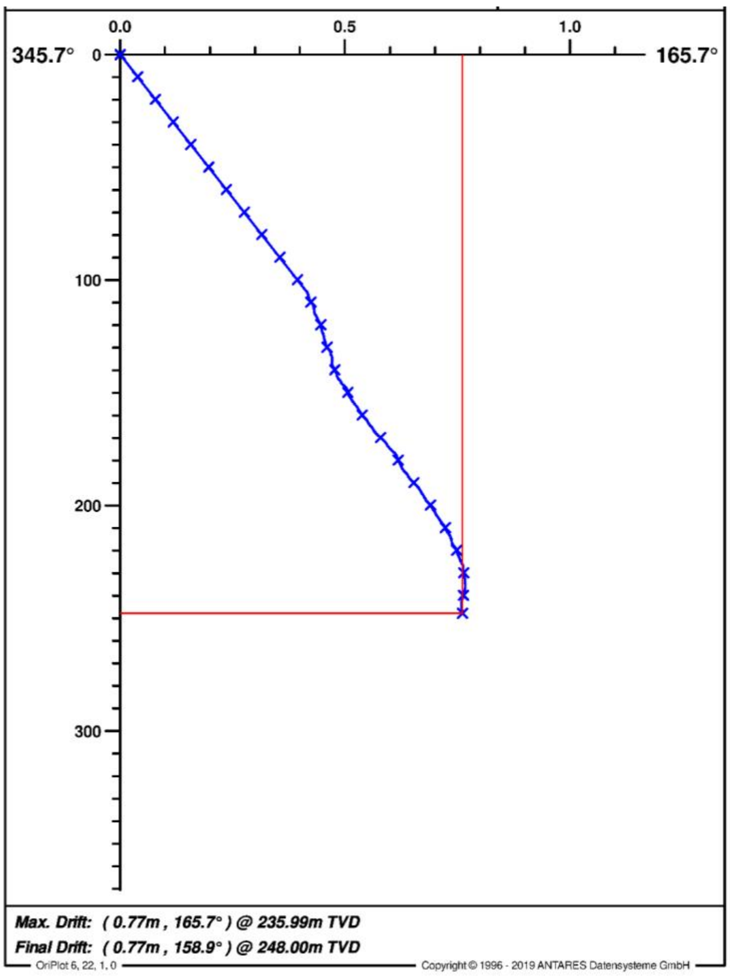

Figure 22: Borehole deviation of 5068_2A in vertical view (unit of both axes is meter).

3.5.4. Refilling and Post-Drilling Finishing Procedure

After completion of the coring and downhole geophysical logging, the borehole was refilled. Fig. 23 shows the preliminary lithological profile at that point (based on core ends, core catchers, and preliminary MSCL data) and the borehole geometry. The following refilling plan was then proposed by the hydrogeological consultants (Dr. von Moos AG, Appendix A) and accepted by environmental authorities (Amt für Umwelt, Kanton Thurgau), the drilling contractor (Fretus AG) and the University of Bern:

- 253-55 m: Cementation in 2-3 stages using sulphate-resistant cement (product used: Küchler INJEKTHERM 110 HS)
- 55-50 m: Swelling clay (product used: Mikolit 300 M)
- 50-12 m: Clean gravel
- 12-5 m: Swelling clay (product used: Mikolit 300 M), water to be added to ensure fast swelling.

- 5-0 m: Clean cover material & humus/soil (“Deckschicht (Erde/Humus)”)

3.5.5. Borehole geometry and preliminary lithology assessment

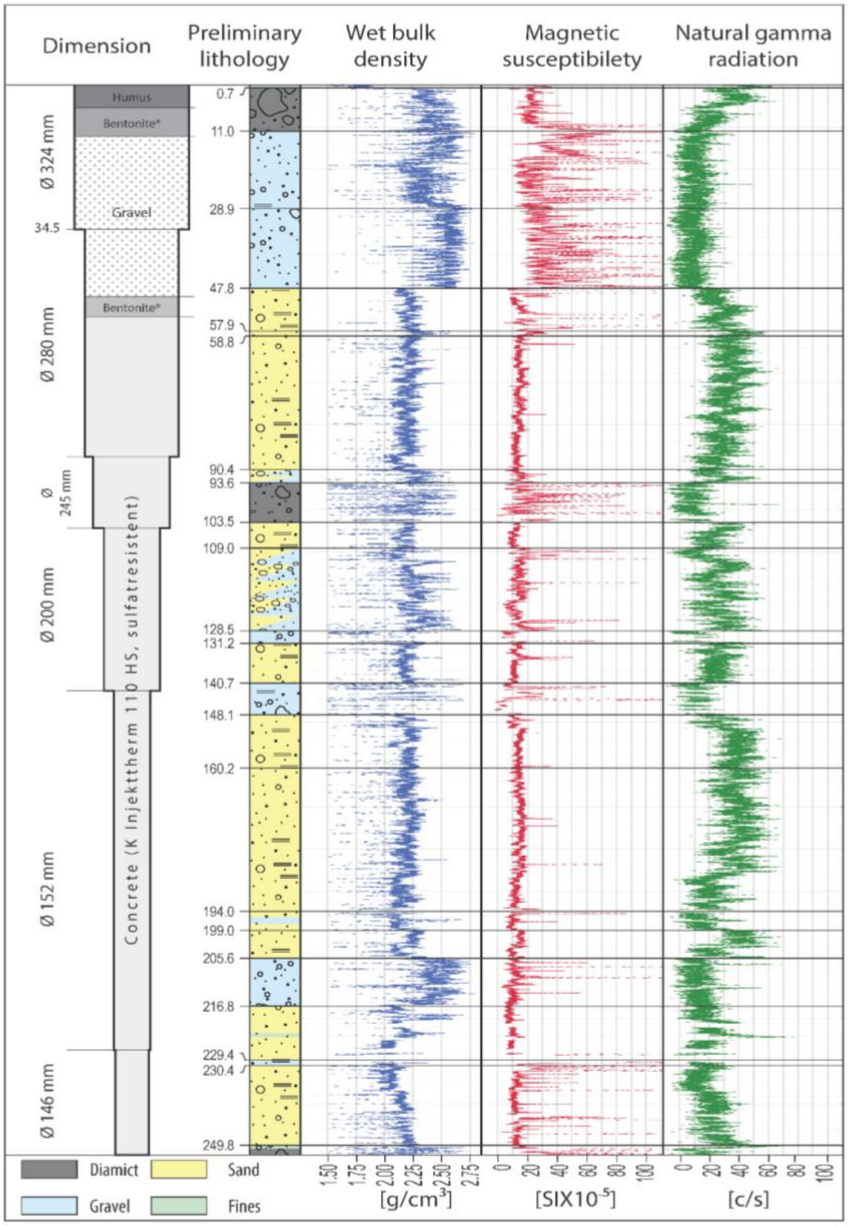

Figure 23: Borehole geometry and preliminary lithological profile (based on core end and MSCL data only) with final refilling scheme.

The drilled succession of the Basadingen overdeepening (Fig. 23) can be roughly divided into two parts: In the lower part between 252 and c. 48 m depth, the valley filling consists of sand with a highly variable silt/clay content, which is divided into larger packages by gravel and diamict layers. Between c. 90 and c. 148 m depth, the dominance of sands decreases, and alternating bedding with gravels on a meter to decimeter scale is observed. The upper part of the succession, between c. 48 and c. 11 m depth, consists of mostly sandy gravels and is capped by a primarily diamictic succession above c. 11 m.

3.6. Scientific operations on-site

The scientific operations for the core drillings were coordinated by the University of Bern. At least one scientist (mainly S. Schaller) was on site to accompany the core drilling, take samples, and to MSCL scan the cores. The drill-site geologist/scientist was supported by a second scientist and the external drilling advisor (L. Seslak) if needed.

3.6.1. Workflow drill-core handling

The cores handling was divided between the drilling team and the scientist according to defined procedures. After recovery, the drill crew and the scientists would usually first inspect the lithology visible at the core end. The drill crew was then responsible for closing the plastic liner with caps, adding a preliminary label (with core run, driller's depth, and orientation) and cutting the core into 1 m-sections if needed (Fig. 20). The core catchers were usually not kept as separate sections but pushed back into the liner. The core would then be handed over to the drill-site scientist, who documented the drilling procedure per core in a detailed core-run protocol (Fig. 24) and completed labelling of the core and the core-box according the ICDP standards. As there was no stable network coverage on the drill site, the data upload to mDIS was usually done at the end of the working day.

Geologist:	Place:	Core run (CR):	Date:

Core info for mDIS	Core ID:

Core on Deck (CoD)	Top Depth [mblf]	Drilled Core Length [m]	Nr of Section	Core type		Core Ø [mm]	Oriented	
				Hammer	Rotation		Yes	No

Reason for core loss/ General core remarks:

Barrel length [m]	Bit type	Drilling fluid type	Additional drillers info:

Section info for mDIS	Section ID:

Section length [m]	Exists extra Core catcher	CC pushed back	Weight [kg]	Nobel gas samples		Deep-Bio samples	
				Yes	No	Yes	No

CC-Section info for mDIS	Length [m]:	Weight [kg]:	Nobel gas samples: yes/no	Deep-Bio samples: yes/no

Lithology:	Nobel gas Samples
If light exposed:	Deep-Bio Samples
General Remarks:	

Figure 24: Core-run protocol template filled out by the drill-site scientist. The paper-based version was then

transferred to mDIS.

The drill-site scientist also took the on-site samples according to the sample requests and instructions for noble-gas and deep-biosphere sampling (section 6.2). These samples were taken before closing of the liner if the core end suggested a suited lithology and high core quality. Samples were automatically assigned an IGSN (International Geo Sample Number) and labelled according to the ICDP-standard, automatically generated by mDIS.

The cores were stored in wooden core boxes and first transferred to the forestry repository at Josenbuck by car. There, the cores were scanned with the ICDP-OSG's Geotek MSCL and temporarily stored. The cores were then transported to the cool storages at the Institute of Geological Sciences, University of Bern, and once this was full, to the one at Eawag, Dübendorf (usually within 2-3 days after recovery).

3.6.2. On-site sampling

Biosphere sampling (method identical to site 5068_1; see 2.6.3)

According to sample request DOVE_2_2-A-MBIO, we took samples to search for microbial activity within the fine sediments at intervals of ca. 3 m and within the coarse sediments at intervals of ca. 10 m throughout the whole core. We stored the samples temporarily in a cool box, before freezing them in a freezer in the forestry repository at Josenbuck (usually within hours after sampling). We took 61 samples and, after the drilling was completed, we sent them to University of Geneva for further investigation in February 2022.

Noble-gas porewater sampling (method identical to site 5068_1; see 2.6.3)

According to sample request DOVE_1_2-A-NOBE, we took bulk-sediment samples of preferably fine-grained clastics with trapped pore water at intervals between ca. 10 - 20 m due to varying geology and the developed sampling strategy. We took a total of 16 samples, which were sent batch-wise during the drilling operation to Eawag, Dübendorf for further analysis. The samples will be used to date the glacial sediment succession using the ^{4}He/U-Th method on the pore water.

Bulk samples from borehole widening

When working with the Düsterloh-Hammer technique, the driller first pulled the core, then widened the bore hole to the diameter of the casing (Ø 324 mm and later to Ø 280 mm) and then remove the excess material using the Düsterloh (with varying core chambers attached). This excess material is a disturbed mix of the last core/casing interval, but the components are relatively original. We therefore sampled additional bulk samples of this material in 5l buckets as back-up material for upcoming analysis (e.g., clast analysis).

MSCL geophysical core logging (method identical to site 5068_1; see 2.6.3)

Same procedure and tools as at Site 5068_1, with the addition that at Site 2 (5068_2) natural gamma radiation including K, Th, and U-Log was also measured. For details please see Explanatory notes.

3.6.3. Downhole geophysical measurements

Downhole geophysical measurements and a vertical seismic profile (VSP) were conducted upon completion of the coring operations from 26. - 29.10.2021. Prior to logging the open hole section (105-250 m) a return run was ordered to have a clean borehole and stable borehole for logging. Thomas Grelle, Carlos Lehne and Hermann Buness (all LIAG, Hanover) carried out the downhole geophysical measurements.

Table 10: Wire-line logging overview. Tool abbreviations: BHTV: Borehole Televiewer, CAL: Caliper, DLL: Dual laterolog resistivity, EBS: Elemental composition, GR: Gamma Ray, NN: Neutron porosity, PE: Photoelectric index, SGR: Spectral Gamma Ray, SONIC: Sonic log, SUSZ: Magnetic susceptibility Log, VSP: Vertical Seismic Profile. OH: measurements in open hole, CH: measurements in cased hole

Date	Run	Parameter	From [m]	To [m]	Hole Condition
26.10.2021	1	BHTV	250	175	OH
	1	CAL	250	175	OH
	1	DLL	250	175	OH
	1	EBS	250	175	OH
	1	NN	250	175	OH
	1	PE	250	175	OH
	1	SGR	250	175	OH
	1	SONIC	250	175	OH
	1	SUSZ + GR	250	175	OH
Remarks: CSK-164 drill string retracted to 175 m					
27.10.2021	2	BHTV	175	120	OH
	2	DLL	175	120	OH
	2	NN	175	120	OH
	2	SGR	175	120	OH
	2	SONIC	175	120	OH
	2	SUSZ+GR	175	120	OH
	2	VSP	246	120	OH+CH
Remarks: CSK-164 drill string retracted 120 m, EBS not working					
28.10.2021	3	BHTV	120	105	OH
	3	SUSZ + GR	120	105	OH
	3	VSP	208	82	OH+CH
Remarks: CSK-164 drill string retracted 105 m					
29.10.2021	4	CAL	175	105	OH
	4	NN	120	105	OH
	4	PE	175	105	OH
	4	SGR	120	0	OH+CH
	4	SONIC	120	105	OH
Remarks: -					

The first measurement was made using spectral gamma ray SGR (i.e., the instrument measures the sum of natural gamma ray (GR) plus K (wt%), Th (ppm), and U (ppm)) along the entire length of the borehole through the drill string. The drill string was then removed by the drill crew at intervals to depths that precluded collapse of the borehole (175 m, 120 m, and 105 m). The remaining probes were deployed in the area of the open hole:

- BHTV; Borehole Televiewer, ultrasonic image of the borehole wall
- CAL; Caliper (in perpendicular directions, in mm),
- DLL; Resistivity (in Ωm, both near- and far-field),
- EBS; pulsed neutron induced borehole n-/γ-spectroscopy; element composition (in cps)
- NN: Porosity (%),
- PE: Photoelectric absorption (barns/electron; b/e) and density (g/cm^3 in Fig. 26),
- SONIC; Seismic velocity (in m per second),
- SUSZ; Magnetic susceptibility (10^{-4} SI in Fig. 26),
- VSP; Vertical seismic profile.

3.7. Storage, initial core description and 1st sampling party

Please see Chapter 2.7. For sample accessibility please contact: Falvio Anselmetti, University of Bern

3.8. Site-specific preliminary scientific assessment

3.8.1. Geology

See Chapter 3.5.5 for the preliminary lithological assessment and Figure 23 for a graphical overview of the lithological units.

3.8.2. Geophysics

The Explanatory Notes describe in detail how the pre-processing of the data of the measurement campaign at Site 5068_2 was done. This includes, among other things, the matching of the depths of the individual measurements, the elimination of false measurement data, and the splicing of measurement curves. The respective composite dataset for hole 5068_2_A is shown in Fig. 26.

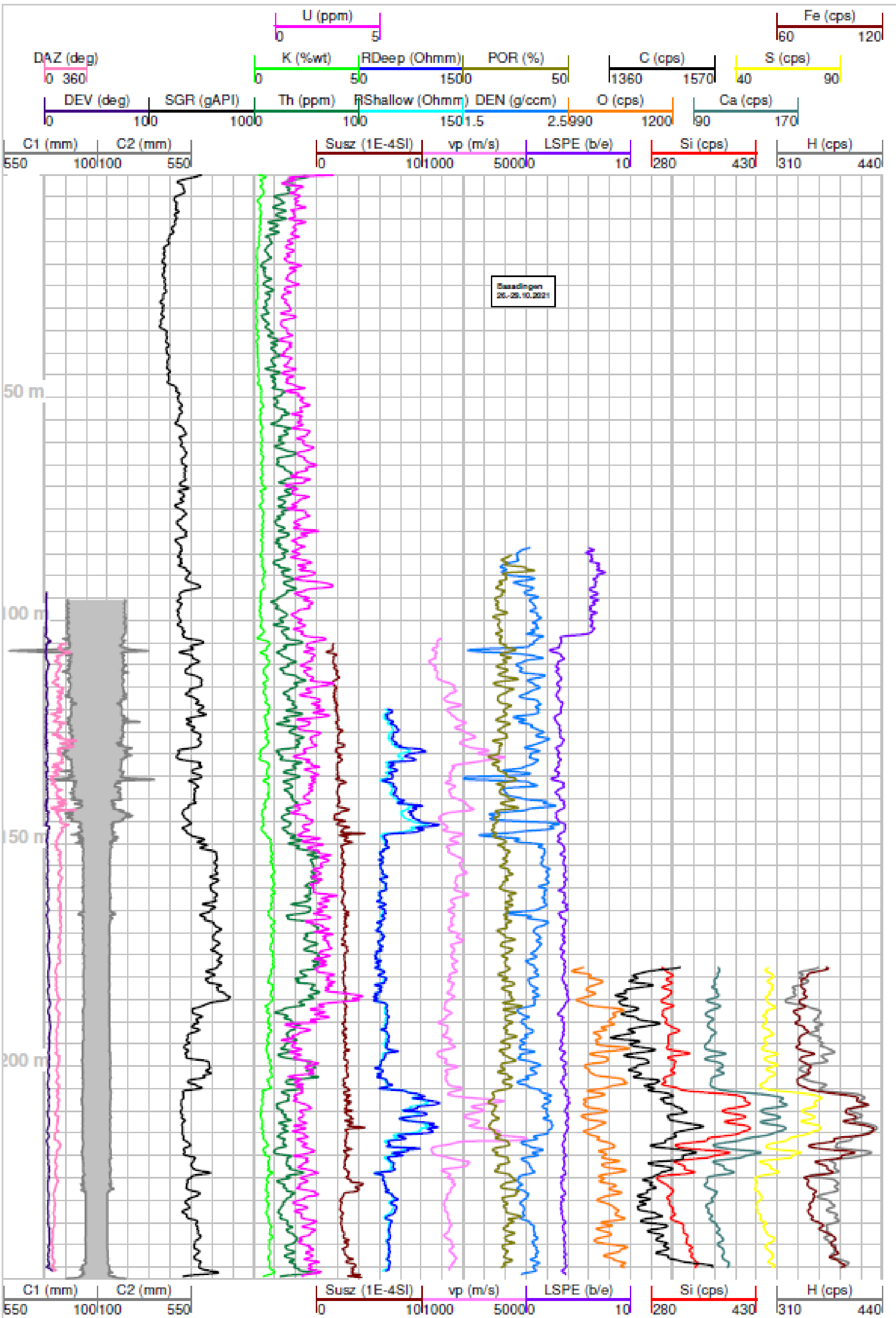

Figure 26: Results of the downhole geophysical measurements on the open hole of 5068_2_A.

4. Site 5068_3

4.1. Site Introduction

The drill-site is located south of Munich, Germany in the municipality of Schäftlarn. To the east lies the slope of the Isar valley and further to the west the Lake Starnberg. The investigated overdeepened structure was eroded by glacial activity of the Isar-Loisach glacier. It is located in a distal position in the foreland glacier-lobe, just south of the limits of the maximum ice extent of the last glaciation. It is suggested by Jerz (1979) that the Schäftlarn overdeepening is a northeast-directed branch basin of the Wolfratshausener basin. Drilling operations in 2017 conducted by the LfU (Bavarian Environment Agency – Bayerisches Landesamt für Umwelt) retrieved 198.8 m of Quaternary sediments. The core can be divided into diamicton remnants (198.8-198.5 m) at the base, overlain by silty sand with dropstone presence (198.5-184 m), again overlain by partly laminated silt (184-170 m), fine sand interlayered with silt and dropstones (170-158 m) and partly laminated silt with decreased presence of dropstones (158-115.5 m). The sequence is topped by sandy-silty gravel (115.5-6 m) and a clast supported diamicton (6-0 m) below the surface. 5068_3_A is stored in the drill-core storage facility (LfU reference number: 8034BG015807) of the LfU in Hof an der Saale, Germany.

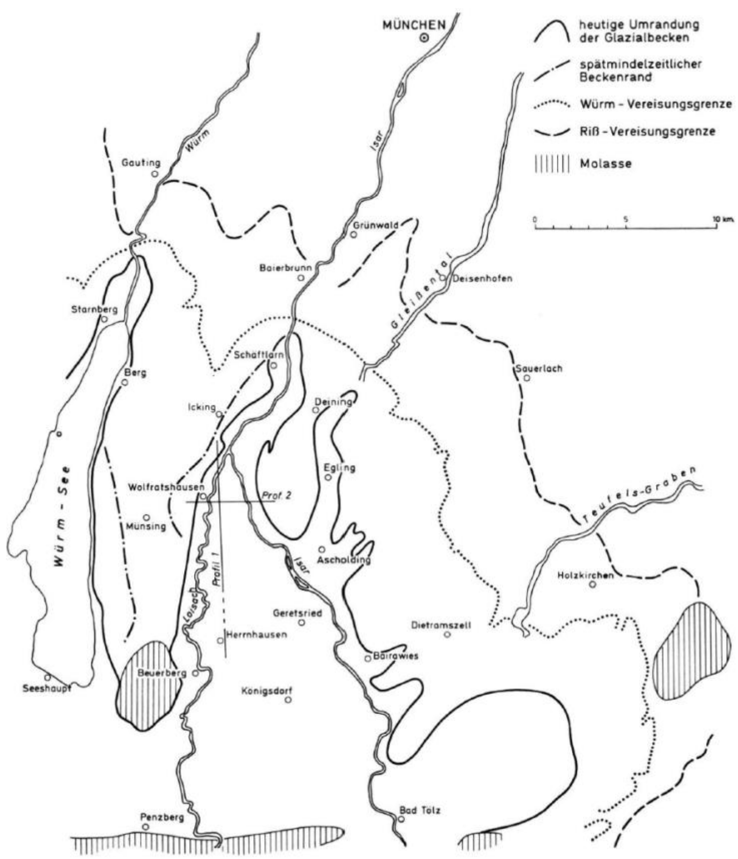

Figure 27: Map of the overdeepened structure of the Wolfratshausen basin and the drill-site Schäftlarn located in a north-east extending branch basin published in Jerz (1979). Context is provided by evidence of past glaciations on the surface.

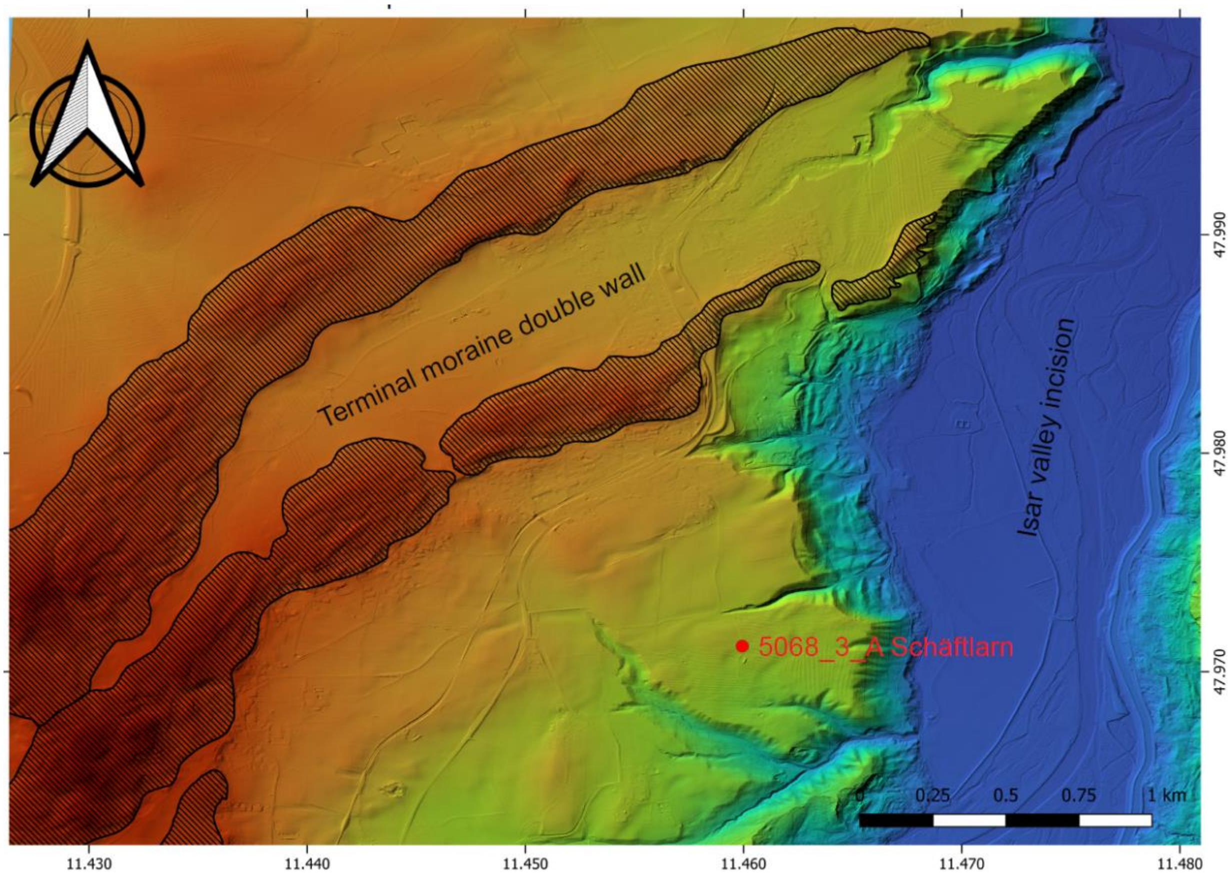

Figure 28: Map of the surrounding area of drill-site 5068_3. The site is located south of the limits of the maximum ice extent of the last glaciation. Digital Elevation Model (DGM 1m resolution) provided by the Bayerische Vermessungsverwaltung.

5. Site 5068_4

5.1. Site Introduction

Site 5068_4 Neusillersdorf is located west of Freilassing and Salzburg on the border between Germany and Austria. The site is positioned centrally under the foreland lobe of the Salzach paleoglacier. A distinct branch basin diverting northwest from the main glacier basin was detected by the LfU (Bavarian Environment Agency – Bayerisches Landesamt für Umwelt) during their update of the Quaternary base map. The 136 m long core 5068_4_A, drilled by the LfU in 2009 targeted this overdeepened branch basin and consists of 117 m of Quaternary sediments on top of 19 m of Flysch bedrock. The Quaternary sediments can be further divided into a base diamicton (117-115 m) overlain by fine-sand/silt sized laminated sediments (115-27 m) that are covered by sandy-gravel/diamicton sediments (27-0 m). 5068_4_A is stored in the drill-core storage facility (LfU reference number: 8143BG015394) of the LfU in Hof an der Saale, Germany. For first results and a more detailed drill-core description we refer to Fiebig et al. (2014).

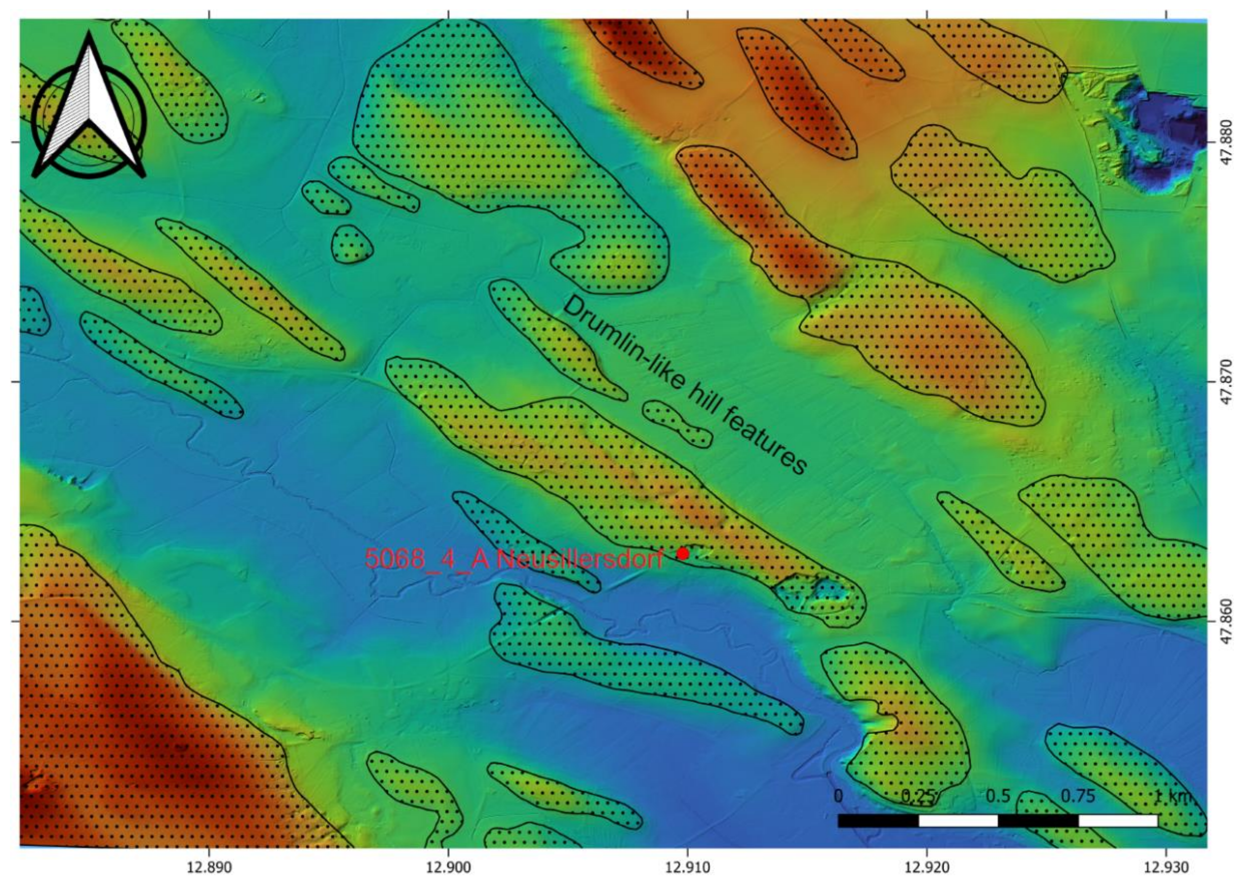

Figure 29: The drill-site 5068_4 is located in a landscape characterized by drumlin-like glacial hills. These hills are oriented parallel to the paleo ice flow direction. Digital Elevation Model (DGM 1m resolution) provided by the Bayerische Vermessungsverwaltung.

6. Site 5068_5

6.1. Site Introduction

Drill-site 5068_5 is located near Bad Aussee (Austria), in the central part of the Northern Calcareous Alps within the extent of the Pleistocene Traun Glacier. Geophysical data (Steinhauser et al., 1985) show a narrow, up to 1100 m deep structure with a highly unusual shape for an overdeepened basin ('Hole of Bad Aussee'). A possible explanation for this feature is the dissolution of a large salt body under subglacial conditions resulting in the formation and subsequent filling of a lake. Drilling operations by the Salinen Austria AG recovered 880 m of Quaternary sediments. They can be divided into ~ 700 m of fine sediments, interpreted as being of glaciolacustrine origin at the base and ~ 200 m of cover sediments. The cover deposits can be further divided into a coarse gravel sequence (~ 200 – 67 m), interpreted as glaciofluvial sediments ("Vorstoßschotter"), and a thick cover of subglacial till (~ 67 – 0 m). A first general description of 5068_5_A was published in Husen van & Mayr (2007).

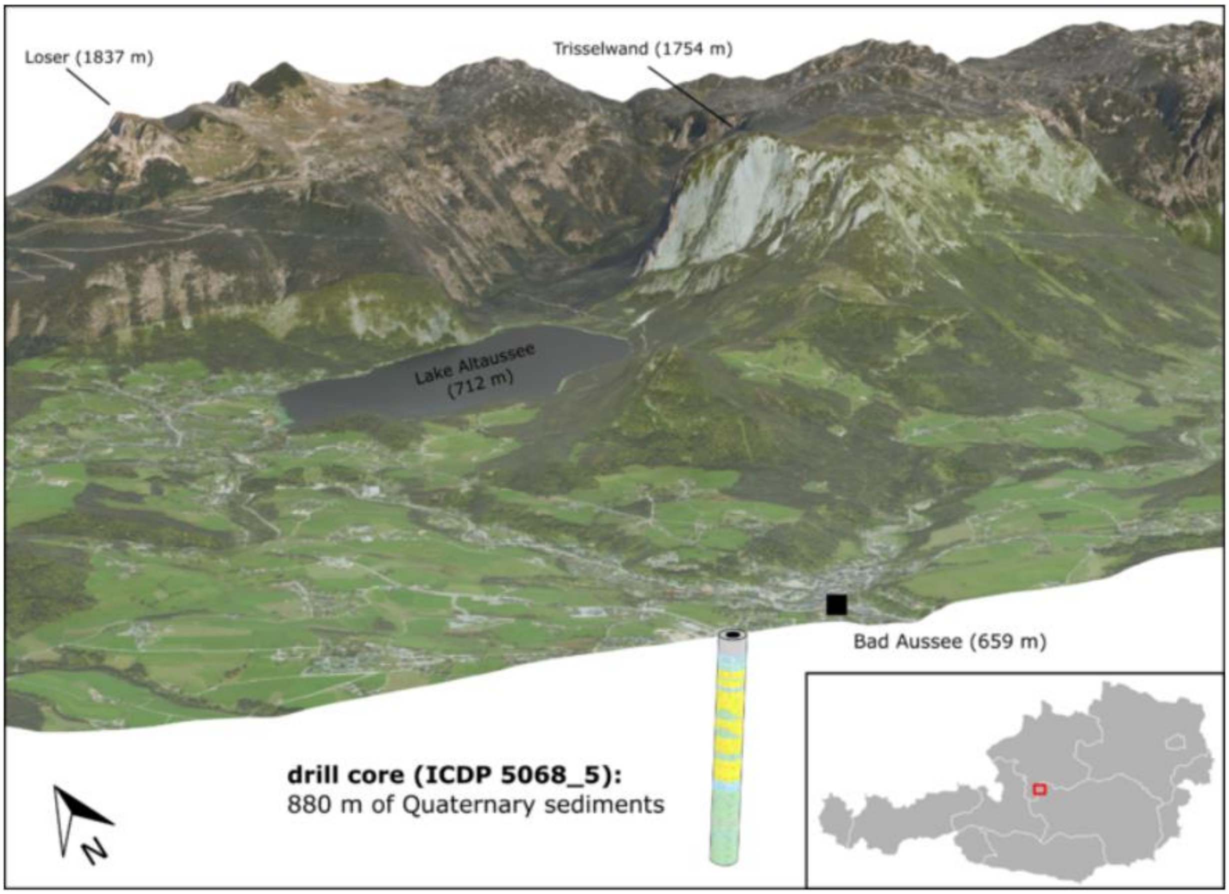

Figure 30: 3D-visualisation of the drill-site and the 5068_5_A drill-core. (Source of orthophoto: www.geoland.at, source of digital elevation model: gis.stmk.gv.at)

7. Site 5068_6

7.1. Site Introduction

The Site 5068_6 is a so-called legacy site. Drilling was undertaken by the State Office for Geology, Resources and Mining of Baden-Württemberg (LGRB) in 2016 where the core material is stored. The original identifier at the LGRB is: 8124-1291. The borehole was drilled to a depth of 144 m with a bedrock depth of 133 m.

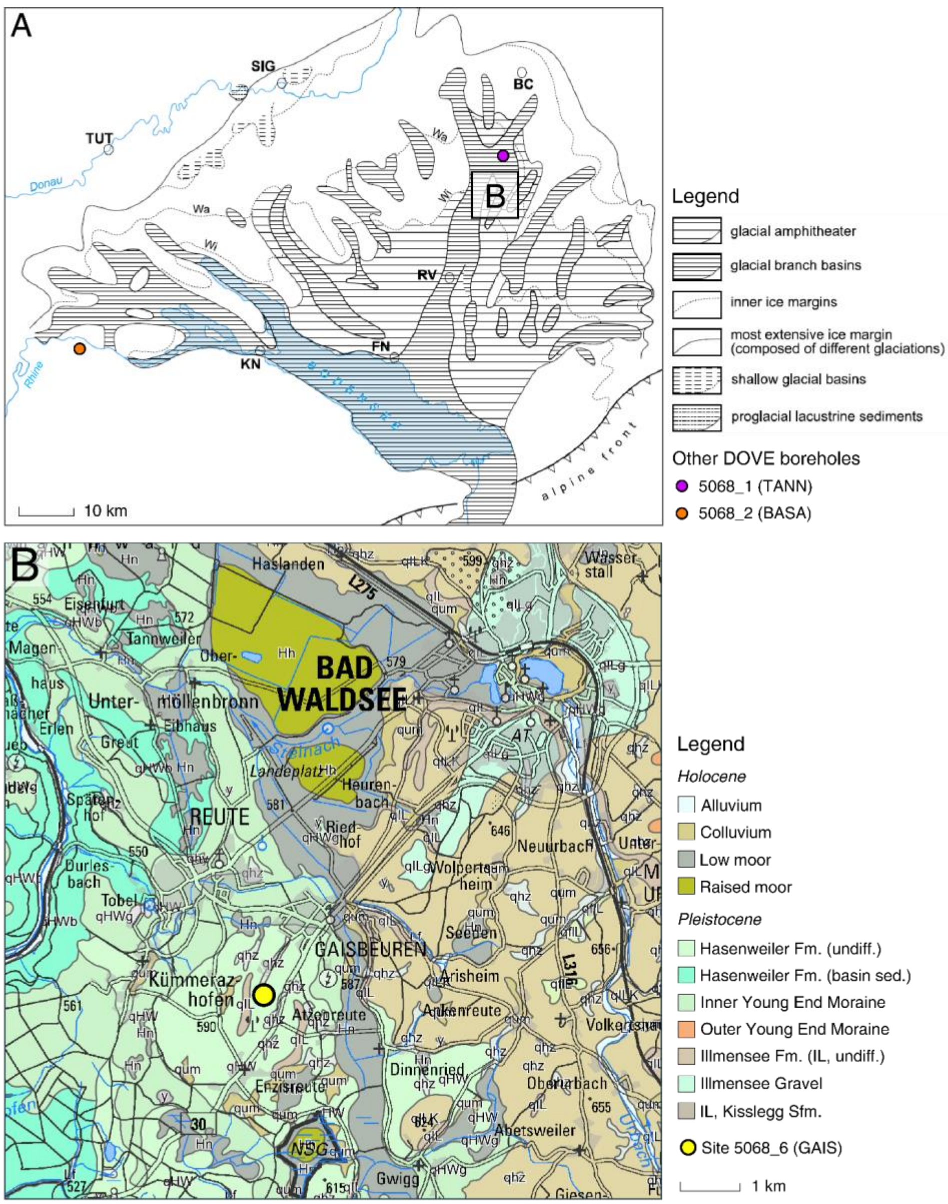

Figure 27: Overview map of the Lake Constance amphitheatre with boreholes 5068_1 and 5068_2 (A; from Ellwanger et al., 2011, altered) and the vicinity of the 5068_6 drill site (B; map data courtesy of the LGRB)

The site is located near the village of Gaisbeuren, which lies at the southern end of the Tannwald Basin, an overdeepening that has presumably been eroded during the third-to-last Hosskirch Glaciation (Ellwanger et al., 2011; Ellwanger, 2015) (Fig. 27). There, another isolated basin (Gaisbeuren Basin) underlying the Tannwald Basin is presumed based on results from a previous but not anymore existing drill core, which is not unlikely to represent an early Middle Pleistocene glaciation (Ellwanger, 2015). Due to the supposed exceptional stratigraphic position of the Gaisbeuren Basin, drilling was undertaken.

Previous investigations include:
- in-liner drilling and borehole geophysical survey
- whole-core scans for magnetic susceptibility and natural remanent magnetisation
- preliminary profile description based on core catcher pieces

8. DOVE Operational Dataset

The following tables list the data, metadata and images included in the DOVE phase 1 operational dataset (DOVE-Phase 1 Scientific Team et al., 2023b). The complete dataset is available on the GFZ data services repository using the following link https://doi.org/10.5880/ICDP.5068.001 or through the ICDP DOVE project website https://www.icdp-online.org/projects/by-continent/europe/dove-switzerland. Explanatory remarks (DOVE-Phase 1 Scientific Team et al., 2023c) are available together with the dataset on the project website https://www.icdp-online.org/projects/by-continent/europe/dove-switzerland or using the following link: https://doi.org/10.48440/ICDP.5068.002. This includes descriptions on basic laboratory measurements.

NOTE: The operational dataset as well as this report are work in progress and will be updated at least two more time from now on (October, 2023) for the legacy drill sites.

8.1. Data und Metadata from mDIS

Table 11: Available archive file (zip) containing the following reports & data from the DOVE Project Phase 1. Light gray files are still to come.

	DATA	Description or Related Lists (pdf files)	DOVE Locations (xlsx, csv, zip)
1	All Data		All Data
2	Expedition		Expedition
3	Site Locations		All Sites
4	Hole Locations		All Holes
5	Cuttings (5068_1) & Borehole Expansion samples (5068_2_A)		5068_1_A 5068_1_B 5068_1_C 5068_2_A
6	Cores	CoreSection-Report_5068_1_C CoreSection-Report_5068_2_A CoreSection-Report_5068_3_A CoreSection-Report_5068_4_A CoreSection-Report_5068_5_A CoreSection-Report_5068_6_A	5068_1_C 5068_2_A 5068_3_A 5068_4_A 5068_5_A 5068_6_A
7	Core Sections		5068_1_C

			5068_2_A 5068_3_A 5068_4_A 5068_5_A 5068_6_A
8	Section Splits		5068_1_C 5068_2_A 5068_3_A 5068_4_A 5068_5_A 5068_6_A
9	Samples	List of all Samples taken from Site 1 – 5 until 17 Aug 2023	5068_All Samples
10	Sample Request	All Requests for Samples taken in the field and during 1st sampling party	5068_Sample Requests
11	Lithological Description of Section Units (Visual Section Logs)	this includes: • mDIS records on lithology • Table on Lithological Units • Visual Core Description (VCD) Logs per Section (pdf)	5068_1_C 5068_2_A 5068_3_A 5068_4_A 5068_5_A 5068_6_A Lithological Units SectionLogs_VCD Hole 1C SectionLogs_VCD Hole 2A SectionLogs_VCD Hole 3A SectionLogs_VCD Hole 4A SectionLogs_VCD Hole 5A SectionLogs_VCD Hole 6A
12	Driller Reports	Daily Drillers reports exported from mDIS Data Tables & scans of written reports	5068_1_A 5068_1_B 5068_1_C 5068_2_A
13	Borehole Logging Data	Borehole Logging Data, Meta Data on Runs & Logs (csv) and Composite Logs (combined in 1 zip file for each hole); composite logs also as separate files	5068_1_BL_All Data 5068_2_BL_All Data 5068_3_BL_All Data 5068_4_BL_All Data 5068_1_BL_CompositeLogs 5068_2_A_BL_CompositeLog 5068_3_A_BL_CompositeLog 5068_4_A_BL_CompositeLog

			Summary of Tools
14	Vertical Seismic Profile	All VSP Data Site 1 (zip file incl Read me)	5068_1_VSP
15	Auxiliary Tables (incl.)	Sites 1 & 2	Borehole Diameter Casing Diameter
16	MSCL Data	Data Files Site 1 and 2 (zip) Calibration File (xlsx) (also see Explanatory Remarks)	5068_1_C 5068_2_A MSCL Calibration File
17	Additional Data	Carbon, Nitrogen, Sulfur, Water, Uniaxial Shear and Compressive Strength	5068_1_C 5068_2_A
18	READ ME	External Link	https://doi.org/10.48440/ICDP.5068.002

8.2. Image Reports and Primary Images exported from mDIS

NOTE: The images of the operational dataset are work in progress and will be updated at least two more time from now on (October, 2023) for the legacy drill sites. As of now they are available for Sites 1 and 2.

Available images include

1) **Section images** were taken from the archive half once the core was opened at the University of Bern (Sites 5068-1 & 2). Image file names begin with the abbreviation CS followed by the combined_id of the sections and are available in JPEG format.
2) **Cuttings images** taken at the drill site (Site 5068-1). The file names start with the abbreviation CU followed by the combined_id and are available in JPEG format
3) **Hole overview** reports showing images of all sections taken sorted after depths (exported from mDIS)
4) **Core overview** were taken from the archive half once the core was opened at the University of Bern (Sites 5068-1 & 2). Image file names begin with the abbreviation CS followed by the combined_id of the sections and are available in JPEG format.

Table 1: Available image files from the DOVE Project Phase 1 (as of October 2023)

	DATA	Description	Locations/Holes
1	Hole Overview Reports	Image Hole Overview (pdf files)	5068_1_C 5068_2_A
2	Section Images	Slabbed Section Overviews (zip)	5068_1_C 5068_2_A
3	Cutting Images	Images (zip file with .jpg)	5068_1_B 5068_1_C
4	Core Overview	Image Core Overviews (pdf files)	5068_1_C 5068_2_A

9. Summary of Preliminary Scientific Assessment

OVERALL

Preliminary data indicates that it will be possible at all the sites to better understand the local glaciation and landscape history and – by merging it with the other sites – in the entire alpine region.

SITE-SPECIFIC

Site 5068_1

In the Tannwald Basin at site 5068_1 glacial deposits were successful drilled within an overdeeped valley with high-quality core recovery of with a core with 95% recovery. The ICDP 5068_1_C drill hole first penetrated a succession of gravel-dominated, partly diamictic units. Below 38 m the sediments become finer, mostly silt dominated with varying clay content, occasionally interrupted by sand units (e.g., at 73–81 m and 99–104 m). In this section, rare outsized clasts were visible and indicate the presence of dropstones. At 136 m, the sediments become coarser and well-sorted sand units alternate with fine-grained diamicts, occasionally containing a significant amount of gravel. Sand becomes dominant at 149 m and the bedrock Tertiary Molasse deposits were encountered at 155 m. The bedrock is marly in appearance at the top (including macroscopically-observable fossil fragments), occasionally transsected by pure sandstone. The occurrence of sandstone increases towards the bottom and finally dominates from 164 m to the final depth of 166 m. In addition:

- Three boreholes were finished and kept open for future research (cross-hole seismic).
- We were able to conduct borehole geophysics in open-hole conditions, which is remarkable for this kind of sediment.
- The boreholes were sampled by the local state authority to test the water quality at the filtered points.
- Future work will refine the preliminary lithological succession and integrate it the various other datasets, especially age dating of the sediments, reflection seismic and borehole geophysics.

Site 5068_2

At site 5068_2 the infilling of the Basadingen overdeepening was successfully cored down to the basal part at a depth of 252 m in mostly excellent core quality. Only the transition to the bedrock could not be reached (by probably only a few meters) due to major drilling difficulties. Based on the preliminary core assessment (prior to opening), the recovered sequence can roughly be divided into two parts: In the lower part, between 252 and 48 m depth, the valley filling consists mainly of sands, which are divided into larger packages by gravel and diamictic interbeds. Between c. 90 and 148 m depth, the sands are interbed gravels (forming dm-m thick beds). In the upper part of the core between 48 and 11 m depth the valley fill is overlain by gravels and above 11 m by diamicts. Future work will refine this preliminary lithological succession and integrate it the various other datasets.

Site 5068_3: upcoming
Site 5068_4: upcoming
Site 5068_5: upcoming
Site 5068_6: upcoming

10. Conclusions

This operational report summarizes the relevant operational aspects of DOVE-Phase 1. For DOVE such a joint report is particularly important because the operations have been conducted under different operational conditions: Sites 5068_1 and 5068_2 were freshly drilled, sites 5068_3 and 5068_6 were drilled earlier but in anticipation of the DOVE project and temporarily stored, and sites 5068_4 and 5068_5 are legacy cores initially not anticipated for use in DOVE. Despite these differences, this report shows that the recovered cores and data are for most parts of equivalent quality across all sites. This common dataset is an excellent basis for the upcoming data analysis and integration steps towards the overarching, pan-Alpine goals of DOVE.

The coring operations at all sites show that drilling operations in overdeepenings are very challenging. This is mainly due to the highly variable, unconsolidated and difficult to predict lithological successions encountered in this overdeepened valley fills. However, with the chosen drilling strategies we have achieved very high recovery and excellent core quality. The emphasis on core quality has led to longer than expected drilling operations (but generally within budget constraints).

In conclusion, the operational procedures have proven very reliable and successful. The operations for DOVE-Phase 1 have set a new standard of how such valley fills can be explored successfully and can be adopted for a potential upcoming DOVE-Phase 2 (see Anselmetti et al. 2022).

11. Acknowledgements

DOVE is financially supported by ICDP, Deutsche Forschungsgemeinschaft (DFG, grant nos. KR2073/3-1, BU 2467/1-2, GA749/5-1, BU2467/3-1, BU3894/2-1, BU3894/3-1, and PR 957/6-1, DFG Project: 2100361301), Nagra, ENSI, LGRB, LFU, Leibniz Institute for Applied Geophysics (LIAG), BOKU Vienna, University of Bern, the Regierungspräsidium Freiburg, Landesgeologie.

Drilling at Site 5068_1 was carried out by H. Anger's Söhne, Bohr- und Brunnenbaugesellschaft mbH. Despite a number of technical problems and protracted drilling operation, they successfully completed the three drillholes and supplied good quality core with a recovery rate of 95%. We thank the firm's contact person, Mirko Huber, for constructive talks and helpful suggestions. The drillsite at Winterstettenstadt was leased from Herr and Frau Wiedmann and we are grateful for their support. A number of local groups and schools visited the site and we thank them for their interest. Greta Clasen at LIAG coordinated the media and press releases.

Site 5068_2 was drilled by Fretus AG, we are thankful for providing us with high-quality drill cores despite many technical challenges. We also acknowledge strong support by the communities of Basadingen- Schlattingenby the Bürgergemeinde Basadingen-Schlattingen, the members of the Jagdgesellschaft Hegi Belzhalden, the local residents, and the involved services of the political community Basadingen-Schlattingen and the Kanton of Thurgau. Technical staff of LIAG assisted with the seismic pre-site surveys and the downhole logging.

We acknowledge all ICDP workshop participants in Como, who contributed to realizing this larger DOVE initiative.

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13. Appendices

A: Hydrogeological report by Dr. von Moos AG

B: Drill Site Layout during drilling boreholes 5068_1_B and 5068_1_C

Appendix A – 5086_2 Hydrogeological report by Dr. von Moos AG

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Aktennotiz: **Hydrogeologische Bohrbegleitung**

Verfasser: Lawrence Och

Datum: 03.02.2022 erg: Visum: GH

Verteiler:

– Amt für Umwelt des Kanton Thurgau (erika.tanner@tg.ch)

– Sebastian Schaller, Uni Bern (sebastian.schaller@geo.unibe.ch)

– Marius Büchi, Uni Bern (marius.buechi@geo.unibe.ch)

1. Einleitung / Auftrag

Im Rahmen des Forschungsprojekts "Drilling Overdeepened Alpine Valleys (DOVE)" wurde im Auftrage des Instituts für Geologie der Universität Bern für wissenschaftliche Zwecke auf der Parzelle Kat.-Nr- 2610 bei Muedihaa in Basadingen-Schlattingen über der glazial übertieften Waltalingen-Basadingen-Rinne eine Kernbohrung (BASA 1) abgeteuft (Landeskoordinaten: 2'698'774 / 1'278'321 / 445.1 m ü.M.). Da die Tiefbohrung in einem Grundwassergebiet ausgeführt wurde, mussten gemäss Bewilligung Nr. 2021.01-122 des Amts für Umwelt des Kantons Thurgau die Bohrarbeiten sowie der Rückbau mit Verfüllung durch eine hydrogeologische Fachperson begleitet werden. Gemäss unserem Angebot vom 4. Mai 2021 und der Auftragsbestätigung mit Email vom 5. Mai 2021 haben wir die Bohr- und Verfüllarbeiten hydrogeologisch begleitet. Die Arbeiten werden in dieser Aktennotiz dokumentiert und beurteilt.

2. Ausgeführte Arbeiten

Die Kernbohrung dauerte vom 25. Mai bis zum 13. Oktober 2021 und erreichte eine Endtiefe von 253 m unter OK Terrain. Dabei kam es vom 1. bis 27. Juli 2021 in einer Tiefe von 126 m unter OKT aus bohrtechnischen Gründen (Probleme mit der Verrohrung, welche überbohrt werden musste) und vom 27. August bis 5. Oktober 2021 in einer Tiefe von 228.3 m unter OKT (Ersatz Bohrgerät) zu längeren Unterbrüchen.

Die Bohrung wurde von 0 bis 57 m unter OKT als Trockenbohrung im Rammbohrhammerverfahren (System Düsterloh) und zwischen 57 und 253 m unter OKT als Spülbohrung im Seilkernbohrverfahren ausgeführt. Zur Stabilisierung der Bohrlochwand wurde ein Spülungszusatz verwendet (GS 550), welcher bei der Trockenbohrung auch zur Schmierung der Verrohrung eingesetzt wurde. Die Bohrung wurde durchgehend und mit der Tiefe abnehmendem Durchmesser verrohrt (vgl. Anhang A1).

Die Bohrkerne wurden in opaken Linern extern gelagert und nicht geöffnet. Die geologische Aufnahme wurde vom Geologen Sebastian Schaller der Universität Bern (Auftraggeber) anhand des ca. meterweise sichtbaren Bohrguts vorgenommen (vgl. Anhang A1). Die Bohrung wurde vom 5. bis 10. November 2021 rückgebaut und verfüllt.

Die Dr. von Moos AG stand während der gesamten Bohrung regelmässig mit Sebastian Schaller und zeitweise mit dem Bauführer des Bohrunternehmens (Fretus AG) in Kontakt. Die Tagesrapporte des Bohrunternehmens sowie eine tabellarische Nachführung der Bohrtiefen, Wasserstände, Wassereintritte und Spülverluste wurden uns regelmässig durch Sebastian Schaller übermittelt. Baustellenbegehungen durch Mitarbeiter der Dr. von Moos AG fanden am 31. Mai, 23. Juni und 9. November 2021 statt.

3. Hydrogeologische Folgerungen

Gemäss Bohrprofil im Anhang A1 ist von folgender **geologischer Schichtabfolge** auszugehen:

0 – 22 m: Moräne (letzteiszeitlich)
22 – 48 m: Buchberg-Schotter
48 – 253 m: Moränenkomplex (ältere Eiszeiten) mit Seeablagerungen und Kieslager

Gemäss einer älteren Bohrung, welche in der näheren Umgebung bis auf 201 m u.T. abgeteuft wurde, sollte der obere Teil des älteren Moränenkomplexes (Möhlin- und Beringen-Eiszeiten) überwiegend aus Seeablagerungen und der untere Teil vor allem durch Moräne aufgebaut sein. Da die Kerne der aktuellen Bohrung nicht im Detail aufgenommen werden konnten (opake Liner), sind die Schichtgrenzen noch nicht eindeutig bestimmbar. Der **Fels wurde nicht erreicht**. Allerdings wurden unterhalb von ca. 250 m Tiefe Molassekomponenten (Fels) beobachtet. Die Flanken der Waltalingen-Basadingen-Rinne verlaufen gemäss heutigem Wissensstand von oben nach unten durch Obere Süsswasser-, Obere Meeres- und Untere Süsswassermolasse.

Anlässlich der Trockenbohrung bis in eine Tiefe von 57 m wurden **Wasserzutritte** in Tiefen von ca. 3 und 10 m unter OKT innerhalb der Moräne sowie bei 28 m unter OKT innerhalb des Buchberg-Schotters festgestellt. Bei den oberen Zutritten dürfte es sich um Schichtwasser handeln, wobei der Wasserstand nicht gehalten wurde. Die Wasserzutritte aus dem Buchberg-Schotter führten zu einem **Wasserstand**, welcher sich über die gesamte Bohrung grösstenteils zwischen 26 und 32 m unter OKT (ungefähre Koten 413 bis 419 m ü.M.) bewegte. Während der gespülten Bohrung wurden vollständige **Spülverluste** in Tiefen von ca. 90 – 110 m, 125 – 130 m, 140 – 145 m, 205 – 230 m sowie im Bereich der Endtiefe bei 250 m unter OKT festgestellt. Dabei dürfte es sich um Lagen von gut durchlässigem, überwiegend sandig-kiesigem Material handeln. Wesentliche Wasserzutritte aus dem Moränenkomplex unterhalb des Buchberg-Schotters konnten nicht festgestellt werden.

4. Rückbau und Verfüllung der Bohrung

Die Verfüllung der Bohrung hatte so zu erfolgen, dass das im Buchberg-Schotter zirkulierende Grundwasser weder von Wasserzuflüssen von oben (Geländeoberfläche) noch von unten beeinträchtigt werden kann. Nach dem vollständigen Rückzug der Verrohrung wurde die Bohrung gemäss Anweisungen der Dr. von Moos AG und in Rücksprache mit Auftraggeber, Bohrunternehmer sowie AfU Thurgau folgendermassen verfüllt:

0 – 5 m: Deckschicht (Erde/Humus)
5 – 12 m: Tonabdichtung (Mikolit 300M)
12 – 50 m: Kies
50 – 55 m: Tonabdichtung (Mikolit 300M)
55 – 253 m: Zement, sulfatresistent (K Injektherm 110 HS)

5. Schlussbemerkungen

Die Kommunikation mit Auftraggeber und Bohrunternehmer verlief häufig und zufriedenstellend. Anlässlich der Begehungen konnten hinsichtlich gewässerschutzrechtlichen Auflagen keine Bedenken angemeldet werden. Durch die vorstehend erläuterte Verfüllung der Bohrung sind keine nachteiligen Auswirkungen auf das Grundwasservorkommen im Buchberg-Schotter zu erwarten.

Zürich, 3.2.2022
Dr. von Moos AG

Anhang:

A1 Bohrprofil Forschungsbohrung BASA 1, nicht massstäblich (dat. 24.11.2021, Universität Bern)

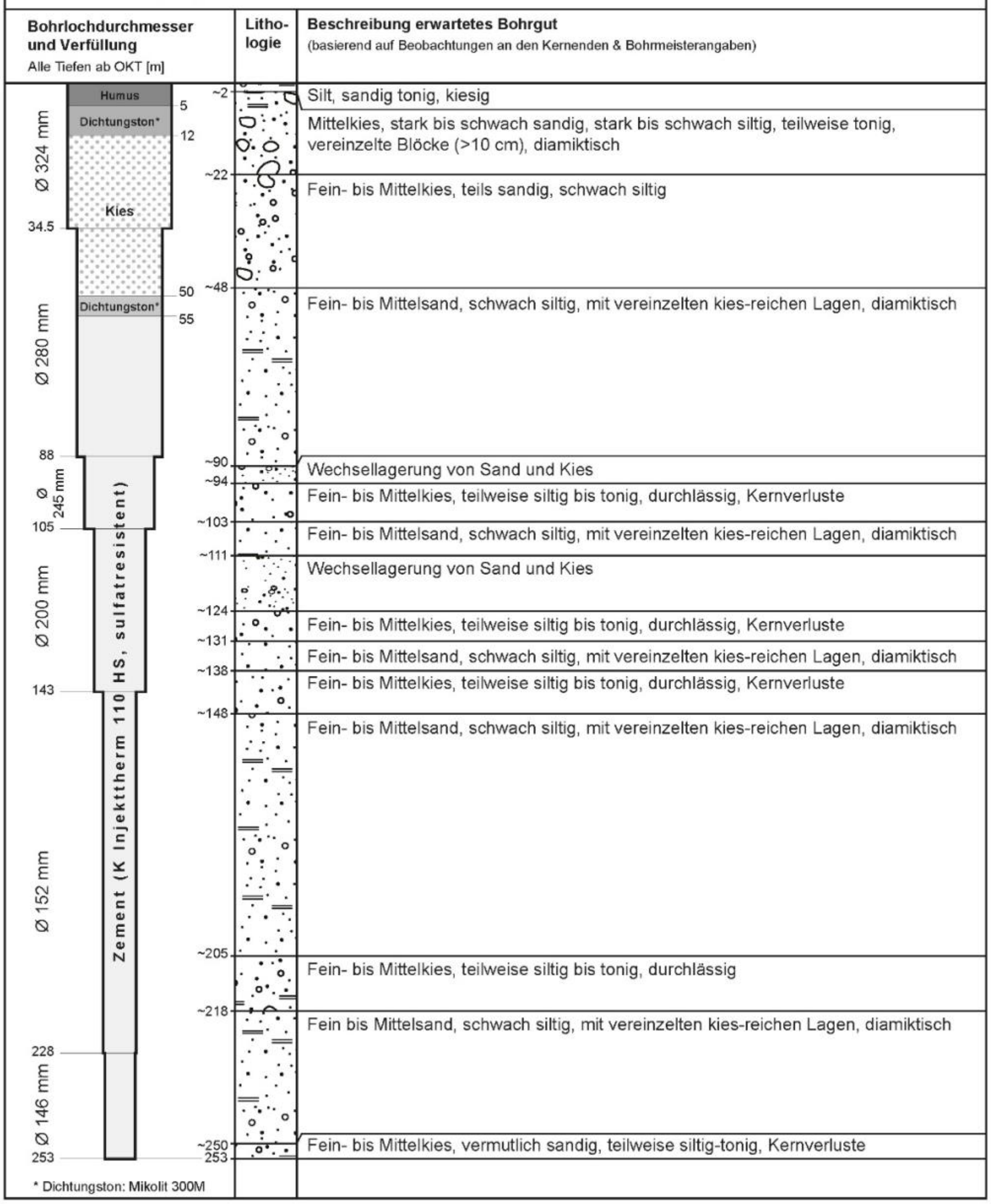
Tiefbohrung BASA 1, Muedihaa, Basadingen-Schlattingen

Bericht Nr. 13162
Anhang A1

ICDP-DOVE Forschungsbohrung BASA1 / 5068-2, Basadingen-Schlattingen

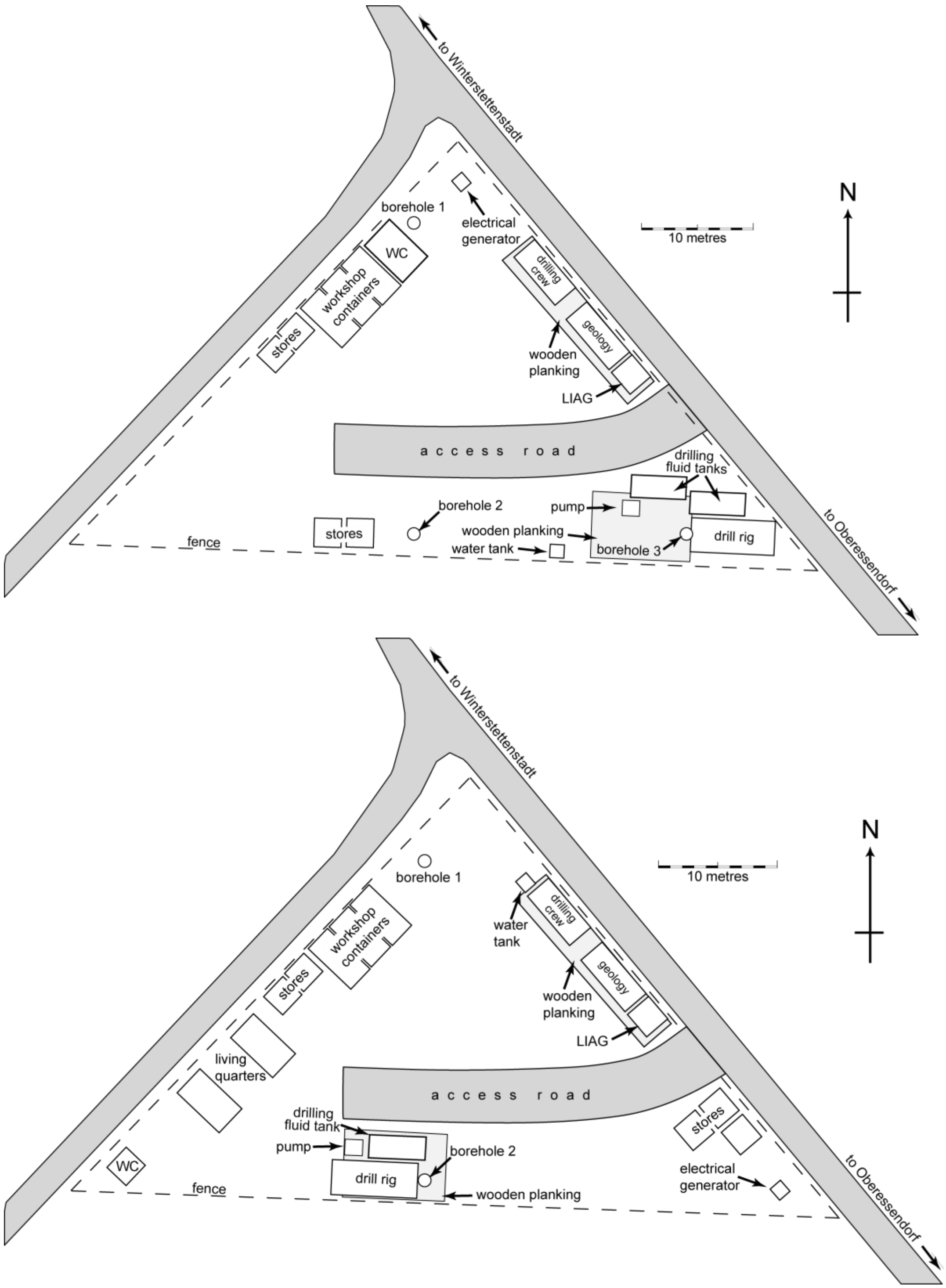
Bohrloch-Architektur, Verfüllung und vorläufige lithologische Aufnahme

Koordinaten (LV95)	2'698'774 / 1'278'321	Bearbeiter:	S. Schaller, M. Buechi, Universität Bern
Oberkante Terrain (OKT)	445.1 m ü. M.	Datum:	24.11.2021



Erstellt von: Sebastian Schaller, Universität Bern

Appendix B –



Layout of the drillsite (5068_1) for the borehole B (top) and C (bottom); supplement to chapter 2.4