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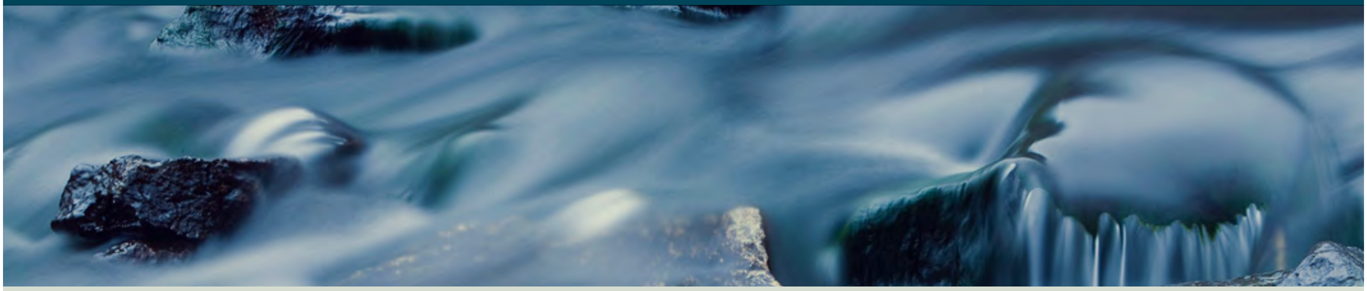

Burfell
Hydroelectric Project Extension

Geological Report

Key Page

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Title: Burfell Hydroelectric Project Extension - Geological Report

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Abstract:

Landsvirkjun plans to extend the Búrfell Power Station, South-Iceland. Almenna verkfræðistofan hf carried out geological investigation in 2012 at the site, including drilling three cored boreholes and reviewing the earlier investigations with two alternatives in mind for a new station: Surface powerhouse and Underground powerhouse. The report presents the results.

Keywords: andesite, Búrfell Station, Búrfell Extension, boreholes, conglomerate, geology, hydroelectric project, Iceland, joints, moraine, olivine basalt, packer test, point load, RQD, rock mass quality Q, sandstone, Sámsstaðaklif, scoria, Thjorsa, tholeite basalt, Trjáviðarlækur, Þjórsá.

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1 INTRODUCTION

1.1 General

The *Búrfell Hydroelectric Project Extension*[1] has to do with the proposed construction of a second power station at the Búrfell-site, Þjórsárdalur (Thjorsardalur), South Iceland. The older hydroelectric power station and project will be referred to as *Búrfell Station*.

Refer to Figure 1-1 below for aerial view of the close surroundings, Drawing 01 for a general location map, Drawing 02 for a close-up map of the construction site of the two alternatives of the Búrfell HEP Extension and the same on aerial photo in Drawing 03.

Figure 1-1 Viewing from southwest to northeast with the current Búrfell Station by Fossá under Sámsstaðamúli mull and the proposed Búrfell Extension site right of Sámsstaðaklfi[2] *. Photo: Emil Þór Sigurðsson 16 August 2012.*

1.2 Búrfell Station and Búrfell HEP Extension

For detailed description of the project, refer to Almenna verkfræðistofan (2012A and 2012B). Below is the background of the project described:l

The construction of hydropower plants at the Þjórsá and Tungnaár watershed commenced with the construction of the Búrfell Station (1966-1972, 210 MW) and the Þórisvatn Reservoir (1970-1972). Following years two hydropower plants were built in the Tungnaár river; the Sigalda Station

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[1] Also called Búrfell HEP Extension or Búrfell Extension for short. In some of the reports from 1980-1990 the project is frequently called Búrfell II.

[2] The name Sámsstaðaklif (Sámsstaða-cliff) is used for the N60°E-trending fracture and the gully at the southern end of it, as well as the hillside on each side of it.

(1973-1978, 150 MW) og the Hrauneyjafoss Station (1977-1981, 210 MW). Later the Sultartangi Dam (1982-1984) and the Kvíslarveita Diversion (1980-1985) were built.

In 1980 it appeared that the Búrfell Station would become a bottleneck in the hydropower chain when the above mentioned projects were completed. Large amount of unharnessed water would flow past the station and there would be mismatch in the rated power between the Búrfell Station at the one hand and Hrauneyjafoss Station and Sigalda Station at the other hand. Therefore, Landsvirkjun sought ways to increase the rated power of Búrfell Station. The company concluded initially that the most feasible project would be a new powerstation near the Sámsstaðaklif hill, in the vicinity of the existing station. The proposed project consisted of a new headrace canal on the top of Sámsstaðaklif hillside, a penstock down the hill, a surface powerhouse housing two 70 MW Francis turbines and a 2 km long tailrace canal with its downstream end about 1 km away from the Burfell Station.

Already in 1981 the excavation of the tailrace canal had begun. During the summers 1981 to 1985, 1988 and 1989 some 1,4 million m³ of material was excavated. In addition, the site for working camps was prepared.

In the end of the 90s a revised design of a smaller extension of the Búrfell Station was prepared and tender design of 100 MW extension was initiated. In 1992 the project was put on hold due to changed market conditions. At that moment about 0,5 million m³ of material had yet to be excavated in the tailrace canal.

During 1997 and 1998 new turbines were installed in the existing Búrfell Station, increasing rated power from 210 MW to 270 MW. The net rated head is 115 m and the rated discharge was increased to 280 m³/s.

Today, 60 % of the time the Burfell Station is working close to its rated power. During the winter months on average 30 m³/s of discharge passes by the station and more than 100 m³/s from May to September.

With this in mind Landsvirkjun has now decided to revive the plan to build a new hydropower plant in the Sámsstaðaklif hill, with the intension to harness more water and have the chance to reduce the load on the Burfell Station. The rated power can be as high as 140 MW.

Two schemes are being studied. The first alternative is the above mentioned scheme with a surface powerhouse and a penstock down the Sámsstaðaklif hillside. The second alternative is to build underground powerhouse in the hill. Previous studies by Landsvirkjun indicate that the undergrond scheme is an economical solution and possibly more environmental friendly (Almenna verkfræðistofan (2012A and 2012B)).

1.3 The investigation and report

The geological investigation for the Búrfell Extension was performed by Almenna verkfræðistofan hf. (Almenna Consulting Engineers Ltd.) for Landsvirkjun in the summer of 2012.

Two alternatives or options for the Búrfell Extension are considered, called Underground powerhouse alternative and Surface powerhouse alternative.

In the report, the dot (.) is used for separation of thousands and for decimal places the comma (,) is used.

For investigations in 2012 and other recent ones, the coordinates in planview are either the geographic longitudes and latitudes or they are the Icelandic ones with ISN93 as reference (Umhverfisráðuneytið (1999)) “with coordinates in Lambert’s conformal conical projection with standard parallels 64°15'N and 65°45'N and central meridian 19°W. False eastings and northings are both 500.000,00 at 65°N and 19°W” (Landmælingar Íslands (1997)).

For elevation ISH2004 is used as reference (Umhverfisráðuneytið (2011)).

2 GEOLOGICAL BACKGROUND INFORMATION

2.1 General geology of Iceland

On the general geology of Iceland, reference is made to a special issue, *The dynamic geology of Iceland,* of the journal *Jökull* in the year 2008 (Freysteinn Sigmundsson et al. (2008)) and related literature. Some of it is presented in Appendix A.

For the geology of the area around Búrfell HEP Extension, reference is made to a journal article (Elsa G. Vilmundardóttir et al. (1985)).

For the more detailed engineering geological/geotechnical work, the reader is referred to the reports presented in Section 2.2 below.

2.2 Engineering geological investigations

Research has been ongoing in the area around Búrfell Station and Búrfell HEP Extension for decades as described in section 1.2. Below reports are listed in chronological order for most of the important geological investigations from that time:

- Harza Engineering Company International (1963):
    - *Burfell project. Project planning report.*
        - *Volume I – Summary Letter and Report.*
        - *Volume II – Appendices.*
- Haukur Tómasson (1967):
    - *Jarðfræðirannsóknir virkjunarstaðarins við Búrfell.* (In Icelandic).
- Ingibjörg Kaldal (1980):
    - *Búrfell II. Laus jarðlög.* (In Icelandic).
- Snorri Páll Snorrason (1981):
    - *Jarðfræði Sámstaðaklifs.* (In Icelandic).
- Pétur Pétursson (1982):
    - *Búrfell II. Loftboranir á stöðvarhússtæði.* (In Icelandic).
- Almenna verkfræðistofan (1982):
    - *Stækkun Búrfellsvirkjunar. Rannsóknir á jarðlögum og byggingarefnum.*
- Ágúst Guðmundsson, Elsa G. Vilmundardóttir and Snorri P. Snorrason (1983).
    - *Geological map of bedrock. Scale: 1:50000. Name: Búrfell – Langalda. Number: 3540 B.*
    - Published by Orkustofnun – Vatnsorkudeild and Landsvirkjun.
- Bjarni Bjarnason (1983):
    - *Búrfell II. Aðrennslisskurður, stöðvarinntak og stöðvarhúsgrunnur. Kjarnaborun 1983.* (In Icelandic).
- Jón Ingimarsson (1985):
    - *Mat á lekt jarðlaga á stöðvarhússtæði.* (In Icelandic).

Appendix B shows the bedrock map of the area from 1963 (Harza Engineering Company International (1963)) and Drawing 14 shows a part of the bedrock map of the area from 1983 (Ágúst Guðmundsson et al. (1983)).

3 GEOLOGICAL INVESTIGATIONS IN 2012

3.1 Introduction

In June 2012, three cored boreholes were drilled at the site of the planned Búrfell Extension and six boreholes were drilled in the same campaign with rotary pneumatic percussion drilling, see Table 3-1.

Drawing 04 and Drawing 05 show the boreholes from previous investigation campaigns as well as the ones from 2012 in connection with the Surface powerhouse alternative and the Underground powerhouse alternative, respectively.

Table 3-1 Exploration holes drilled in the campaign of 2012.

Borehole number	**Depth of hole (m)**	**Coordinates with ISN93 as reference[3]**		**Elevation with ISH2004 as reference[4]**		**Length of 3" ODEX-casing (m)**	**Range of NQ-size core (m)**
		North or X (m)	**East or Y (m)**	**At top of casing (m a.s.l.)**	**At ground (m a.s.l.)**		
Cored boreholes							
BF-30	174,1	460998,08	400336,45	268,39	268,18	2,30	2,30 to 174,10
BF-31	48,18	461096,89	400469,09	266,71	266,53	2,60	2,60 to 48,18
BF-32	84,3	460809,06	400131,84	181,87	181,57	3,0	3,0 to 84,3
Rotary pneumatic percussion drilled boreholes *(coordinates taken by hand-GPS and elevation from map)*							
BF-33	3	461038	400469	No casing	252	No casing	No core
BF-34	3	461030	400447	No casing	254	No casing	No core
BF-35	3	461013	400413	No casing	254	No casing	No core
BF-36	3	460998	400441	No casing	251	No casing	No core
BF-37	3	461011	400461	No casing	251	No casing	No core
BF-38	3	461024	400472	No casing	251	No casing	No core

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[3] Refer to Section 1.3.

[4] Refer to Section 1.3.

3.2 Exploratory drilling

Exploratory drilling was carried out by Ræktunarsamband Flóa og Skeiða ehf (RSFS). Each of the three cored holes is cased with 3” ODEX drilled-casing (Atlas Copco (2008)), 2-3 m long. The core was recovered with Longyear NQ triple tube equipment (Boart Longyear Ltd. (2012)), giving cores of 45 mm diameter. The 3” rotary pneumatic percussion drilled holes were drilled with the same drill rig using 76 mm drill bit.

3.3 Logging of boreholes

Detailed graphic logs of cored-boreholes from 2012 are shown in Appendix C, graphic logs of cored-boreholes from earlier campaigns are presented in Appendix D and pictures of the cores in Appendix E. Interpretation of the rotary pneumatic percussion drilling 2012 is shown in Appendix F.

The regular Rock Quality Designation, RQD, i.e. for core pieces longer than 10 cm, is shown, as well as values for 30, 50 and 100 cm pieces, where RQD is the percentage of core pieces longer than 10 cm (or 30, 50 or 100) of the core interval assessed.

Also on the logs are results on ground water table, core recovery (in percentage; can be more than 100% due to slight inaccuracy in the measurements on the core lengths and recovery), point load tests (see Section 3.4) and Lugeon or packer permeability tests (see Section 3.5).

The rock mass quality presented is “Qc” (or “Qcore”) rather than the traditional Q as the results are mainly based on observations of the core rather than the whole rock mass. The Q-system was defined in Norway (Norwegian Group for Rock Mechanics (2000)) and has been adapted for use in Iceland over the years with experience from tunneling (Vegagerðin (2009)). The core from BF-1, BF-18, BF-19, BF-20 and BF-21 was logged anew and the Qc value rated according to practice of today in Iceland.

Support of structures is not dealt with in this report but for reference purposes Figure 3-1 is presented.

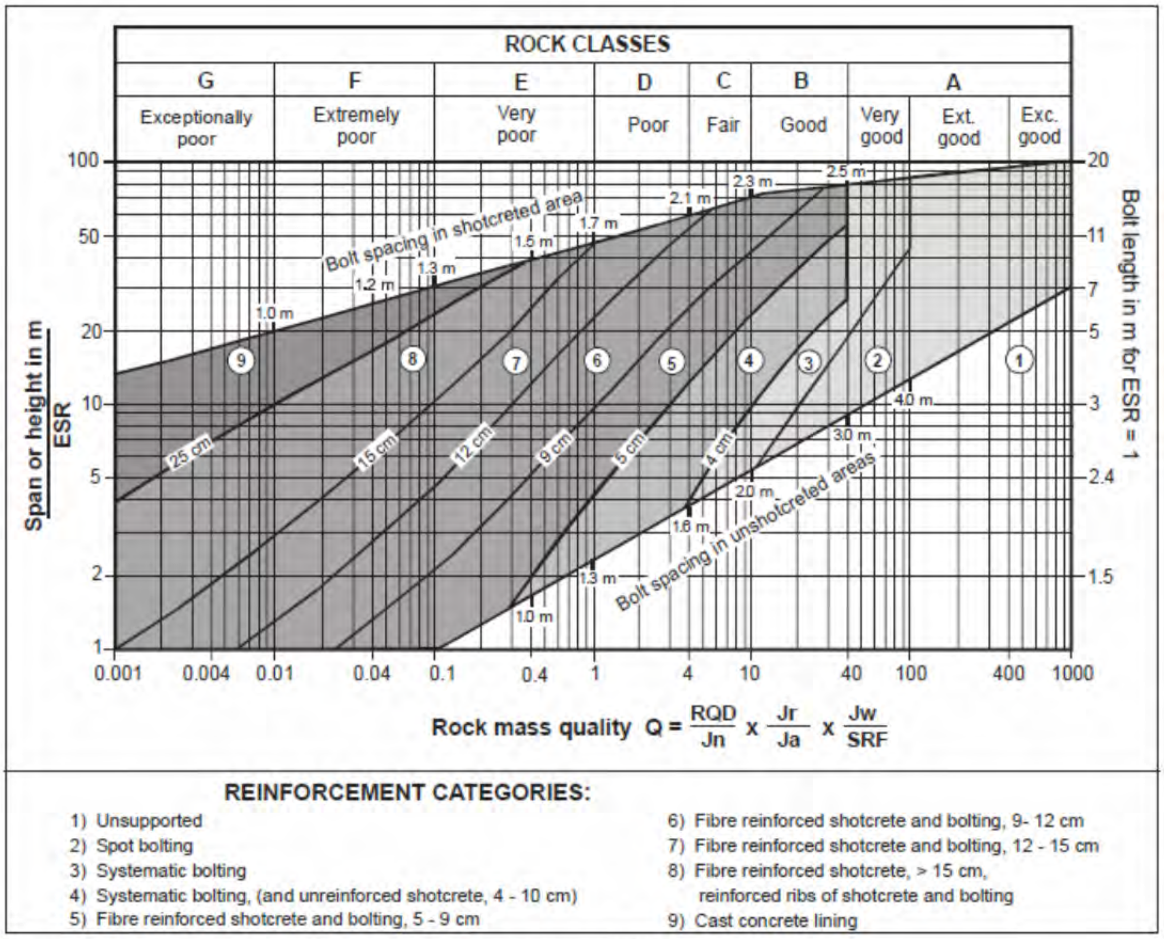

Figure 7. The *Q* support chart (from Grimstad and Barton, 1993)

Figure 3-1 Rock mass quality. From Palmstrom and Broch (2006).

3.4 Point load tests

Point load tests were carried out as soon after drilling as possible on the D = 45 mm core (+/- 0,5 mm) in a diametral setup, i.e. with force applied perpendicular to the length of the core. The test procedure and calculation of results shown in Table 3-2 follows operating instructions of the point load test apparatus (ELE International (2003)) and description of the Norwegian Group for Rock Mechanics (2000):

$$I_{s50} = I_s * F = \left(\frac{P\ (N)}{D^2(mm2)}\right) * \left(\frac{D\ (mm)}{50\ (mm)}\right)^{0,45}$$

Here, Is is the point-load strength index and 50 refers to a 50 mm core; F is a core-size correction factor; P is the measured load at failure, and D is the measured diameter of the core being tested. In the current case this becomes:

$$I_{s50} = I_s * F = \left(\frac{P\ (N)}{45^2(mm2)}\right) * \left(\frac{45\ (mm)}{50\ (mm)}\right)^{0,45} = \left(\frac{P\ (N)}{45^2(mm2)}\right) * \ 0,954$$

Table 3-2: Results of point-load testing.

Point load measurements						
Borehole	**Depth (m)**	**Stratigraphic member**	**Number of tests**	**Average measured load at failure, P (N)**	**Point load strength index, I_{s50} (MPa)**	**Comments**
BF-30	18,20-18,60	Conglomerate	2	4700	2,2	
BF-30	31,27-31,54	Conglomerate	4	9700	4,6	
BF-30	73,74-74,0	Andesite	4	23400	11,0	
BF-30	75,49-75,66	Andesite	3	19900	9,4	
BF-30	83,55-83,8	Andesite	3	13000	6,1	
BF-30	95,30-95,60	Andesite	4	31000	14,6	
BF-30	96,85-97,07	Andesite	3	27000	12,7	
BF-30	104,3-104,47	Tholeiite	3	27300	12,9	
BF-30	115,75-116,02	Tholeiite	3	19900	9,4	
BF-30	116,3-116,6	Tholeiite	4	1300	0,6	*
BF-30	118,30-118,57	Tholeiite	3	19,5	9,2	
BF-30	120,04-120,27	Conglomerate	4	3,4	1,6	*
BF-30	126,6-127,0	Olivine basalt	5	7,7	3,6	
BF-30	138,25-138,60	Tholeiite	5	16,6	7,8	
BF-30	152,3-152,6	Basalt	4	16,4	7,7	
BF-30	160,3-160,6	Olivine basalt	4	13,8	6,5	
BF-30	164,5-164,85	Olivine basalt	4	7,3	3,4	
BF-30	165,36-165,6	Olivine basalt	3	13,4	6,3	
* Strength is below range of advisable use of point load testing (Norwegian Group for Rock Mechanics (2000) and is not included in Table 4-1.						

3.5 Packer tests for hydraulic conductivity

Hydraulic conductivity tests (or permeability tests) were performed in most of the cored holes, the so-called Lugeon test or packer test, using single packer method (Árni Hjartarson et al. (1983)). The results are expressed as lugeon, LU, where one (1) LU “is empirically defined as the hydraulic conductivity required to achieve a flow rate of 1 liter/minute per meter of test interval under a reference water pressure equal to one (1) MPa” (Quinones-Rozo (2010)).

Geological and engineering geological investigations at the Búrfell Station site started soon after 1960 as discussed in Sections 1.2 and 2.2 and many layouts of the project were investigated and several boreholes drilled to investigate each layout. Below are presented permeability tests in holes directly relevant to the present project, i.e.: BF-1 from 1980, BF-18 to BF-21 from 1983, and BF-30 to BF-32 from 2012.

The testing intervals along the depth of the borehole depend on conditions in each hole and therefore they are of variable length.

For results, refer to Table 3-3 and Table 3-4 and the borehole logs in Appendix C, Appendix D and to Figure 3-2 to Figure 3-5.

Table 3-3 Single packer tests in boreholes drilled in the Older Búrfell formation (OB).

Borehole	**Geological formation**	**Depth of packer in borehole (m)**	**Bottom of borehole during packer test (m)**	**Packer test interval or length (m)**	**LU ((l/min)/m)**
BF-1	OB	5	151	146	2
BF-18	OB	9	20	11	5
BF-18	OB	20	40	20	1
BF-19	OB	9	20	11	4
BF-19	OB	20	40	20	6
BF-20	OB	19	30	11	5
BF-20	OB	35	40	5	15
BF-20	OB	40	50	10	7
BF-21	OB	9,5	16	6,5	8
BF-21	OB	18,5	41	22,5	5
BF-21	OB	41	50	9	25
BF-30	OB	7,2	33,6	26,4	0,75
BF-30	OB	33,6	42,13	8,53	2,7
BF-30	OB	42,13	54,6	12,47	6
BF-30	OB	54,6	63,6	9	20
BF-30	OB	63,6	75,42	11,82	9
BF-30	OB	73	82,62	9,62	3
BF-30	OB	85,75	93,6	7,85	45
BF-30	OB	91,6	102,56	10,96	43
BF-30	OB	96,6	111,6	15	10
BF-30	OB	108,6	120,6	12	14
BF-30	OB	117,6	129,6	12	6
BF-30	OB	129,6	144,6	15	6
BF-30	OB	138,6	153,6	15	4
BF-30	OB	153,6	174,1	20,5	12
BF-31	OB	12,6	42,18	29,58	3,5
BF 32	OB	3	21,7	18,7	2
BF 32	OB	52,2	65,13	12,93	2,3
BF 32	OB	61	84,32	23,32	3
BF 32	OB	3	84,32	81,32	3

Table 3-4 Packer tests in holes drilled 1962 in the Sámstaðaklif Basalt formation (SB).

Borehole	**Geological formation**	**Depth of packer in borehole (m)**	**Bottom of borehole during packer test (m)**	**Packer test interval or length (m)**	**LU ((l/min)/m)**
PT-8	SB	1,5	4	2,5	1
PT-8	SB	4	6,8	2,8	200
PT-8	SB	6,8	8,7	1,9	30
PT-8	SB	8,7	11,7	3	120
PT-8	SB	11,7	16,2	4,5	1
PT-8	SB	16,2	20	3,8	30
PT-9	SB	3	6	3	1
PT-9	SB	6	9	3	20
PT-9	SB	9	12	3	1
PT-9	SB	9	12	3	20
PT-10	SB	0,8	21,2	20,4	40
PT-10	SB	21,2	40,5	19,3	25

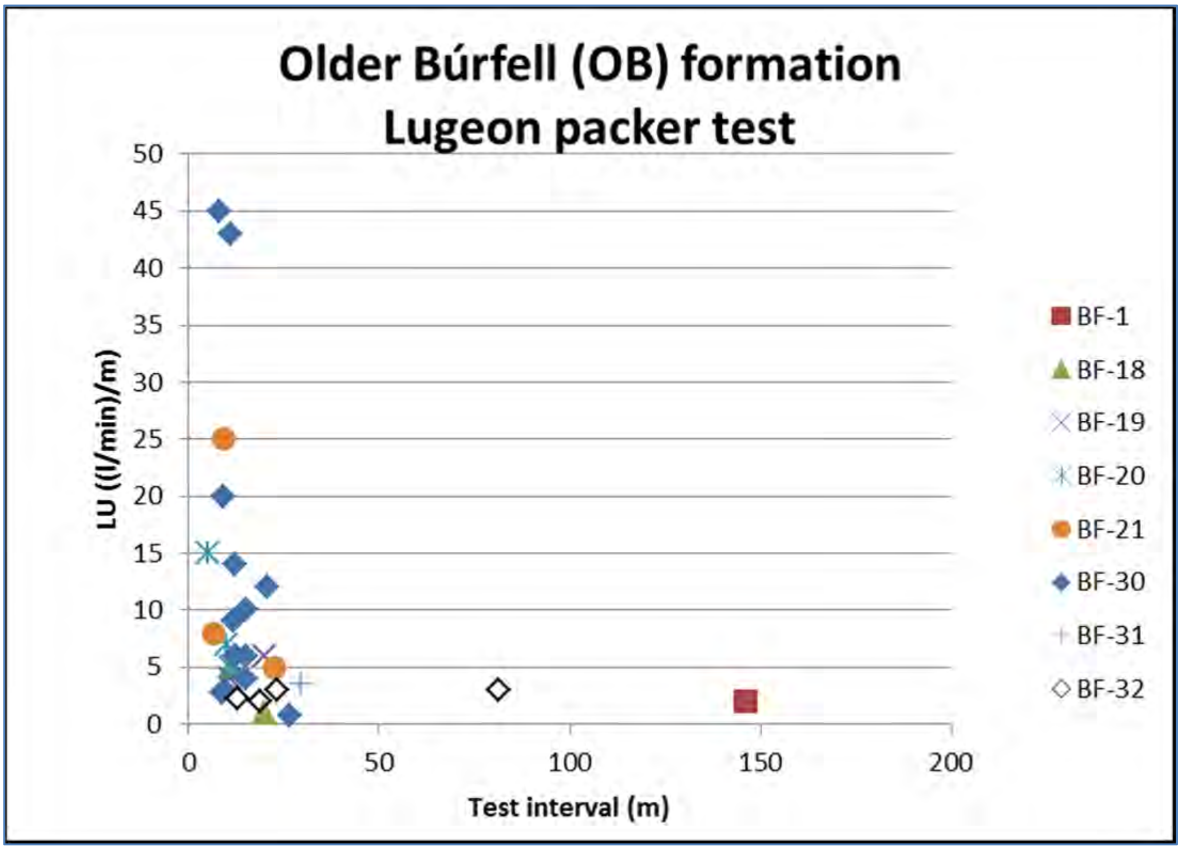

Figure 3-2 Packer tests of holes drilled 1980-1983 (BF-1 to BF-21) and in 2012 (BF-30 to 32) in the Older Búrfell formation (OB). Test interval is in meters and LU is in litres/minute per metre along the test interval.

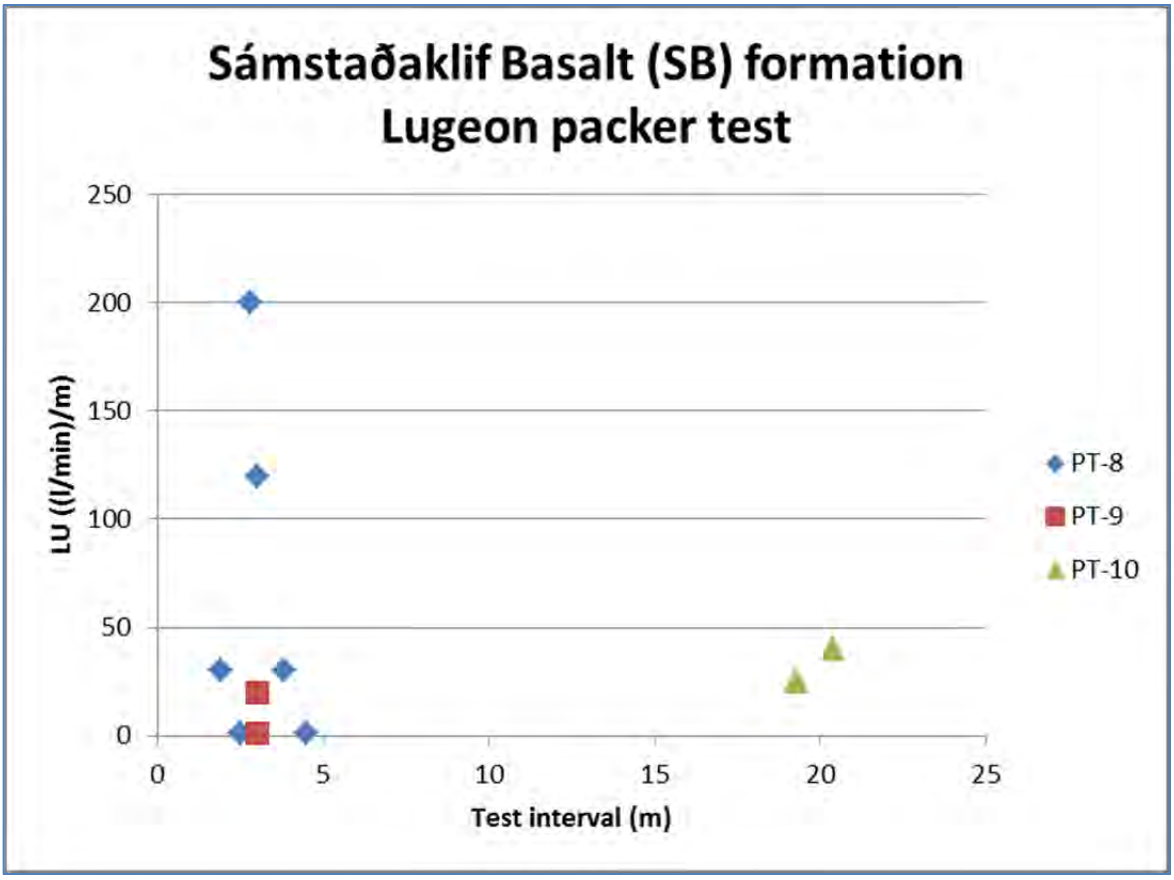

Figure 3-3 *Packer tests in Sámstaðaklif Basalt formation (SB). The holes were drilled in 1962.*

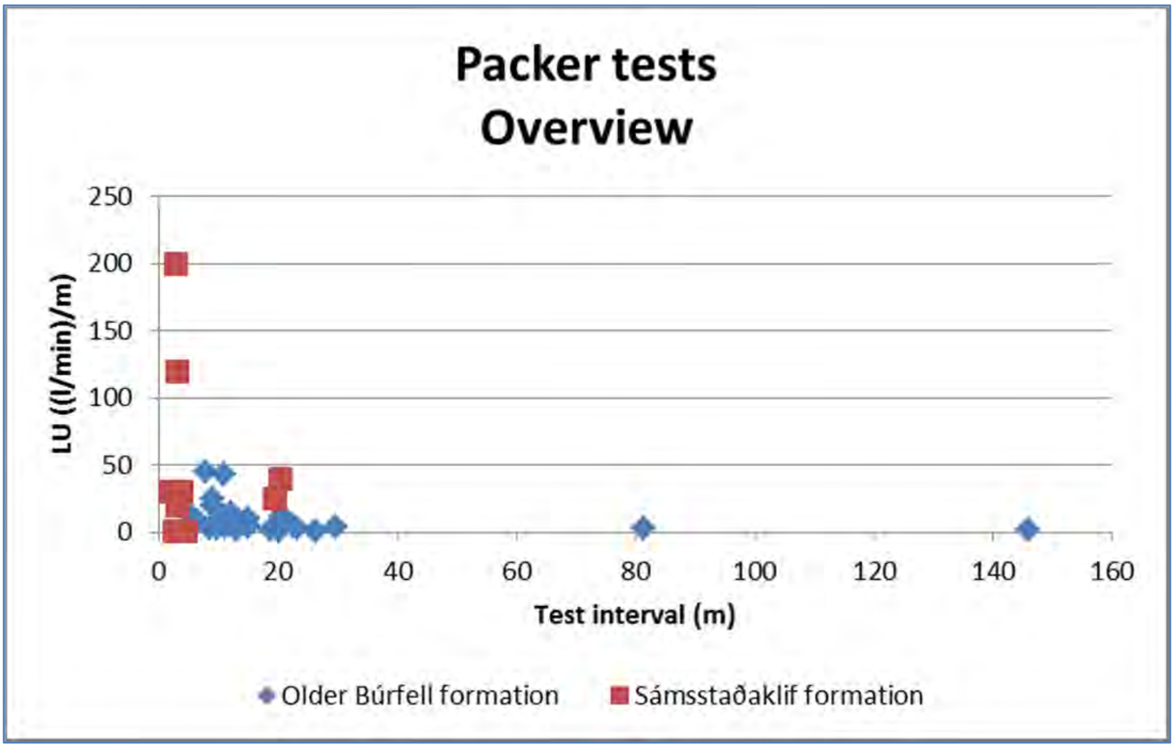

Figure 3-4 *Overview of packer tests in both geological formations*

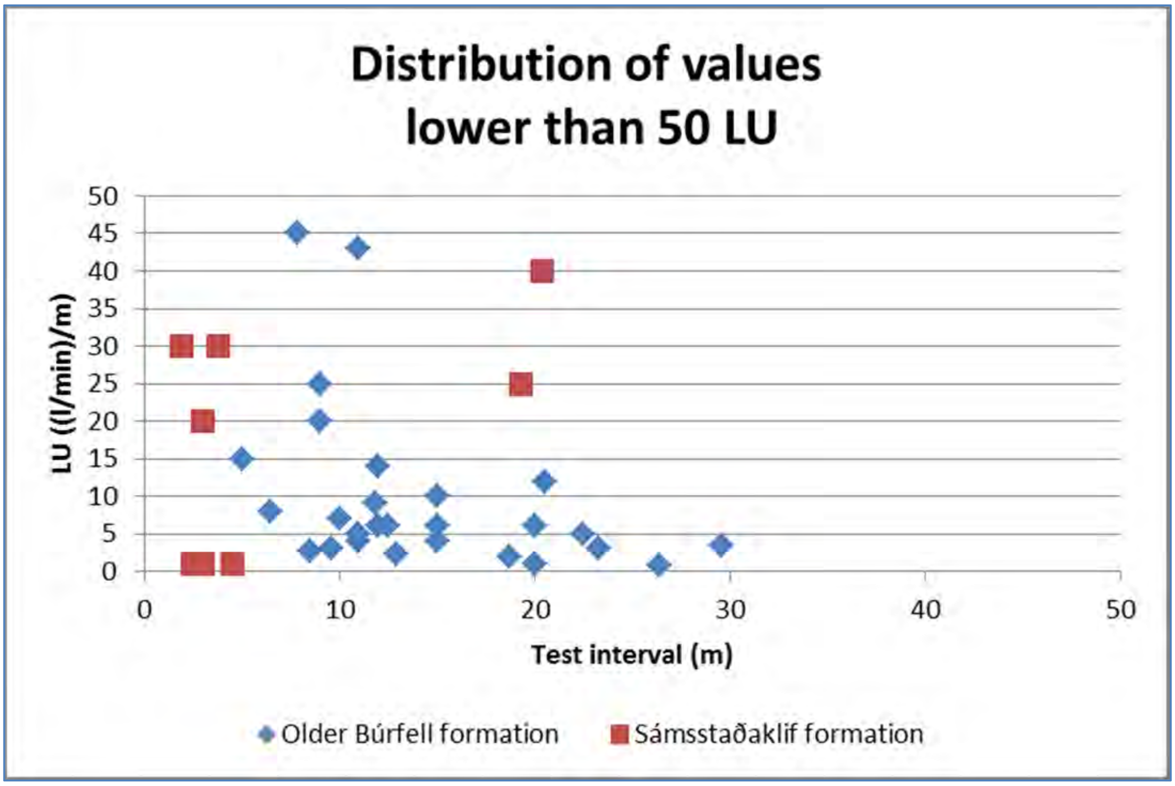

Figure 3-5 Distribution of LU values lower than 50 LU. Two packer tests yielding 120 and 200 LU in PT-8 are omitted in the graph.

3.6 Pumping test for hydraulic conductivity

Pumping test was performed in 1984 (Jón Ingimarsson (1985)) at the powerhouse site of the then proposed Búrfell Extension - Surface Powerhouse Alternative. The rock formation tested is the Older Búrfell. The results are in good concordance with the packer tests and the report summarizes the results of the test as follows:

- Transmissivity, T = 1,0*10-5 m^2/s
- Storage coefficient, S = $4*10^{-4}$ (-)
- K= $(0,5-1,0)*10^{-6}$ m/s

4 LITHOLOGY

4.1 Introduction

In the chapter the stratigraphy and lithology at the site of the Búrfell Extension is described.

4.2 Lithostratigraphic units and properties

When describing the lithostratigraphic units in Table 4-1 below, the terminology from the earlier geological investigation reports discussed in Chapter 2 are used, and results are presented from the investigation in 2012. Besides, the International Stratigraphic Guide (Murphy and Salvador (1994/1999)) has been referred to.

Table 4-1 Lithostratigraphic units of the Búrfell HEP Extension

Lithostratigraphic units at Búrfell Extension and properties of the units					
Stratigraphy			**Properties**		
Formation[5]	**Member[6]**	**Bed or Flow**	**Point load strength index, Is50**	**Range of Qc at each location (-)**	**Permeability, LU ((l/min)/m)**
Sámsstaðaklif glacial till / moraine (GT)*				0,1-0,37	2-3
Sámsstaðaklif basalt (SB)					1-200

Continued

*In Icelandic called jökulberg or jökulruðningur

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[5] Myndun in Icelandic.

[6] Syrpa in Icelandic.

Formation	Member	Bed or Flow	Point load strength index, Is50	Range of Qc at each location (-)	Permeability, LU ((l/min)/m)
Older Búrfell (OB)					
	Conglomerate		2,2 4,6	2,4-6,5 4,3-5,8 3,9-5,2	0,75
	Olivine basalt	Vesicular part of lava-flow		3,9-8,7	
		Complex part of lava-flow		2,7-10,7	2,3
	Tholeiite basalt	Vesicular part of lava-flow		0,7-2,8	
		Dense part of lava-flow	12,9 9,4 9,2 7,8	3,1-9,3 1,3-5,0 2,4-5,4 1,7-3,8	4
		Complex part of lava-flow		1,5-4,6 4,5-10,0 1,4-7,0 2,0-8,1	10 14 3
	Porphyritic olivine basalt	Lava-flow	3,6 12,7	6,6-14,8 1,5-5,7	
	Basaltic andesite	Lava-flow	11,0 9,4 14,6 12,7	1,0-2,1 0,8-1,4 0,7-2,6 1,1-4,0 2,6-5,8 2,0-4,6	
		Vesicular part of lava-flow	6,1		
		Complex part of lava-flow		0,7-2,6 1,3-3,9	6 20 9 45 43
	Scoria			1,2-2,0 4,5-11,9 0,2-0,3 0,3-1,0	3
	Acid tuff			3,0-7,9	

5 EARTHQUAKES AND FRACTURES

5.1 Introduction

Only a brief discussion of some tectonic aspects of the Búrfell area, i.e. seismicity, fractures and faults, will be given in this chapter.

5.2 Earthquakes and seismic zoning

The Búrfell Extension-site is less than 5 km north of the South Iceland Seismic Zone (SISZ), see Figure 5-1, Appendix A and Khodayar et al. (2010).

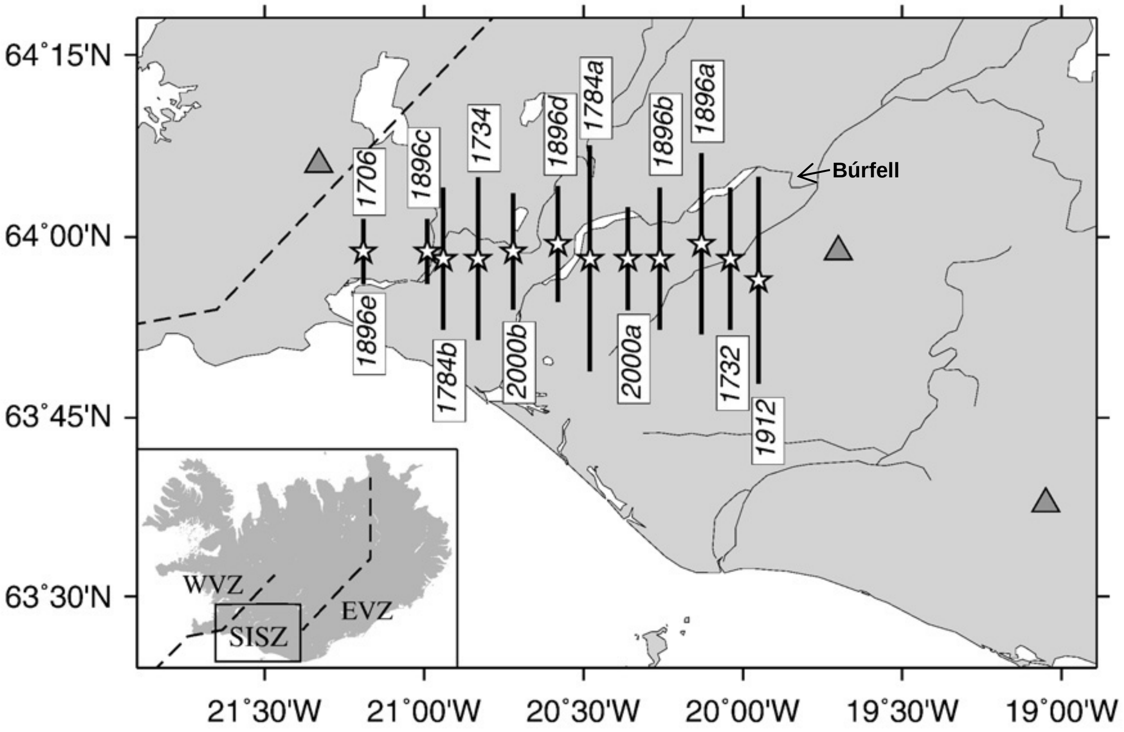

Fig. 1. The computational area including the South Iceland seismic zone (SISZ). Its location on Iceland is shown as inset. Also indicated are: Western (WVZ) and Eastern Volcanic Zone (EVZ); branches of the mid-Atlantic ridge (dashed lines); the position of the volcanoes Hengill, Hekla, and Katla (from west to east; triangles; positions from National Geophysical Data Center (NGDC) http://www.ngdc.noaa.gov and topographical maps). Ruptures (Roth, 2004; solid lines) and epicentres (Einarsson, pers. comm.; stars) of the 13 M≥6 earthquakes from 1706 to 2000 are also shown.

Figure 5-1 Large earthquakes in the South Iceland Seismic Zone (SISZ). From Richwalski and Roth (2008) with the location of mountain Búrfell added. Missing in this figure is the M>=6 earthquake doublet in 2008 (Decriem et al. (2010)) in the west and the 1987 Vatnafjöll M=5,9 earthquake in the east believed to show the extension of the SISZ to the Eastern Volcanic Zone (EVZ) (Ágústsson et al.(1999)).

According to ÍST EN 1998-1:2004 Eurocode 8 (Staðlaráð Íslands (2005 and 2009)), section “3.2.1 – Seismic zones”, “… national territories shall be subdivided by the National Authorities into seismic zones, depending on the local hazard. By definition, the hazard within each zone is assumed to be constant. … For most of the applications of EN 1998, the hazard is described in terms of a single parameter, i.e. the value of the reference peak ground acceleration on type A ground, agR. …" By "type A ground" is meant "rock or other rock-like geological formation, including at most 5 m of weaker material at the surface."

Icelandic authorities have subsequently subdivided Iceland into seismic zones and published in the National Annex to ÍST EN 1998-1:2004 Eurocode 8 (Staðlaráð Íslands (2010)). The Búrfell Extension lies within the zone of highest "horizontal reference acceleration for earthquakes in Iceland", as shown on Drawing 15 that shows part of the "hazard map for Iceland", with "10% probability of exceedence in 50 years … i.e. with a mean return period of 475 years" of agR = 0,50 g.

Besides, in section 4.2.5 - Importance classes and importance factors of ÍST EN 1998-1:2004 Eurocode 8 (Staðlaráð Íslands (2005 and 2009)) it says: "Buildings are classified in 4 importance classes, …." and importance class IV is described as "buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc." And in section 10.6 - Seismic action: "In buildings of importance class IV, site-specific spectra including near source effects should also be taken into account, if the building is located at a distance less than 15 km from the nearest potentially active fault with a magnitude Ms >= 6,5."

Based on this, in the National Annex to ÍST EN 1998-1:2004 Eurocode 8 (Staðlaráð Íslands (2010)), it says: "In those areas, where the distance to the closest potential fault is less than 15 km and agR = 0,5 g …, the Tc(S) parameter for ground type A should be increased from 0,4 s to 0,5 s. … In the South Iceland lowland the near fault area may be defined with a quadrangle whose sides are Hellisheiði in the west, Hekla in the east and the latitudes 64°8' in the north and 63°48' in the south." The above "near-fault-area" has been added to Drawing 15 and on to it has also been added data on fractures from Professor Páll Einarsson of University of Iceland (pers. comm., August 2012).

The fault of the M=7 earthquake of 1912 is closest to the Búrfell HEP Extension in the southwest as seen in Figure 5-1, and the M=5,9 earthquake of Vatnafjöll just south of mountain Hekla (Ágústsson et al.(1999)) is closest in the southeast.

The earthquakes in SISZ typically occur in episodes, on the average every 80 years (Khodayar et al. (2010)), with each episode lasting from days to years (Bryndís Brandsdóttir et al. (2010)). During current episode, starting in year 2000, if not 1987, three earthquakes over six in magnitude have occurred with epicenters 30 to 60 km away, or 25 km if the 1987 Vatnafjöll earthquake of M=5,9 is counted.

5.3 Joints, faults and other discontinuities

Generally speaking, joints, faults, fissures and fractures are types of "discontinuities", i.e. "any mechanical discontinuity in a rock mass having zero or close to zero tensile strength" (Norwegian

Group for Rock Mechanics (2000)). Fractures are seen on the surface and sometimes in boreholes, but a fault need not show up on the surface until after erosion has worked down upper layers. For general discussion of the fractures and faults in the Búrfell area, refer to Snorri Páll Snorrason (1981) and Elsa G. Vilmundardóttir et al. (1985).

Most of the joints observed in the basaltic lava pile and seen in the cored boreholes are caused by cooling of the lavas in question and show no displacement.

It is known from previous research at Sandafell, some 10 km north of Búrfell Station, that open fractures are found in the area (Snorri P. Snorrason, personal communication, November 2012) and a few cases of fractures where found in the cored boreholes of 2012 but without any active movement.

A very clear fracture is visible just north-west of the Búrfell Extension site, the Sámsstaðaklif-fault/fracture, and it meets the northern end of the headrace canal. The fault/fracture has direction of N65°A and fracture of that and similar direction are known to be strike-slip faults but no active displacement or movement have been observed at this fracture.

Three sets of faults/fractures are to be found in the vicinity of Búrfell, see Drawing 16.

One and probably the oldest set has orientation of N30°A to N60°A and it appears to be to be related to volcanic buildup of the general area. The rocks near or at these faults are expected to be more jointed than elsewhere. No sign of recent activity has been observed near these faults.

Second set of faults with orientation from N0°A to N20°A. These faults are quite prominent in the field as visible depression has been eroded along most of them. The orientation is similar to the strike-slip faults that are presently active in the South Iceland seismic zone but are obviously older as the erosion reveals. No signs of recent activity have been observed at or near these faults. A fault of this set seems to lie from the surface powerhouse site and in northerly direction towards cored hole BF-1. Rocks in both places are very jointed, possibly because of the fault. This fault will cross proposed access tunnel for the Underground powerhouse variant of this project.

The third set of faults have orientation of N60°A to N70°A and some of them have been mapped as strike slip faults. Signs of activity related to them (open fissures) have been observed north of the project site, in Sandafell. A fault of this set is to be found just north of the project site, the Sámstaðaklif fault/fracture mentioned before. It cuts through the current headrace canal but will probably not affect the headrace canal proposed in this paper.

6 GEOLOGICAL CONDITIONS FOR UNDERGROUND POWERHOUSE

6.1 Introduction

Below follows a description of the geological conditions at different structures of the Búrfell Extension - Underground powerhouse alternative. The layers discussed all belong to the Older Búrfell formation (OB).

Refer to Drawing 05 for the layout of the Underground powerhouse alternative, to Drawing 06 for a geological section, Appendix C and Appendix D for the logs of the holes for the relevant structure, and Appendix E for pictures of the cored boreholes 2012, and Table 4-1 for properties of the lithostratigraphic units.

In the description, reference is made to the design presented in a report by Almenna verkfræðistofan (2012B).

6.2 Headrace canal and intake

The headrace canal will be partly excavated in a layer of conglomerate, see log of the cored borehole BF-31 in Appendix C and Figure 6-1 and Figure 6-2 below. The same holds for the intake to the pressure shaft; most of the excavation is in the same conglomerate but the lowest part of the intake hits the olivine basalt below the conglomerate. The conglomerate is rich with rhyolite sand and angular rock fragments. The rounded pebbles are however of basalt origin. The layer is reasonably well cemented but with weak lenses, and somewhat jointed but some of the supposed joints are caused by drilling operation and handling. For the properties of the conglomerate layer, see Table 4-1. Two point load tests were obtained from the layer and they yield 2,2 MPa and 4,6 MPa; the Qc-value (Qcores-value) is 2,4 to 6,5. Permeability is low and the packer tests yields 0,75-3,5 LU.

The intake will be founded on the layer of olivine basalt layer just below the conglomerate. The layer is somewhat jointed but not unduly so, with the lower part dense and reasonably competent rock. The Qc value is in the range of 2,7-10,7, and permeability is low as the packer tests yielded 2,3-3,5 LU; see Table 4-1.

The uppermost 15 m of the conglomerate layer yielded poor core recovery and the recovered rocks are mostly pebbles and stones and the groundmass has eroded away due to weak cementing, but the intake and headrace canal appear to be excavated mostly below this weak zone.

Figure 6-1 Looking northwest over Samsstaðaklif with Bjarnalón in the upper right and the headrace canal of the Búrfell Station. The site of the headrace and tailrace canals of the underground alternative of the Búrfell Extension is shown. Photo: Emil Þór Sigurðsson 16 August 2012.

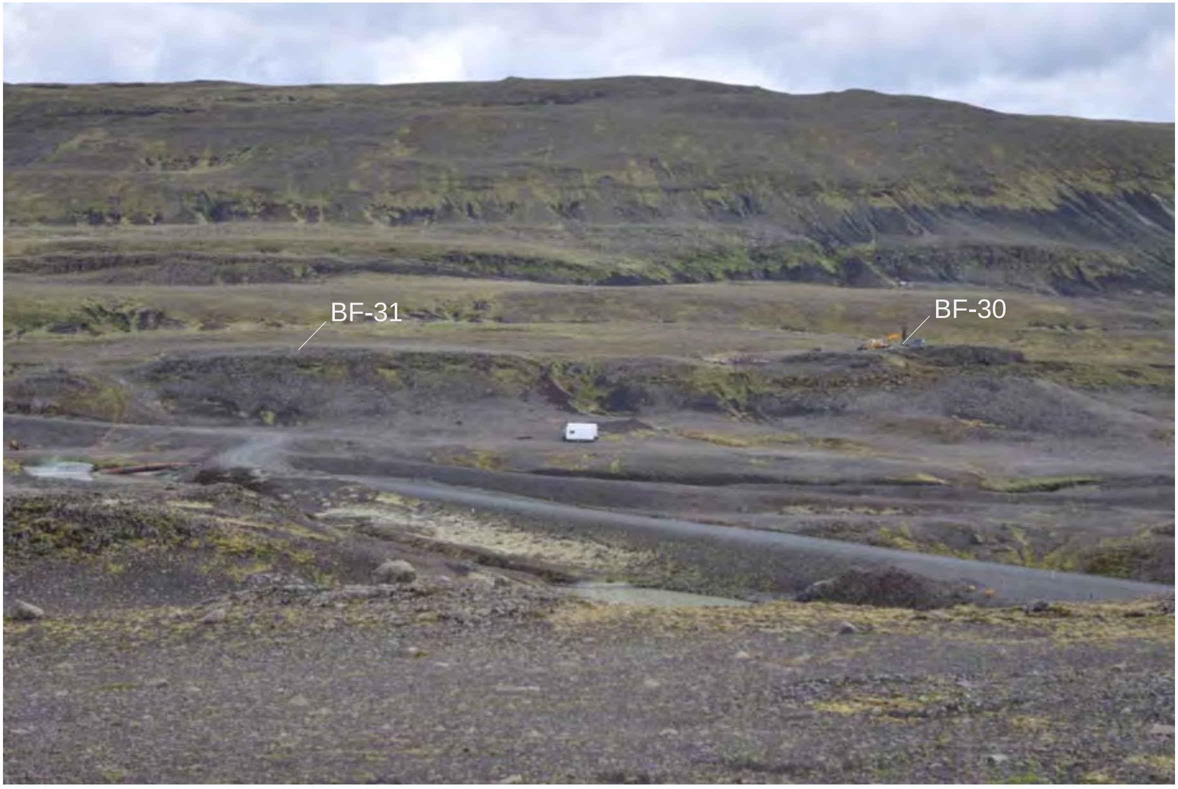

Figure 6-2 Closer look of headrace canal site. Viewing northeast with Skálarfell in the background. Cored borehole BF-30 being drilled close by the cable tunnel-location and showing location of BF-31 east of the headrace canal. Photo: Snorri Páll Snorrason 3 July 2012.

Figure 6-3 The drilling contractor at the site of borehole BF-30. Photo: Áki Thoroddsen 26 June 2012.

6.3 Pressure shaft and cable tunnel

Refer to Figure 6-2 for drilling of BF-30 and the log of that hole in Appendix C and to Drawing 06 and Drawing 07 and Drawing 08 for a geological section of these structures.

The cable tunnel starts at top in thin overburden and then goes through a 32 m thick layer of the conglomerate discussed in Section 6.2.

Below the intake structure a 60 m thick series of several basalt andesite layers are to be found. They reach down to elevation of 168 m a.s.l. The basalt andesite is generally dark, hard, dense and very jointed with irregular, often thin scoria layer at top. The scoria is filled with silt or opal and the fillings are substantial part of the rocks. The Qc value is estimated in the range 0,7-5,8 but the most common values are 1-3. The point load test yielded some 9,4-12,7 MPa. One scoria layer was thick enough to be evaluated separately, giving a Qc value as low as 0,3-1,0.

Below the basalt andesite a series of basalt layers are to be found and they reach to the bottom of BF-30 at elevation of 94,3 m a.s.l. The basalt is mostly tholeiite basalt very jointed and rather hard, and vesicular and dense rocks alternate. The core recovery is rather good. The Qc value ranges from 1,3-10 in the tholeiite and point load tests give 7,8 to 12,7 MPa. The Qc value of thickest scoria layer was evaluated separately and it ranges from 4,5-11,9.

In the middle of the tholeiite series described above is a sequence of cemented conglomerate, porphyritic olivine basalt layer, and a cemented layer of volcanic acid tuff. This 10 m sequence, at elevation 138-148 m a.s.l., has a very good core recovery, is little jointed and has Qc values from 2,4 to 14,8 and a common Qc value around 6-7.

Permeability varies considerably from low values of 6 LU up to moderate values of 45 LU for the pressure shaft and cable tunnel.

6.4 Powerhouse

Refer to Figure 6-2 for drilling of BF-30 and the log of that hole in Appendix C and to Drawing 08 for a geological section of this structure.

The powerhouse cavern is proposed from elevation of 108 m a.s.l. to 145 m a.s.l. and it will cut through several basalt layers. For the Qc values and point load tests and permeability see the log for BF-30 in Appendix C.

The layers at the powerhouse can be subdivided into four sections:

Crown layers at elevation 156 m a.s.l. down to 144 m a.s.l.: Consist of two heavily jointed tholeiite basalt layers and a 2 m layer of coarse conglomerate in between. The permeability test of the sector indicates 14 LU. The tholeiite basalt is jointed and the layers have Qc value in the range of 1,3-5,0. The joints appear to be predominantly caused by cooling of the lava. The lower tholeiite layer shows a fine pattern of healed joints which could be of tectonic origin. Some point load tests were made but the basalt layers are so jointed that the tests are difficult.; the highest value was 9,3 MPa but one sample yielded only 0,6 MPa. The 2m layer of conglomerate is rather coarse with angular stones of various origin, the Qc value is in the range of 4,3-5,8 and point load strength 1,6 MPa.

Upper layers near crane beam section at elevation 144 m a.s.l down to 129 m a.s.l.: A 5m thick sound and little jointed porphyritic olivine basalt with Qc value of 6,6-14,8 and point load strength of 3,8 MPa. Below is a thin tuff and sandstone layer somewhat jointed at top and horizontally layered and Qc is estimated to be 3,0-7,9. Lowest of the upper layers is a 9 m tholeiite basalt layer including scoria on top, moderately jointed and long vertical joints toward the bottom indicate possibly columnar jointing. The Qc value is given in the range of 4-10 and the point load strength 7,8 MPa. The scoria on top of the layer was filled with silt and reasonably well cemented. The upper layers have good core recovery and RQD of 68-89%. Permeability was measured 6 LU in two tests.

Lower part at elevation 129 m a.s.l. down to 118 m a.s.l.: Intensely jointed upper 11 metres of a 14 m thick layer of tholeiite basalt, including scoria on the top, partly crushed, and with a pattern of healed joints visible in the lower part. The Qc value is 1,4-7,0. Some of the joints are filled with thick brownish secondary minerals. The layer is weakly flow-banded.

Foundation layer at elevation 118 m a.s.l. down to 110 m a.s.l.:The topmost layer (118 – 115 m a.s.l.) is a bottom of 14 m thick tholeiite also found in basalt layer. The layer is moderately jointed and flow-banded. Point load strength is 12,7 MPa. Directly under this layer a 4 m thick tholeiite basalt layer is to be found with Qc value of 2,0-8,1.

6.5 Tailrace tunnel

Refer to Drawing 06 for a geological section of tailrace tunnel and Appendix C and Appendix D for the logs of the holes and Figure 6-4, Figure 6-5 and Figure 7-7 for drilling of the BF-32.

Several boreholes have been drilled near the proposed tailrace tunnel. The present evaluation is primarily based on information in BF-20, BF-21, BF-30, BF-32 and SO-01. BF-20 and BF-21 were drilled at the then planned surface powerhouse site in 1983 and SO-01 was drilled near end of possible access tunnels in 1962. BF-30 and BF-32 were drilled in 2012.

The tailrace tunnel will be excavated in heavily jointed tholeiite basalt and basaltic andesite lava-layers of various rock quality and often including scoria. The lava pile dips a few degrees toward north east (approximately 2°). The Qc value of the basalt layers seem to be in the range of 0,5-8 with the most common range 1-4 or thereabout.

Point load test was made in BF-30 of the 14 m thick layer of tholeiite basalt, discussed in Section 6.4 above for the lower part and foundation layer of the powerhouse, and it shows a strength of 12,7 MPa. Point load test are not available from other holes. Permeability in the tholeiite series is rather low, with BF-1 displaying 3 LU and some other holes showing 5-6 LU. Holes BF-20 and BF-21 give values 15-25 LU in some part of the holes.

Borehole BF-32, located right on the west side of the tailrace tunnel, starts at 187 m. a.s.l. on moraine or glacial till (called tillite in some of the former investigations, i.e. a sedimentary rock) and the moraine extends down to about 140 m a.s.l.; underneath is andesite and basalt with scoria. The crown of the tailrace tunnel will be at about 120 m a.s.l. and boreholes BF-02 and BF-09 to BF-17 close to the exit of the tunnel show the moraine with lowest level at 134 m a.s.l., in BF-10. Further away, 35 metres west of the tunnel is the moraine at eleveation 117 m a.s.l. in hole SO-1. Therefore it cannot be ruled out the the tailrace tunnel hits the moraine in some parts. Refer to Appendix G showing the extent of the moraine according to Pétur Pétursson (1982).

In 1962, an exploration-tunnel was excavated with the plan to hit the site of a then planned underground powerhouse (Haukur Tómasson (1967)). Refer to Drawing 05 and Appendix G and Figure 7-7 for the location of this tunnel and Appendix G for the location (“Mynd 1”) and a longitudinal geological section (“Mynd 7”) of the tunnel and Appendix H for a text (part English, part Icelandic) on the progress of the excavation (Haukur Tómasson (1967)).

Figure 6-4 Drilling of BF-32 in progress. Photo: Snorri Páll Snorrason 15 July 2012.

Figure 6-5 Drilling of BF-32 in progress - closeup. Photo: Snorri Páll Snorrason 15 July 2012.

6.6 Access tunnel

Refer to Drawing 09 for a geological section of the access tunnel and Appendix D for the logs of the holes.

The rock pile at the access tunnel is the same as for the tailrace tunnel and the most of rock quality and permeability parameters are similar, refer to Section 6.5. No drilling was done at the site in present drill campaign. The access tunnel will lie close to and below an unconformity just north of it, see Drawing 09. The rocks north of the unconformity are different from the tholeiite suite on the south side and possibly more permeable. The access tunnel will cross a possible vague fault line near borehole BF-1, see Drawing 16. No indications of active or recent movements have been observed near this fault.

Figure 6-6 Sámsstaðaklif-fracture meeting the headrace-canal of Búrfell Station in the centre. Location of access tunnel entrance for Búrfell Extension – Underground alternative. Photo: Emil Þór Sigurðsson 16 August 2012.

6.7 Tailrace and side canal

Refer to Section 7.5 for a description, as the design of the tailrace canal and the side canal is identical for the Underground and Surface powerhouse alternatives.

7 GEOLOGICAL CONDITIONS FOR SURFACE POWERHOUSE ALTERNATIVE

7.1 Introduction

Below follows a description of the geological conditions at different structures of the Búrfell Extension - Surface powerhouse alternative.

Refer to Drawing 04 for a plan view of Surface powerhouse structures and investigation boreholes; Drawing 10 for a geological section along headrace canal to beginning of tailrace canal and Drawing 11 for a geological section across the powerhouse pit. In Appendix C and Appendix D are the borehole logs shown, in Appendix E pictures of available cores from boreholes, and Table 4-1 shows the properties of the lithostratigraphic units.

In the description, reference is made to the same stations (in metres) given along the structures as in the report by Almenna verkfræðistofan (2012A)).

7.2 Headrace canal and diversion dike

The headrace canal starts at the south-side of the canal for the older Búrfell Station, itself starting from the southwest of the man-made intake-lake Bjarnarlón. At about station 0+350 of the new canal, a dike starts on the right or west bank, meeting up with the old dike, and at about station 0+570 the canal ends at the intake to the penstock. The dike swings around the end of the canal and intake in the south, with an access road at the south slope of the dike.

The new canal is excavated on the south or left bank of the older canal and on the south side of the Sámsstaðaklif-fracture see Figure 7-1. Counting from northeast to southwest, the following boreholes cover this structure of the Búrfell Extension or give a likely situation:

- PT-9 at about station 0+120, left of centreline.
    - Excavation for canal starting in SB-formation.
        - Lithology: Hyaloclastite or volcanic breccia.
    - Excavation for canal finishing in OB-formation.
        - Lithology: Conglomerate with a thin sandstone layer in between.
- PT-8 at about station 0+320, right of centreline.
    - Excavation for canal starting in SB-formation.
        - Lithology: Thin overburden on top of hyaloclastite or volcanic breccia.
    - Excavation for canal finishing in OB-fomation.
        - Lithology: Thin sandstone layer with conglomerate underneath.
- PT-10 at about station 0+430, right of centreline.
    - Excavation in SB-formation.
        - Lithology: Olivine basalt intermixed with hyaloclastite.
- BF-18 at about station 0+460 on centreline.
    - Excavation in SB-formation.

        - Lithology: Cube-jointed tholeiite basalt mainly in one layer but probably just hitting scoria at bottom and a second basalt layer of same type.
- BF-19 at about station 0+570 left of centreline.
    - Excavation in SB-formation.
        - Lithology: Thin overburden on top of tholeiite basalt layers and conglomerate layers.

The logs of the boreholes are found in Appendix D and a longitudinal section in Drawing 10.

Figure 7-1 Sámsstaðaklif-fracture meeting the headrace-canal and diversion dike of Búrfell Station in the centre-right. Location of penstock for Búrfell Extension. Photo: Emil Þór Sigurðsson 16 August 2012.

Figure 7-2 Viewing north from mountain Búrfell over headrace canal of Búrfell Station in the lower centre, connected to Bjarnalón Reservoir to the right. Photo: Snorri Páll Snorrason 12 June 2012.

Figure 7-3 Viewing west to Sámsstaðamúli. Headrace canal for the Búrfell Station turning right to the intake. The headrace canal of the Búrfell Extension starts on the nearbank and the pipe in center left passing underneath the diversion dike is located at what will be the right bank of the new headrace canal at about station 0+350. Photo: Steinar I. Halldórsson 3 May 2011.

7.3 Power intake structure and penstock

Counting of stations along the intake and penstock starts at the intake at the end of the headrace canal and the penstock pipe starts at station 0+292 (m) and ending at 0+431 by the surface powerhouse.

The cored borehole closest to the power intake structure is BF-19, see Drawing 04, Appendix D and Drawing 10 and Figure 7-4 to Figure 7-6:

- BF-19 at about “imaginary station 0 minus 008” and 28 m left of centreline.
    - Excavation in OB-formation.
        - Layers from top to bottom of power intake structure pit:
            - 0,5 m of overburden
            - 5 m of tholeiite basalt
            - 2 m of conglomerate
            - 12 m of tholeiite basalt in two layers including 2 m of scoria in between
            - 1 m of sandstone
            - At least 1m excavation into a 6 m conglomerate-layer.

The cored borehole BF-1 is near the beginning of the penstock and by the first anchor block with rock-anchors underneath, see Drawing 04, Appendix D, Drawing 10 and Figure 7-4:

- BF-1 at about station (0+066) and 10 m right of centreline.
    - Excavation in OB-formation.
        - Layers from top to bottom:
            - 2 m of overburden
            - 31 m of jointed and flow-banded basaltic andesite in three layers including up to 4 m thick scoria at top or bottom of layer

At about station 0+120 the penstock-excavation hits a layer of moraine (glacial till; often called tillite in earlier investigations) and this layer gets thicker to the south.

The cored borehole SO-1 is near the end of the penstock and by the second anchor block with rock-anchors underneath, see Drawing 04, Appendix D and Drawing 10:

- SO-1 at about station (0+365) and 7 m right of centreline.
    - Excavation in sediments.
        - Layers from top to bottom:
            - 5 m of overburden mainly of pumice
            - 39 m of moraine
    - Excavation in OB-formation.
            - More than 3 m of tholeiite basalt

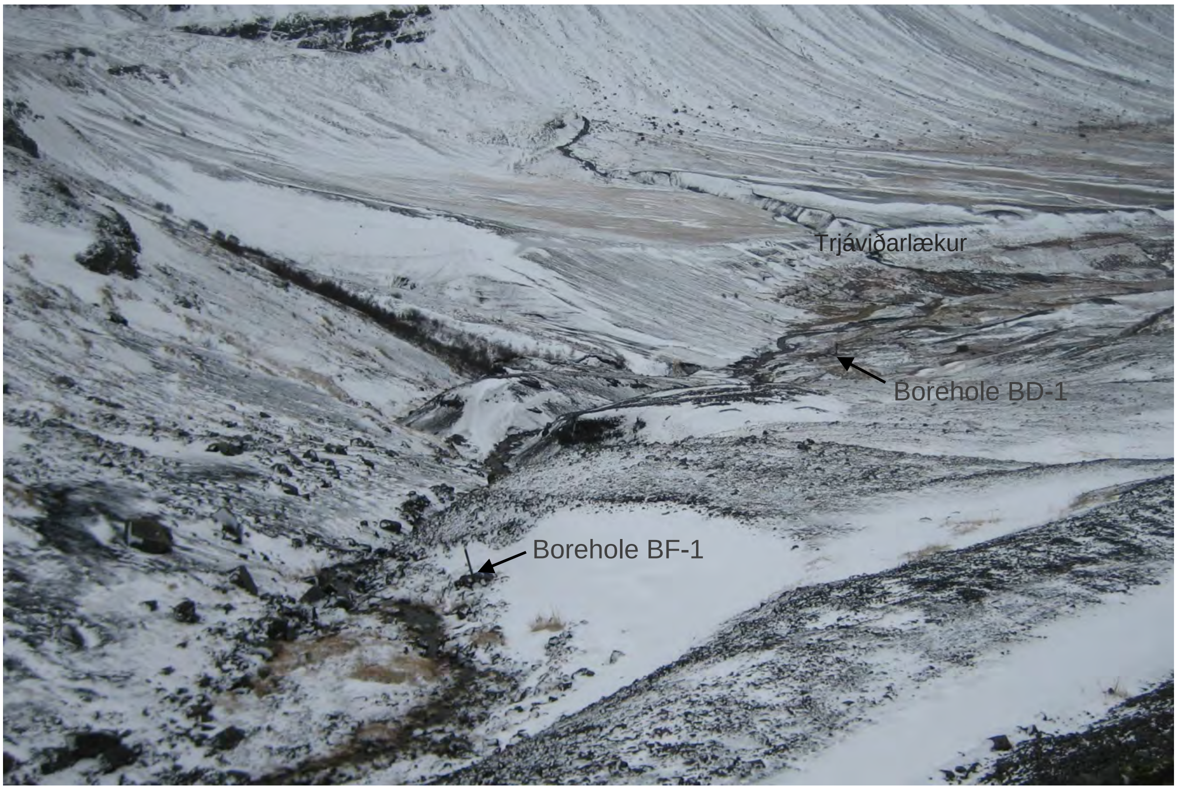

Figure 7-4 Viewing south-southwest with cored borehole BF-1 from 1980 in the foreground and pumping well BD-1 from 1984 at proposed surface powerstation lot. Trjáviðarlækur and other streams opening out to the tailrace canal-to-be. Photo: Steinar I. Halldórsson 2 March 2011.

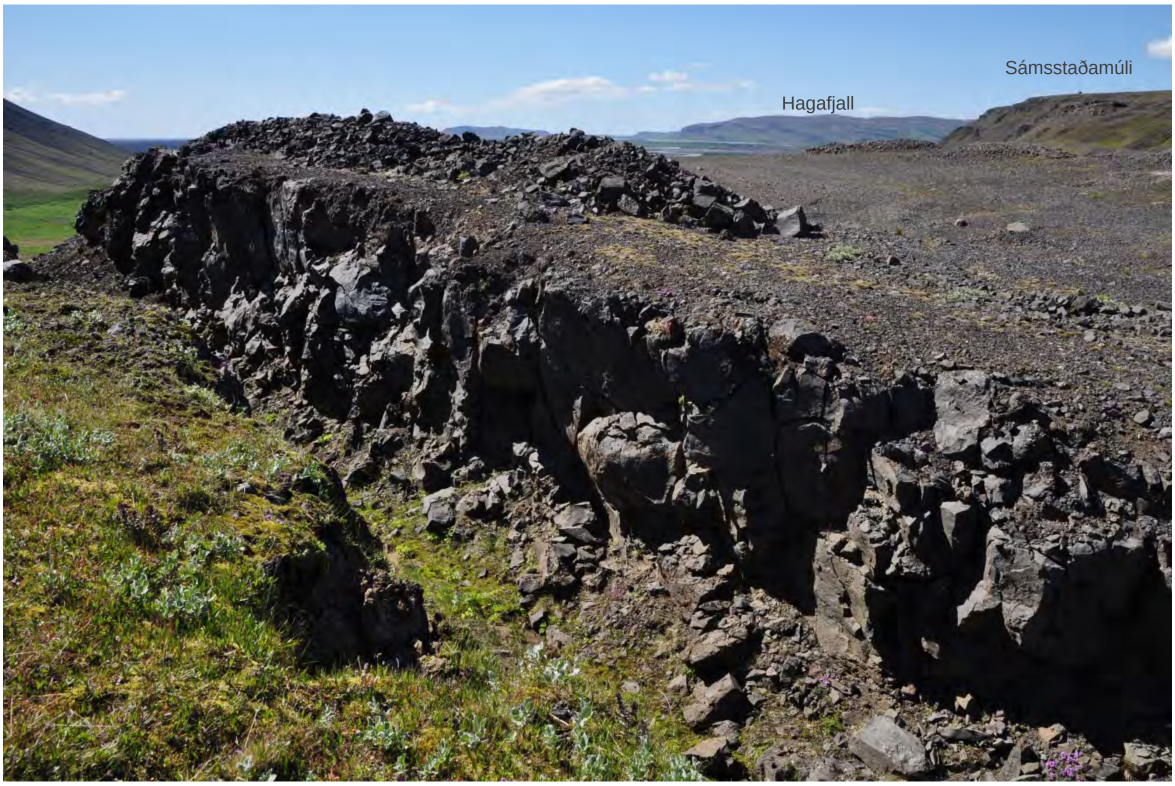

Figure 7-5 Picture taken close to the end of the planned headrace canal at about station 0+530 with the trench in the figure being where the left bank will be. The cut rock in the trench is probably the same as the 5 m thick uppermost tholeiite basalt seen in BF-19 at elevation 239 m a.s.l. to 243 m a.s.l. Viewing west-southwest. Photo: Snorri P. Snorrason 10 July 2012.

Figure 7-6 Bottom of the section of the trench in Figure 7-6 showing the conglomerate layer underneath the tholeiite basalt seen in borehole BF-19 at elevation 237 m a.s.l. to 239 m a.s.l. Photo: Snorri P. Snorrason 10 July 2012.

Figure 7-7 Viewing north. Cored borhole BF-32 being drilled through the moraine. The NE-corner of the surface powerhouse pit will be in the lower far left. The position of the penstock is shown. Photo: Steinar I. Halldórsson 17 July 2012.

7.4 Surface powerhouse

The surface powerhouse is to be located under the west side of mountain Skálarfell and south of Sámsstaðaklif see Drawing 04 and Figure 7-8 and Figure 7-9. Several boreholes have been drilled at the location in earlier campaigns see Drawing 04. Logs of the following cored boreholes are shown in Appendix D:

- BF-10
- BF-20
- BF-21

Drawing 11 shows a geological section across the powerhouse pit based on a report prepared in 1983 (Bjarni Bjarnason (1983)).

The cross-sections number 10 to 13, presented in Appendix I with location shown on Drawing 12, are from thrust rotary soundings by the powerhouse. The sections show the thickness of the pumice („vikur" in Icelandic) on top of the moraine (termed „jökulberg" on the sections)[7]. Much of the pumice has now been excavated as can be read from „present land elevation" in graphic logs og holes BF-02, BF-10, BF-20 and BF-21; this was done after 1982 when water was diverted from the older headrace canal down to the Trjáviðarlækur stream in order to widen and deepen it as a tailrace canal (Almenna verkfræðistofan (1981)) for the proposed Búrfell Extension.

The excavation mentioned removed much of the loose overburden and pumice and the peat seen in the older borehole logs. Instead, the present proposed excavation will in most cases start in the about 5-15 m thick layer of moraine (glacial till) of Holocene age as shown on the logs and in Figure 7-12 and discussed in Section 7.3. This layer that is now called moraine or glacial till is in many or majority of reports termed a sedimentary rock, tillite. It is not always clear which term is correct. Results of measurements in the moraine in borehole BF-32 are shown in Table 4-1, giving rock mass quality, Qc = 0,1-0,4 and permeability, LU = 2-3.

Below the moraine one enters the Older Búrfell formation (OB) made of scoria and jointed tholeite basalt or basaltic andesite members. The RQD shown on the borehole logs of BF-10, BF-20 and Bf-21 in Appendix D is low and in line with the jointed structure of the rock. Permeability in the OB-layers is low to moderate as shown by the packer test, with LU = 5 to 25, but a detailed study in 1984 (Jón Ingimarsson (1985)) gives more reliable information as discussed in Section 3.6.

A possible fault runs from cored borehole BF-1 down to the surface powerhouse site, see Drawing 16.

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[7] Jökulberg means tillite, but now this layer is classified as moraine or glacial till.

Figure 7-8 Viewing northeast towards Bjarnalón Reservoir and the headrace canal of Búrfell Station by and above Sámsstaðaklif. Trjáviðarlækur stream entering from centre right and and meeting streams from Skálarfell and turning west in the lower left. The light colour in the centre right and lower left is mainly reflecting the pumice from Hekla in the overburden. Photo: Emil Þór Sigurðsson 16 August 2012.

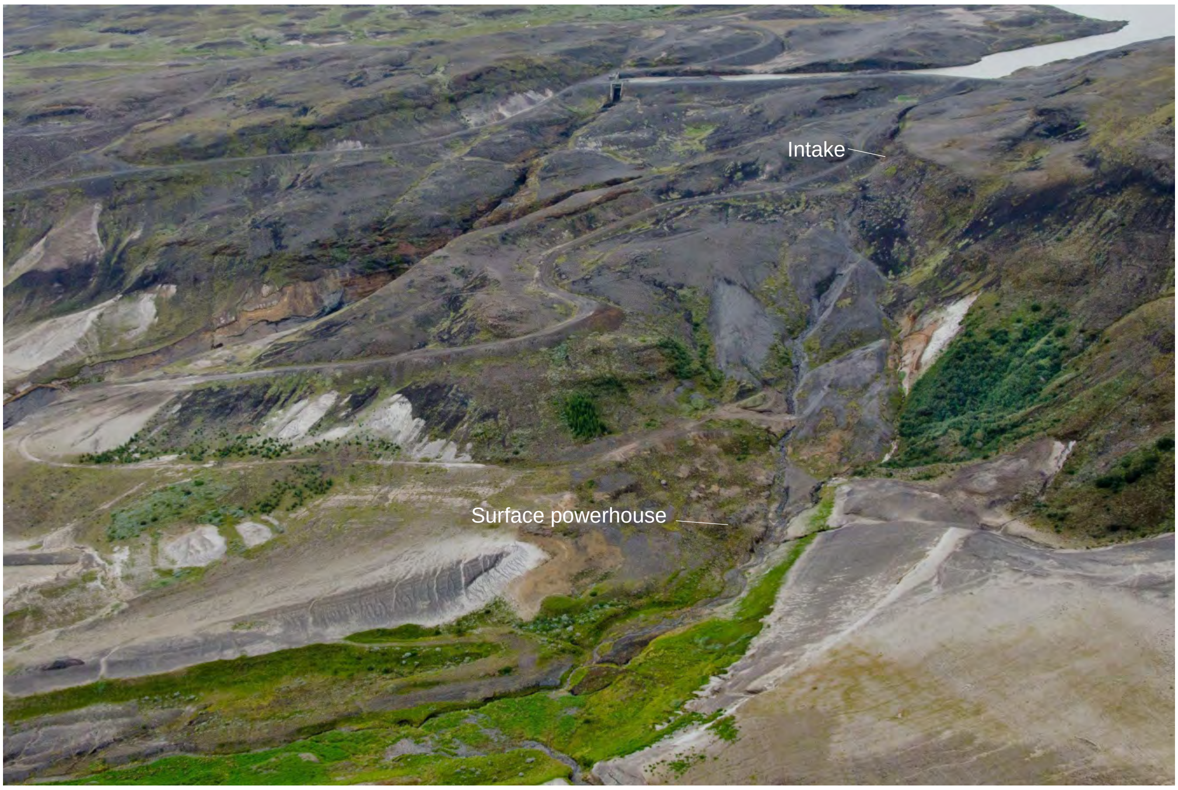

Figure 7-9 Viewing north-northeast with the headrace canal of the Búrfell Station in the upper right. The light and grey colours are mainly due to pumice from Hekla. Photo: Emil Þór Sigurðsson 16 August 2012.

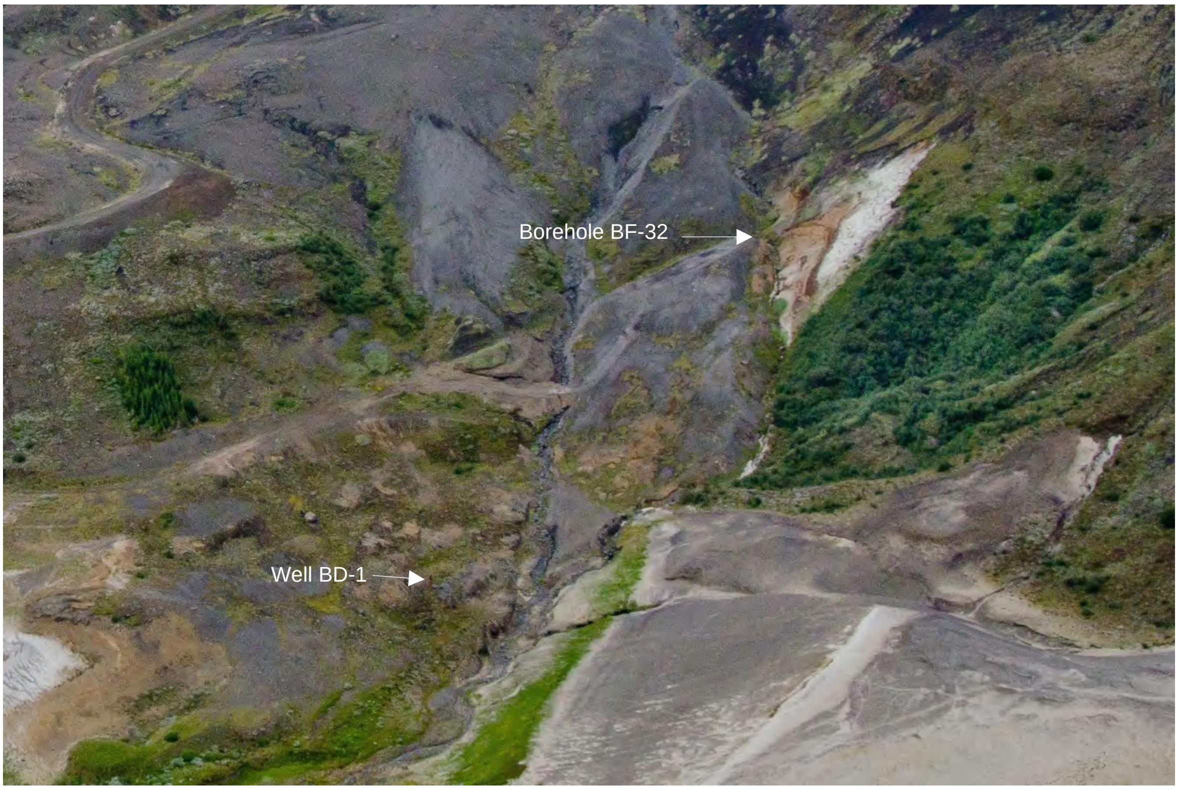

Figure 7-10 Enlargement of part of Figure 7-9. Well BD-1 is located roughly at the middle of proposed surface powerhouse. Borehole BF-32 is roughly 50 m east of station 0+300 along the proposed penstock and on top of glacial till. Photo: Emil Þór Sigurðsson 16 August 2012.

Figure 7-11 Close-up of well BD-1 that was drilled for pumping test in 1984. As can be seen from the height of the surveyor and the exposed casing the excavation at the place is 3-4 metres. Viewing south with mountain Búrfell in the background. Photo: Snorri P. Snorrason 10 July 2012.

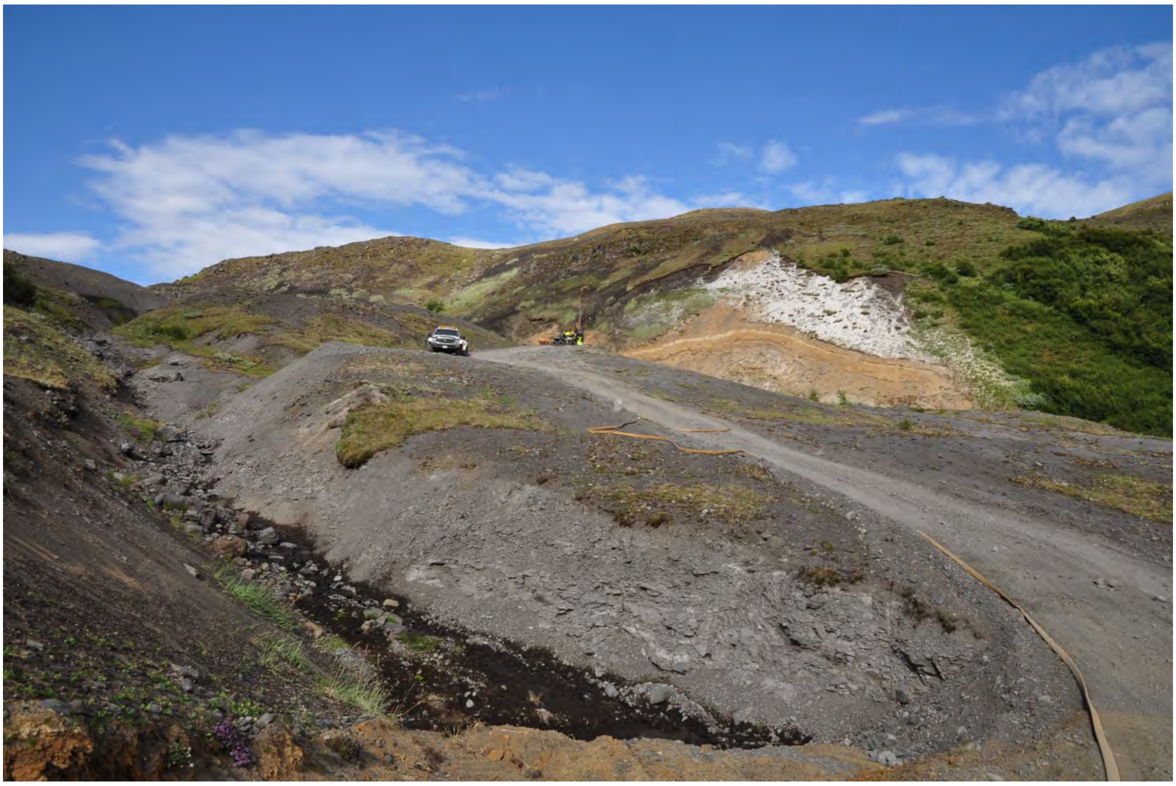

Figure 7-12 Stream cutting through glacial till just north of planned surface powerhouse. Borehole BF-32 being drilled in the background. Photo: Snorri P. Snorrason 12 July 2012.

7.5 Tailrace and side canal

Refer to Drawing 12 for planview of tailrace canal and location of boreholes. For a geological section of this unit of the project refer to Drawing 13 (a and b).

The geology at the tailrace canal is as follows:

On top is a layer of light colored and unconsolidated pumice from Mt Hekla. The pumice layer is several meters thick near the start of the canal where it can reach over 10 m in thickness, but it only reaches half the way down to Fossá, the river that the canal opens into.

Below the pumice is a layer of peat. The peat layer can reach several meters in thickness but it reaches about half the way from the beginning to end of canal.

Below the peat a thick layer of sand is found. The sand layer is of fini-glacial age and appears to be volcanic in origin. It looks fresh, dark or black and is well packed (Almenna verkfræðistofan (1982)), but in some areas the process of palagonitization has begun and has cemented the sand together to some degree, see Figure 7-13, Figure 7-14 and Figure 7-15. A study of the sand layer was performed by Almenna verkfræðistofan (1982) under supervision of Jón Skúlason using thrust/rotary soundings. The sounding rig was able to penetrate some 15 m into the sand or more in some cases see drawings Drawing 13 (a and b). According to the sounding graphs the penetration force varies substantially in the sand but variations from hole to hole appear to be rather small. Most variations are recorded near the upper end of the canal near the Surface powerhouse site. The present design of the tailrace canal does not reach below the sand except in hole A7 see Drawing 13 (a) which is a thrust /rotary sounding where the drill reached glacial till/tillite. This hole is some 300 m downstream from the Surface powerhouse. Apart from the powerhouse and its surroundings and aforementioned hole the centreline of the tailrace canal will be excavated in well packed dark volcanic sand with harder lenses of weak sandstone, most prominent in the lower half of the present canal, see Figure 7-13, Figure 7-14 and Figure 7-15.

Figure 7-13 The tailrace canal and Trjáviðarlækur-stream in 2012. View to the west towards Fossá (not seen in photo) and taken near the middle of the canal. Substantial chunks of the sandstone have been eroded in the flushing operations performed in the area in the early nineteen-eighties. Photo: Snorri P. Snorrason 14 June 2012.

Figure 7-14 Tailrace canal - view to the east. Photo: Snorri P. Snorrason 14 June 2012.

Figure 7-15 Close up look of the sandstone. The lens cap's outer diameter is 68 mm The brownish colour is the formation of palagonite in an early stage. Photo: Snorri P. Snorrason 14 June 2012.

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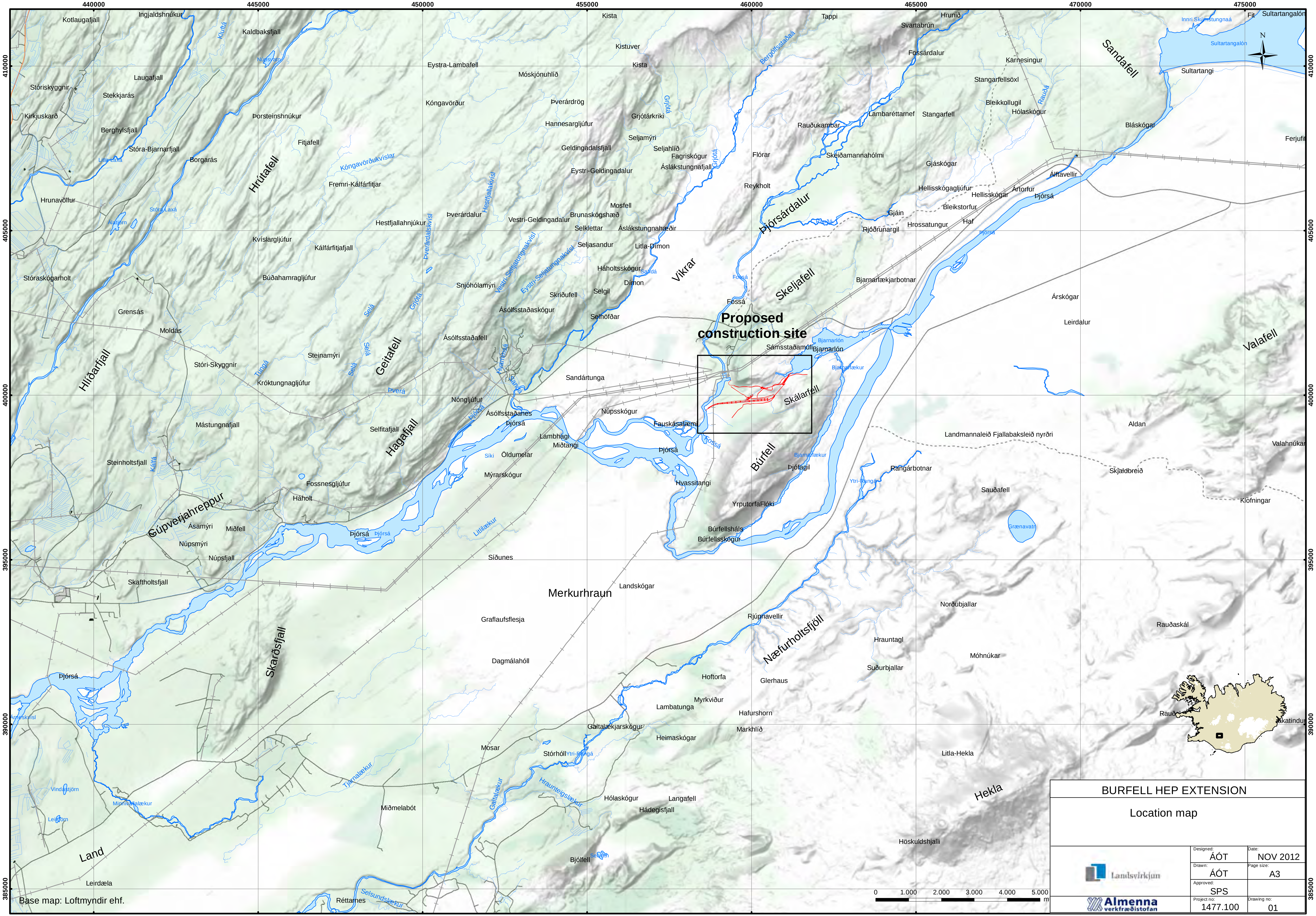
Drawings



Base map: Loftmyndir ehf.

BURFELL HEP EXTENSION

Location map

Landsvirkjun

Almenna verkfræðistofan

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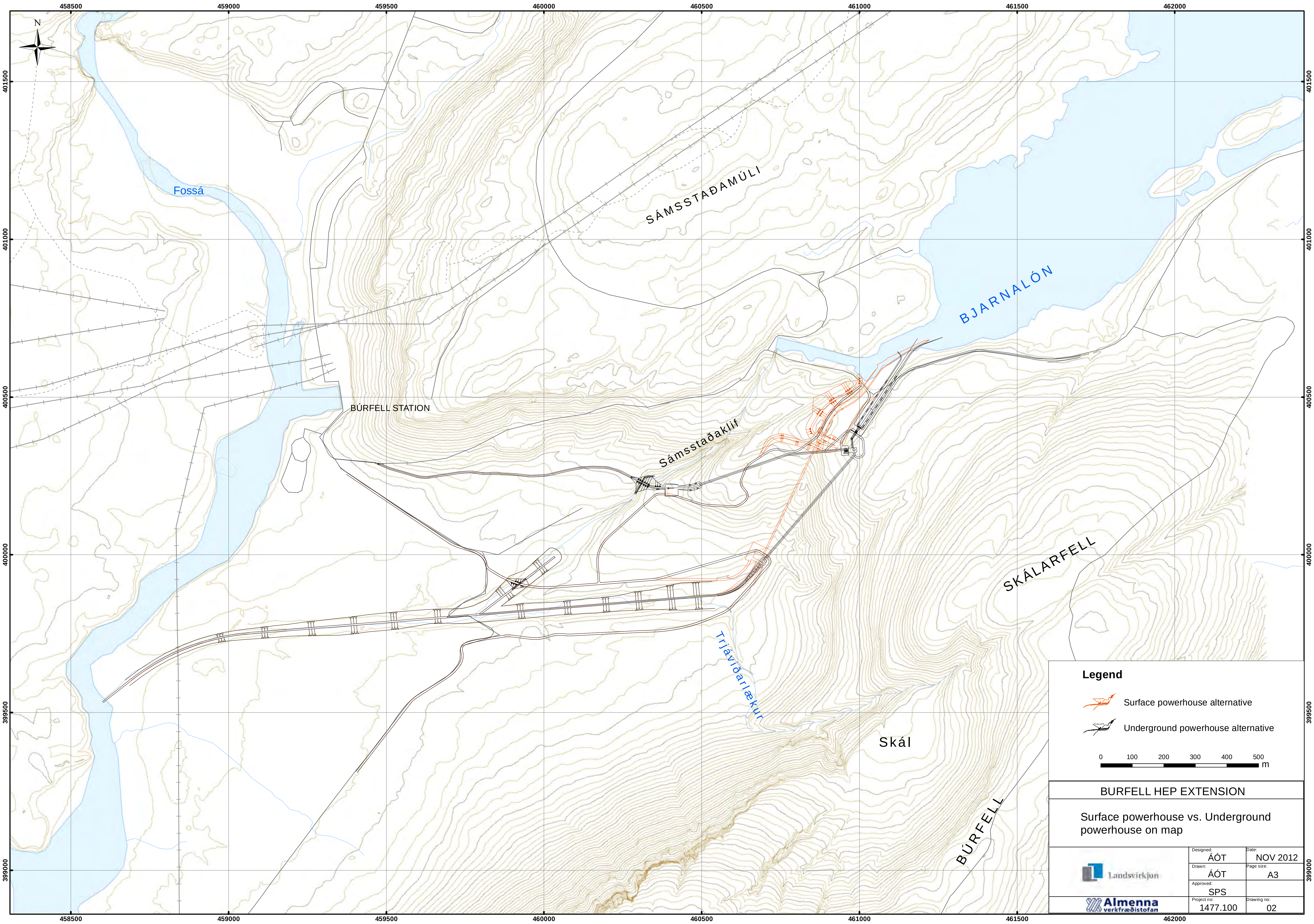

BURFELL HEP EXTENSION

Surface powerhouse vs. Underground powerhouse on map

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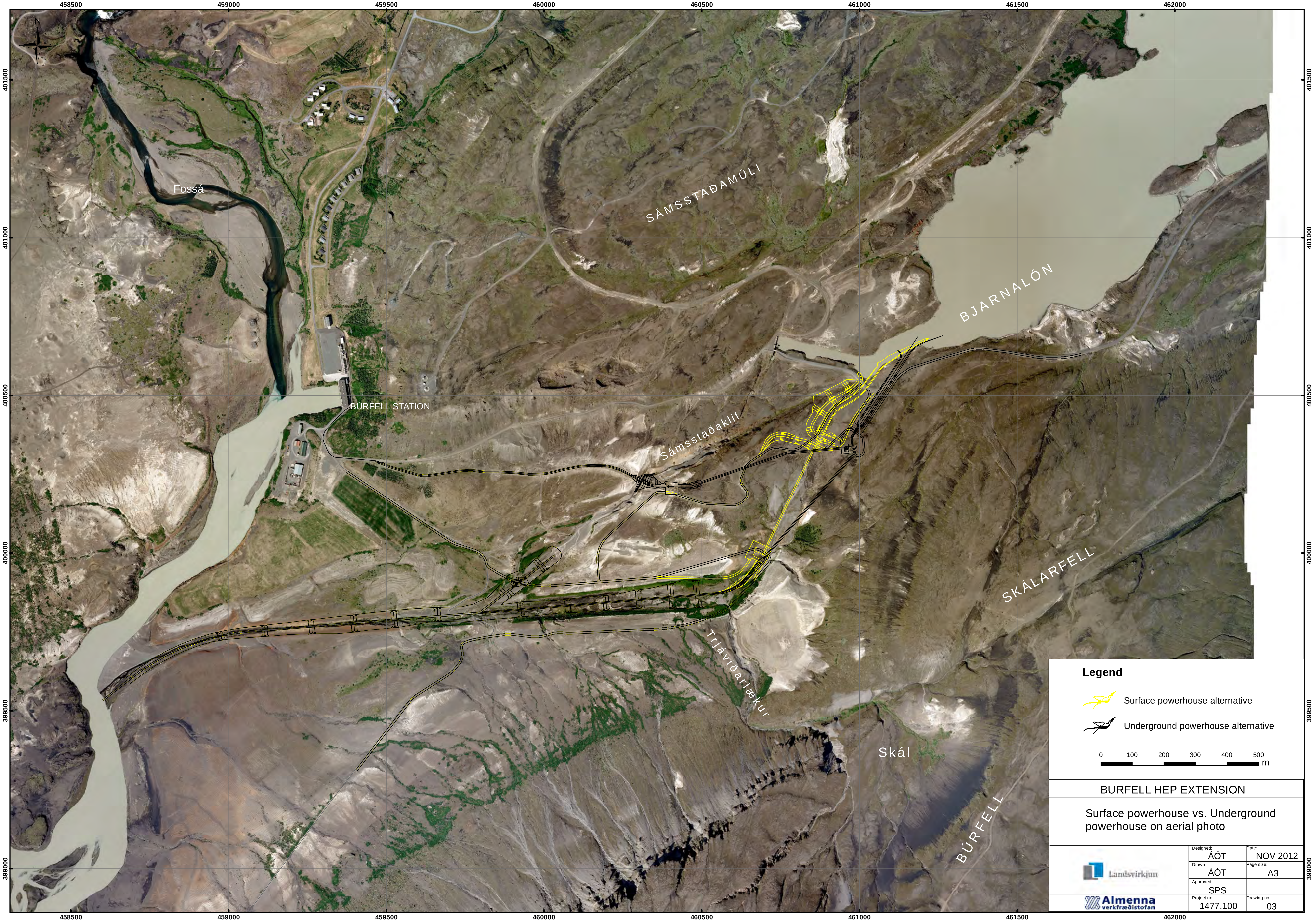

BURFELL HEP EXTENSION

Surface powerhouse vs. Underground powerhouse on aerial photo

Landsvirkjun

Almenna verkfræðistofan

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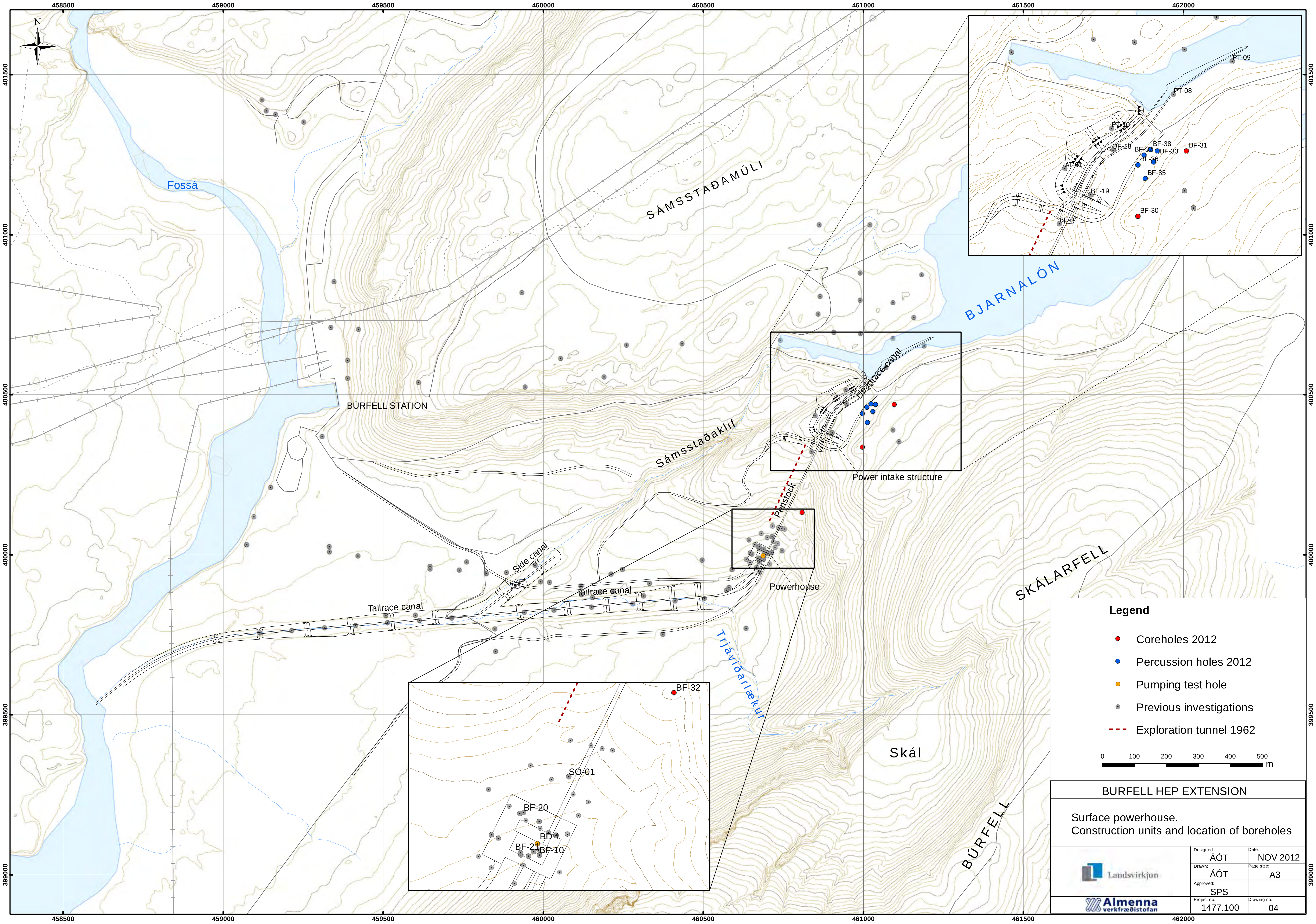

Legend

●	Coreholes 2012
●	Percussion holes 2012
●	Pumping test hole
●	Previous investigations
- - -	Exploration tunnel 1962

0 100 200 300 400 500 m

BURFELL HEP EXTENSION

Surface powerhouse.
Construction units and location of boreholes

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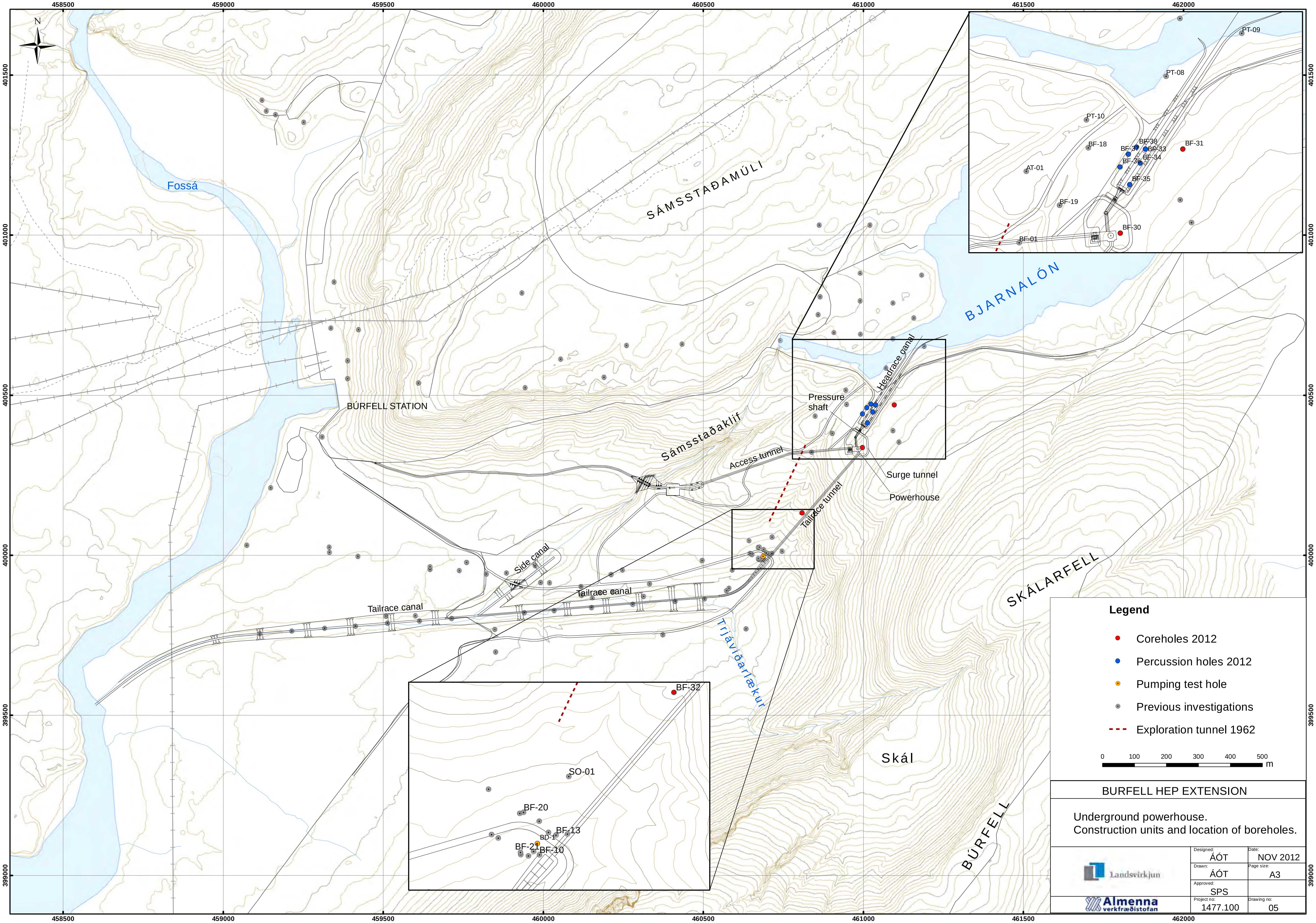
Landsvirkjun

Almenna verkfræðistofan



BURFELL HEP EXTENSION

Underground powerhouse.
Construction units and location of boreholes.

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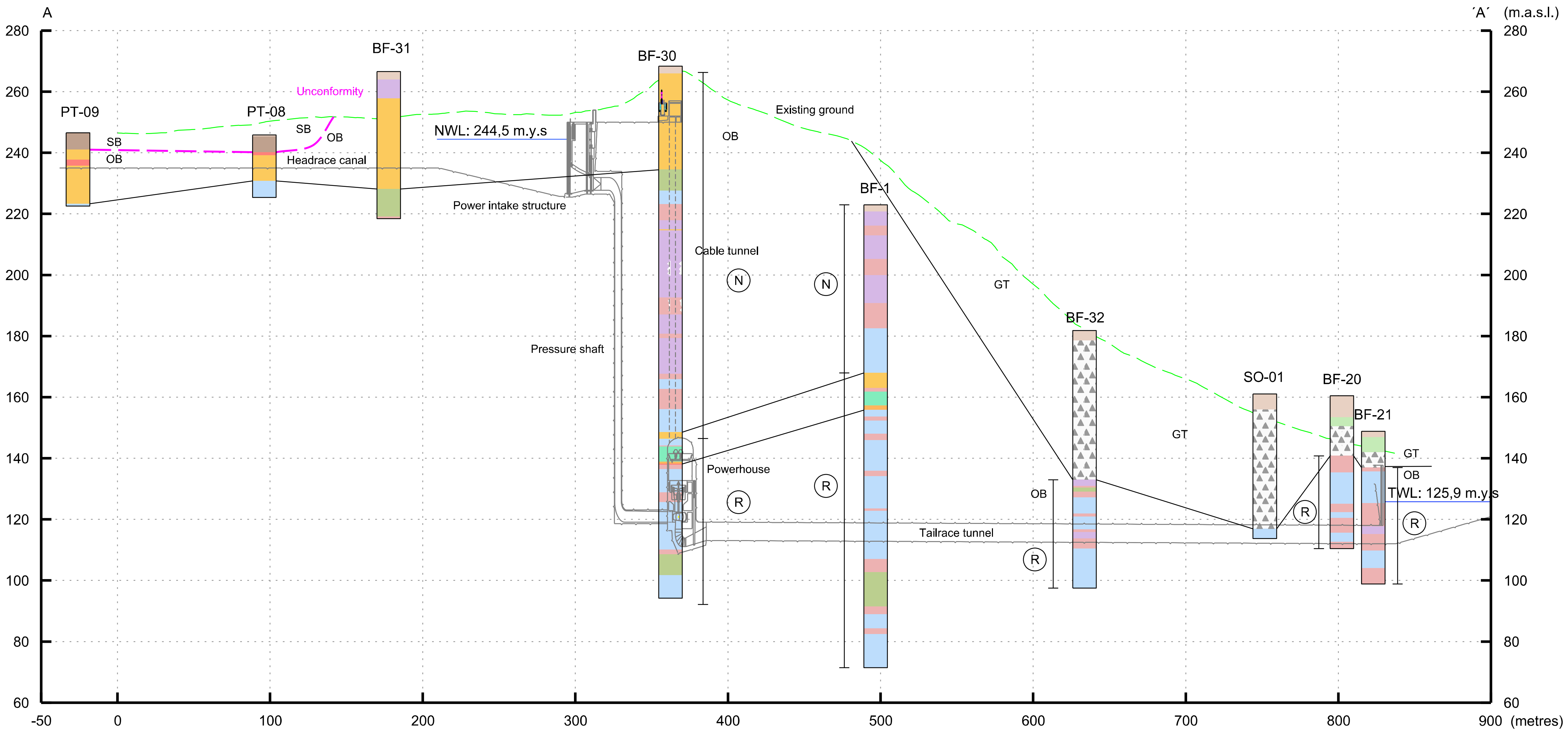
BÚRFELL HEP EXTENSION

Geology



Longitudinal section of geology along Underground Powerhouse alternative

Planview of section and boreholes for Underground Powerhouse alternative

Explanations

- ▨ Overburden
- ▨ Basaltic Andesite
- ▨ Scoria
- ▨ Olivine Basalt
- ▨ Conglomerate
- ▨ Porphyritic Olivine Basalt
- ▨ Hyaloclastite
- ▨ Peat
- ▨ Tuff
- ▲ Moraine
- ▨ Tholeiite Basalt
- ▨ Sandstone
- — Section Line
- — Outlines of Underground Proposal
- — Unconformity

GT	Glacial Till formation
SB	Sámsstaðaklif basalt
OB	Older Búrfell basalt
N / R	Normal/Reverse Geomagnetic polarity

PROJECT

BÚRFELL HEP EXTENSION

Underground Powerhouse alternative
Geology

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Almenna verkfræðistofan

Landsvirkjun

BÚRFELL HEP EXTENSION

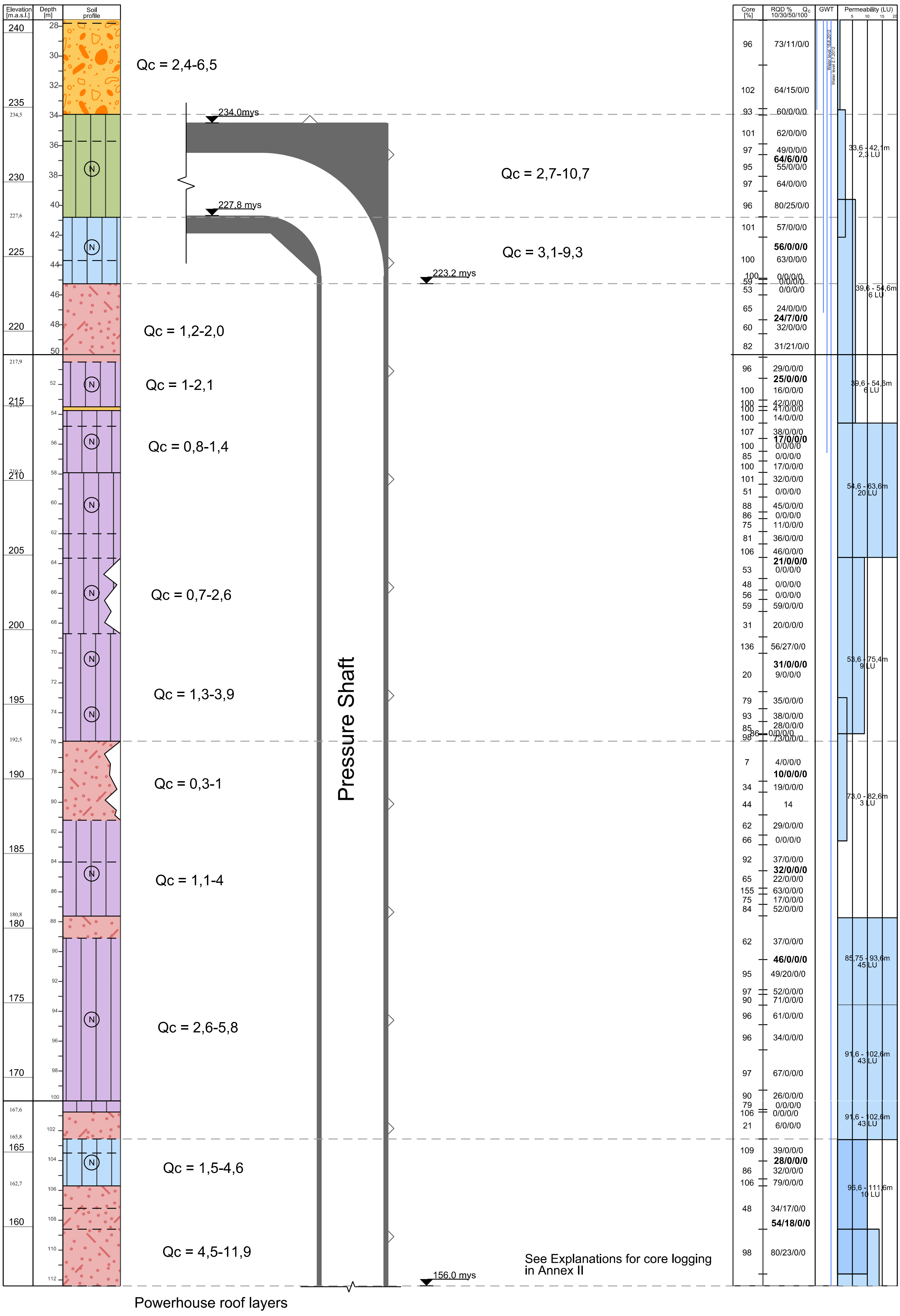
Pressure shaft
Rock quality

Project no.	Drawing no.
1477.100	07

Project no.
SPS/ÁÓT

Date:
November 2012

BF-30 (upper part)



See Explanations for core logging in Annex II

Almenna verkfræðistofan

Landsvirkjun

Búrfell II

Underground powerhouse
Rock quality

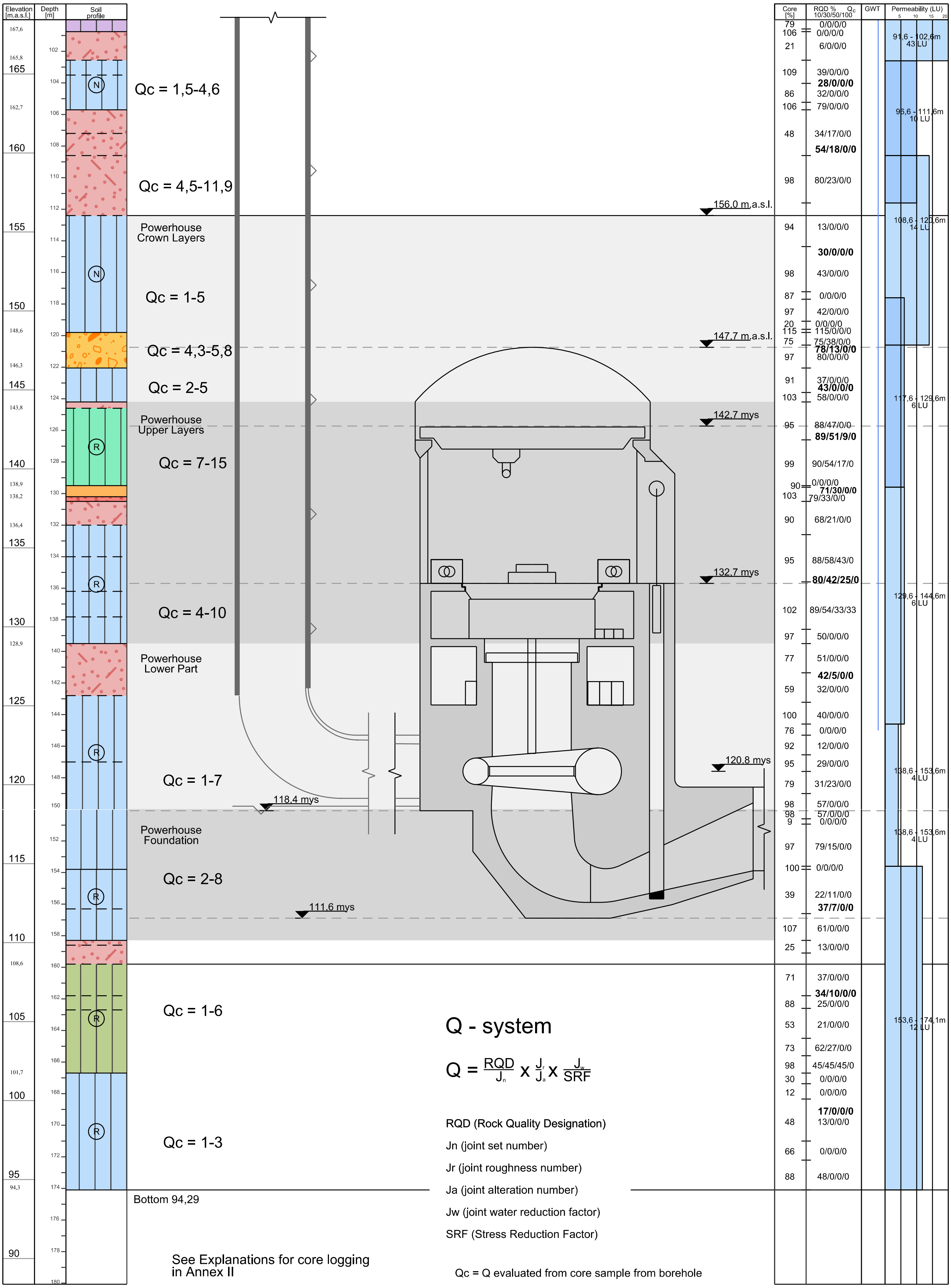
Project no. 1477.100

Drawing no. 08

Project no. SPS/ÁÓT

Date: November 2012

BF-30 (lower part)



Q - system

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

RQD (Rock Quality Designation)

Jn (joint set number)

Jr (joint roughness number)

Ja (joint alteration number)

Jw (joint water reduction factor)

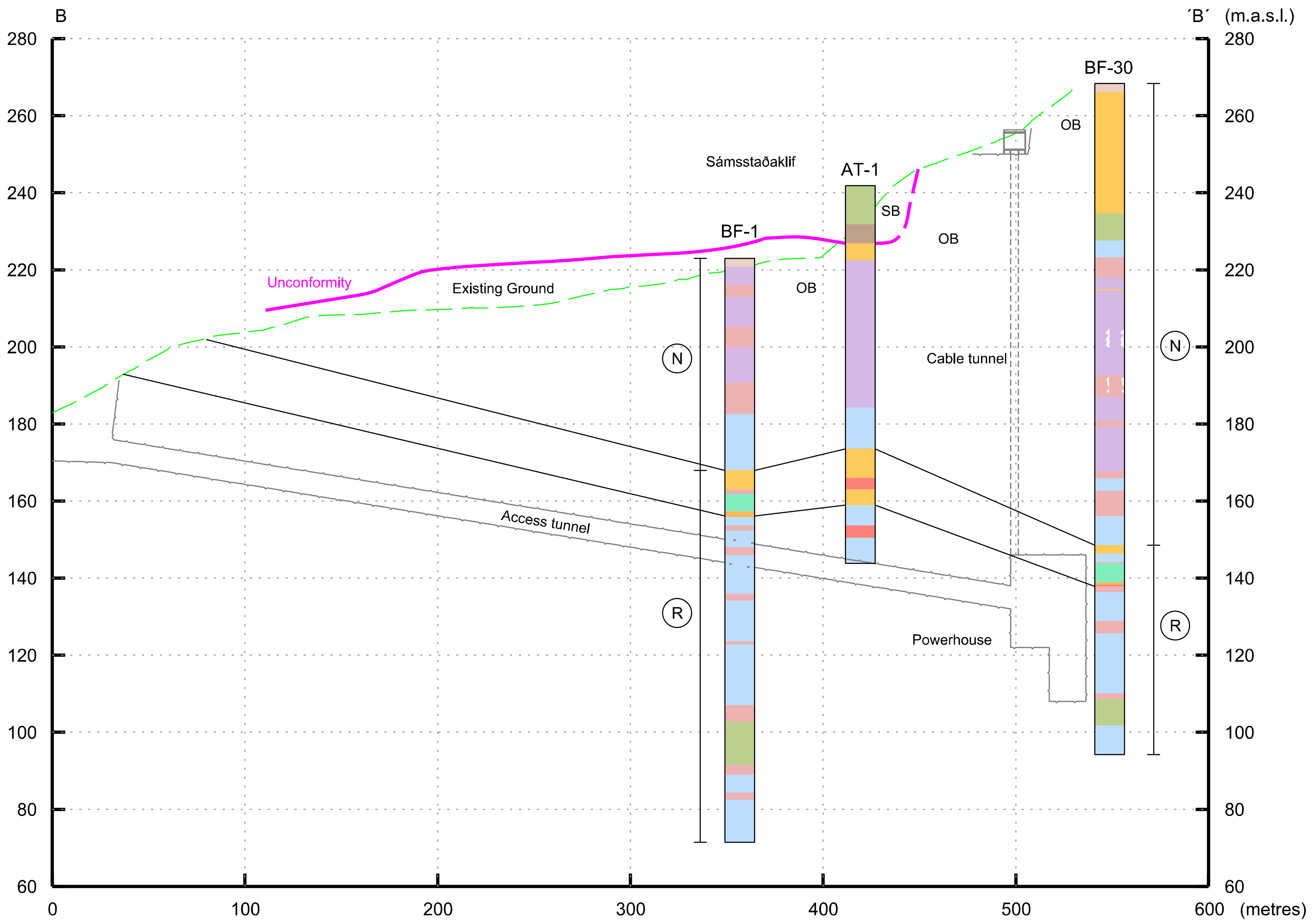
SRF (Stress Reduction Factor)

See Explanations for core logging in Annex II

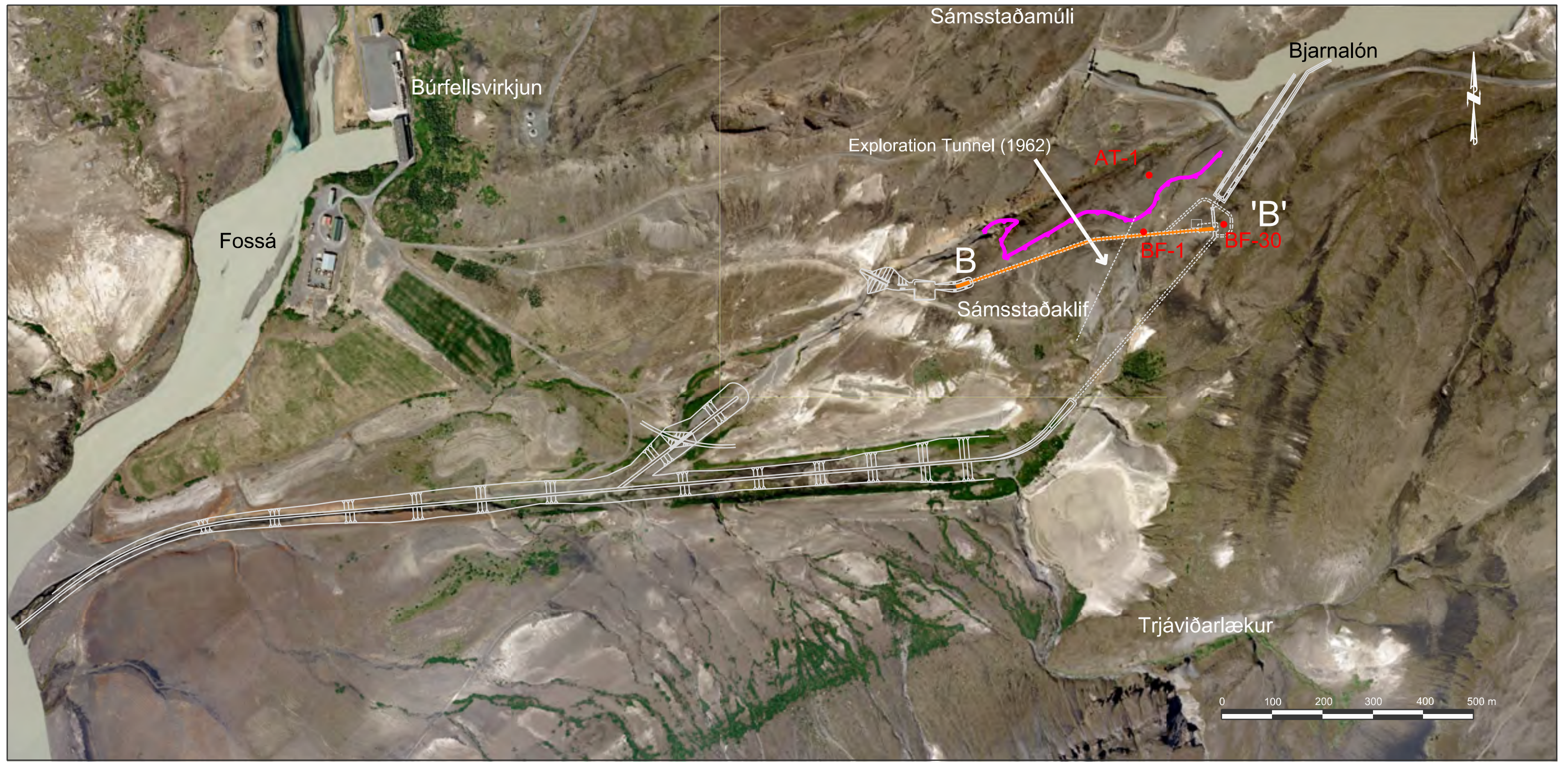
Qc = Q evaluated from core sample from borehole

BÚRFELL HEP EXTENSION

Geology



Longitudinal section of geology along the Access tunnel in Underground Powerhouse alternative



Planview of section and boreholes in Underground Powerhouse alternative

Explanations

▨	Overburden
▨	Basaltic Andesite
▨	Scoria
▨	Olivine Basalt
▨	Conglomerate
▨	Porphyritic Olivine Basalt
▨	Tuff
▨	Tholeiite Basalt
▨	Sandstone
—	Section Line
—	Outlines of Underground Powerhouse
—	Unconformity
SB	Sámsstaðaklif basalt
OB	Older Búrfell basalt
N/R	Normal/Reverse Geomagnetic polarity

PROJECT
BÚRFELL HEP EXTENSION

Underground Powerhouse alternative
Access Tunnel
Geology

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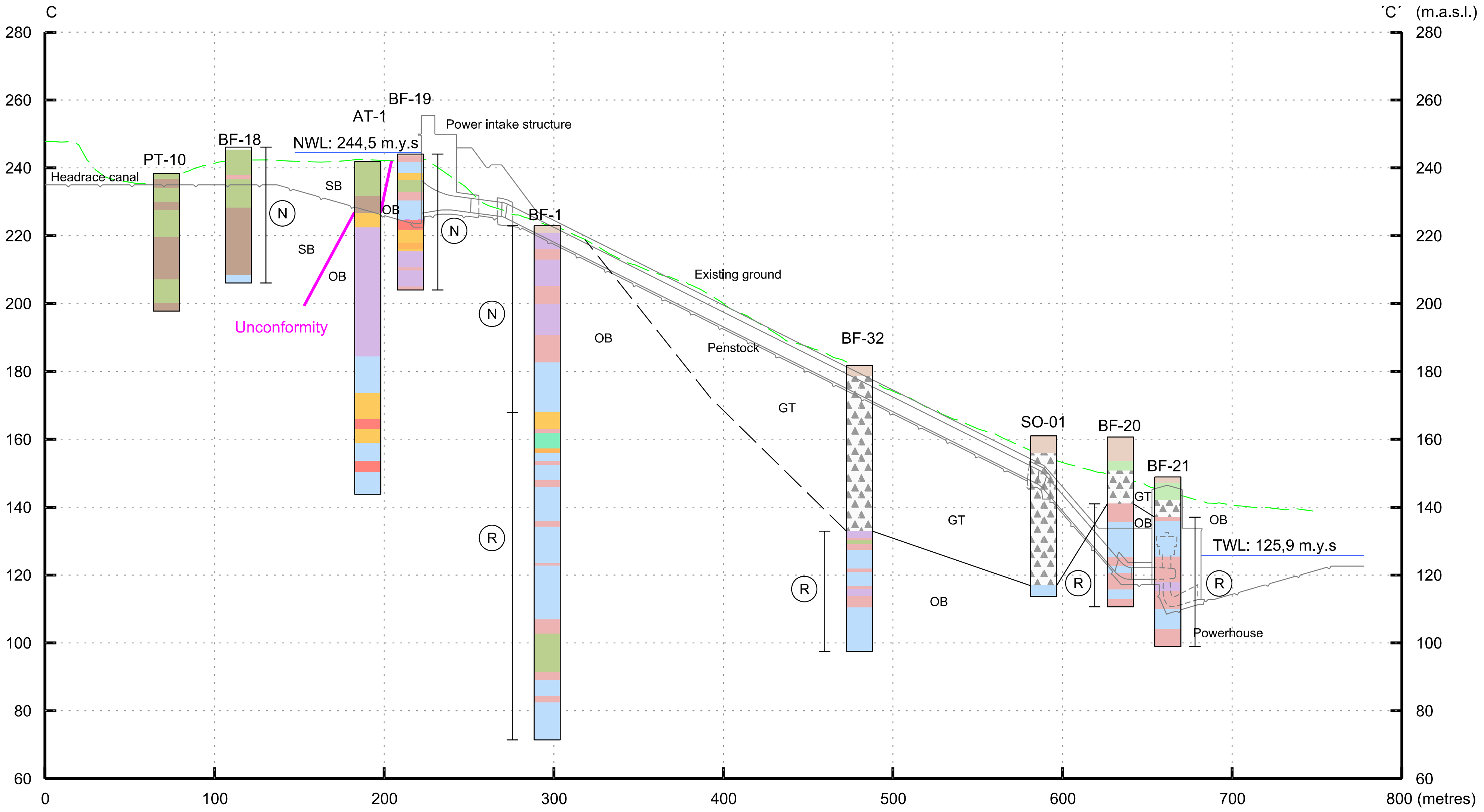
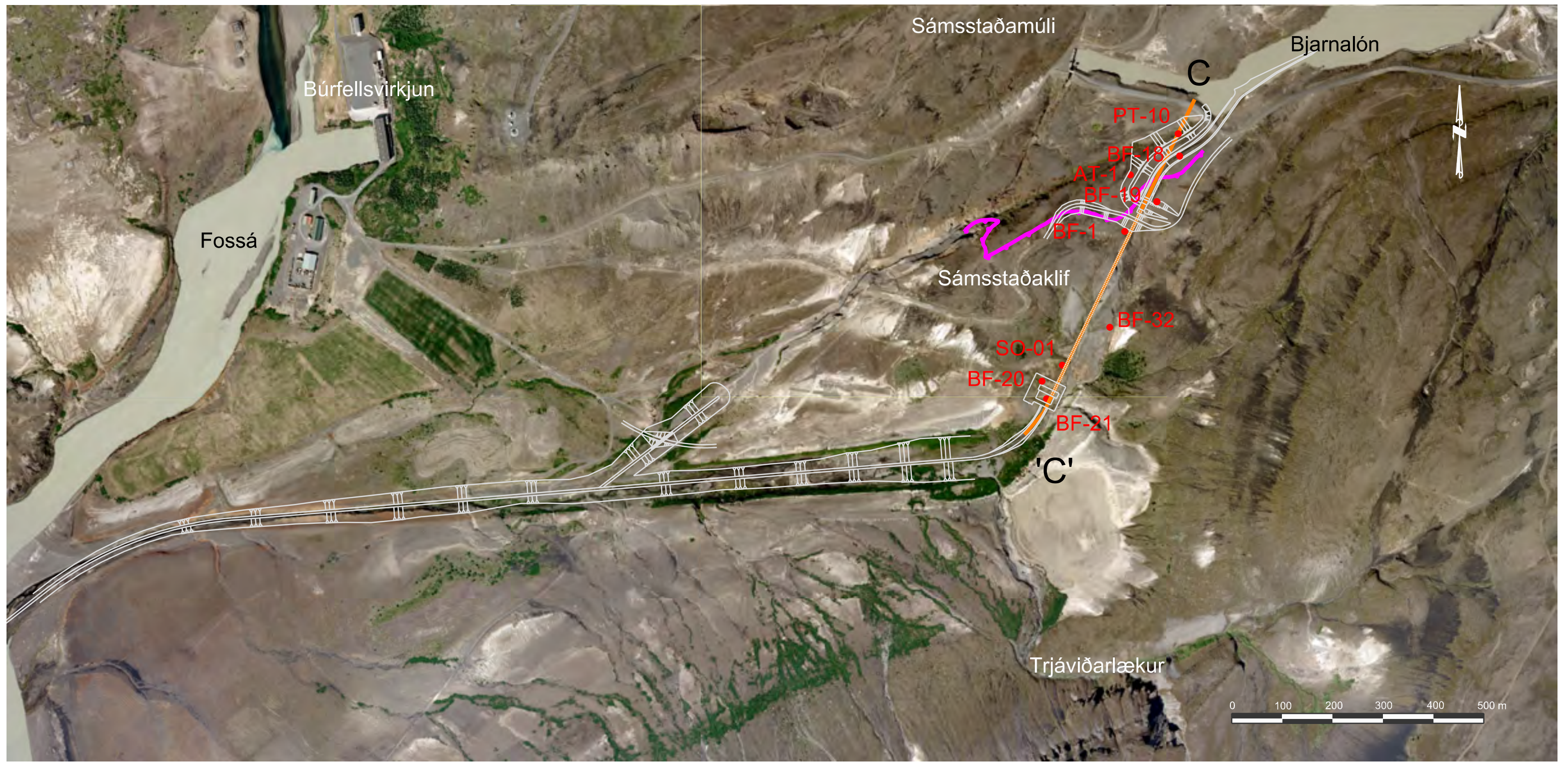
Almenna verkfræðistofan	Project no: 1477.100	Drawing no: 09

BÚRFELL HEP EXTENSION

Geology



Longitudinal section of geology along Surface Powerhouse alternative



Planview of section and boreholes in Surface Powerhouse alternative

Explanations:

🟫	Overburden
🟪	Basaltic Andesite
🟥	Scoria
🟩	Olivine Basalt
🟨	Conglomerate
🟩	Porphyritic Olivine Basalt
🟫	Hyaloclastite
🟩	Peat
🟧	Tuff
▲	Moraine
🟦	Tholeiite Basalt
🟥	Sandstone
—	Section Line
—	Outlines of Underground alternative
—	Unconformity
Ⓝ/Ⓡ	Normal/Reverse Geomagnetic polarity
GT	Glacial Till
SB	Sámsstaðaklif basalt
OB	Older Búrfell basalt

PROJECT
BÚRFELL HEP EXTENSION

Surface Powerhouse alternative
Geology

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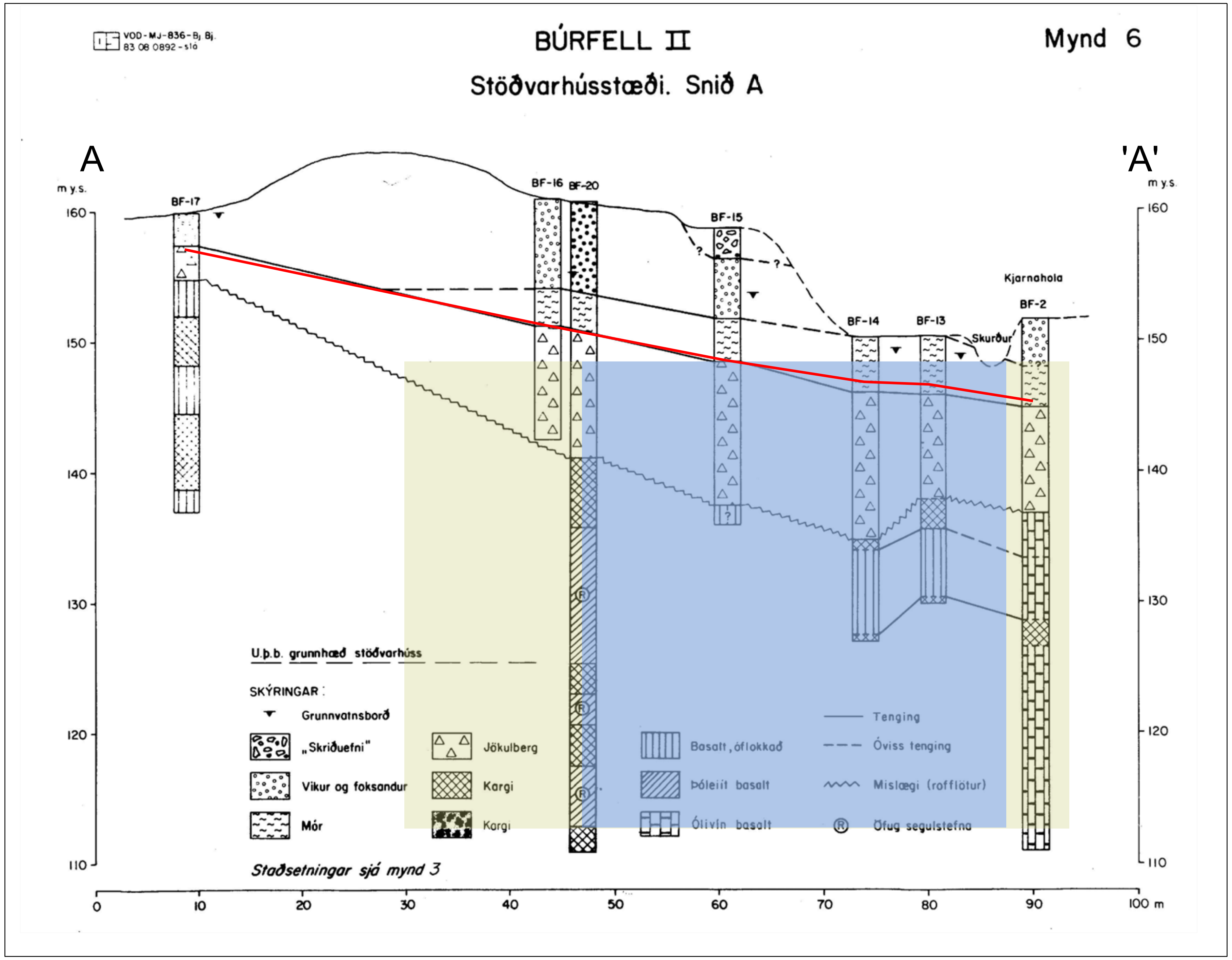
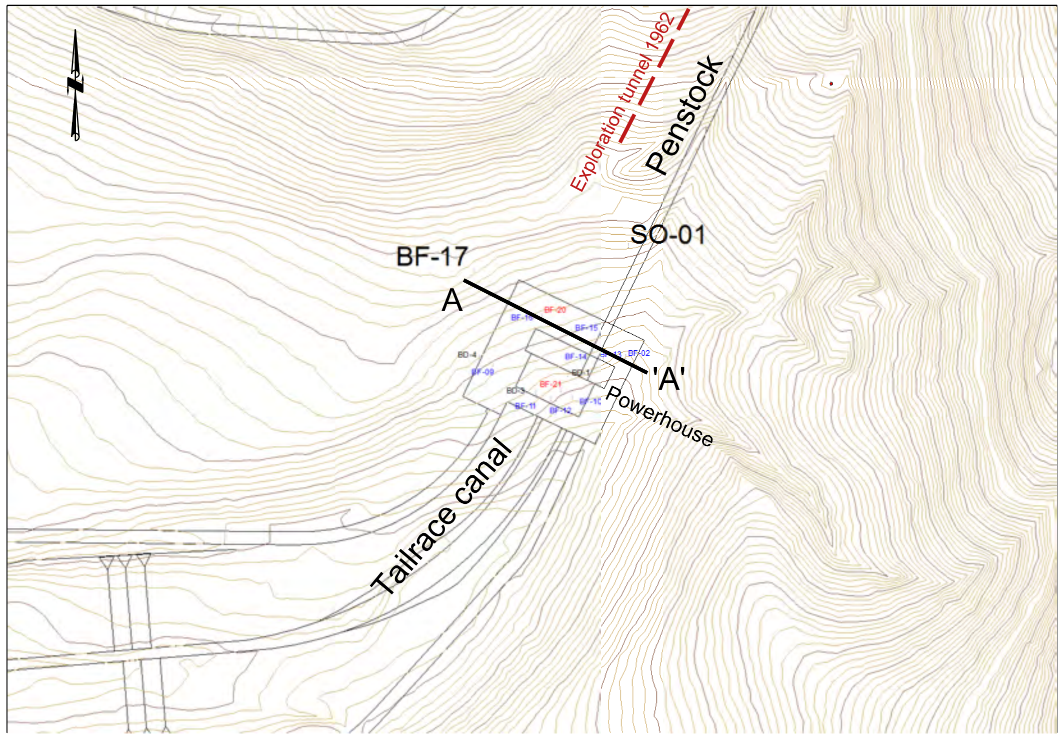
BURFELL HEP EXTENSION





Source of geological section: Bjarni Bjarnason (1983).

🟨 Powerhouse excavation pit

🟦 Powerhouse

— Present land elevation

Icelandic	English
Skriðuefni	Talus
Vikur og foksandur	Pumice and sand
Mór	Peat
Jökulberg	Glacial Till/Moraine
Kargi	Scoria
Basalt, óflokkað	Basalt, unclassified
Þóleiít basalt	Tholeiite Basalt
Ólivín basalt	Olivine Basalt

PROJECT
BURFELL HEP EXTENSION

Surface powerhouse.
Geological section along powerhouse.

Landsvirkjun
Almenna verkfræðistofan

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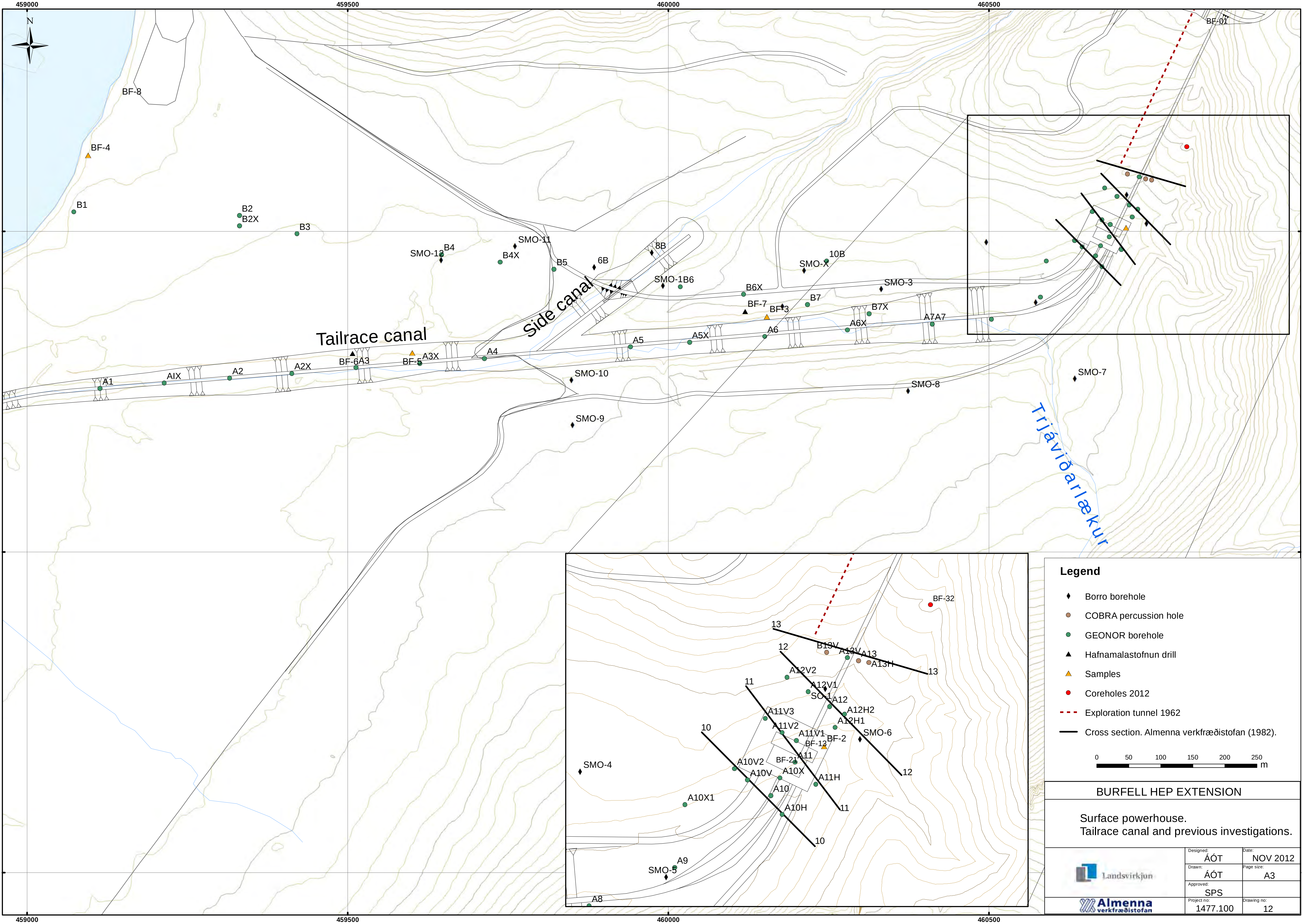

BURFELL HEP EXTENSION

Surface powerhouse.
Tailrace canal and previous investigations.

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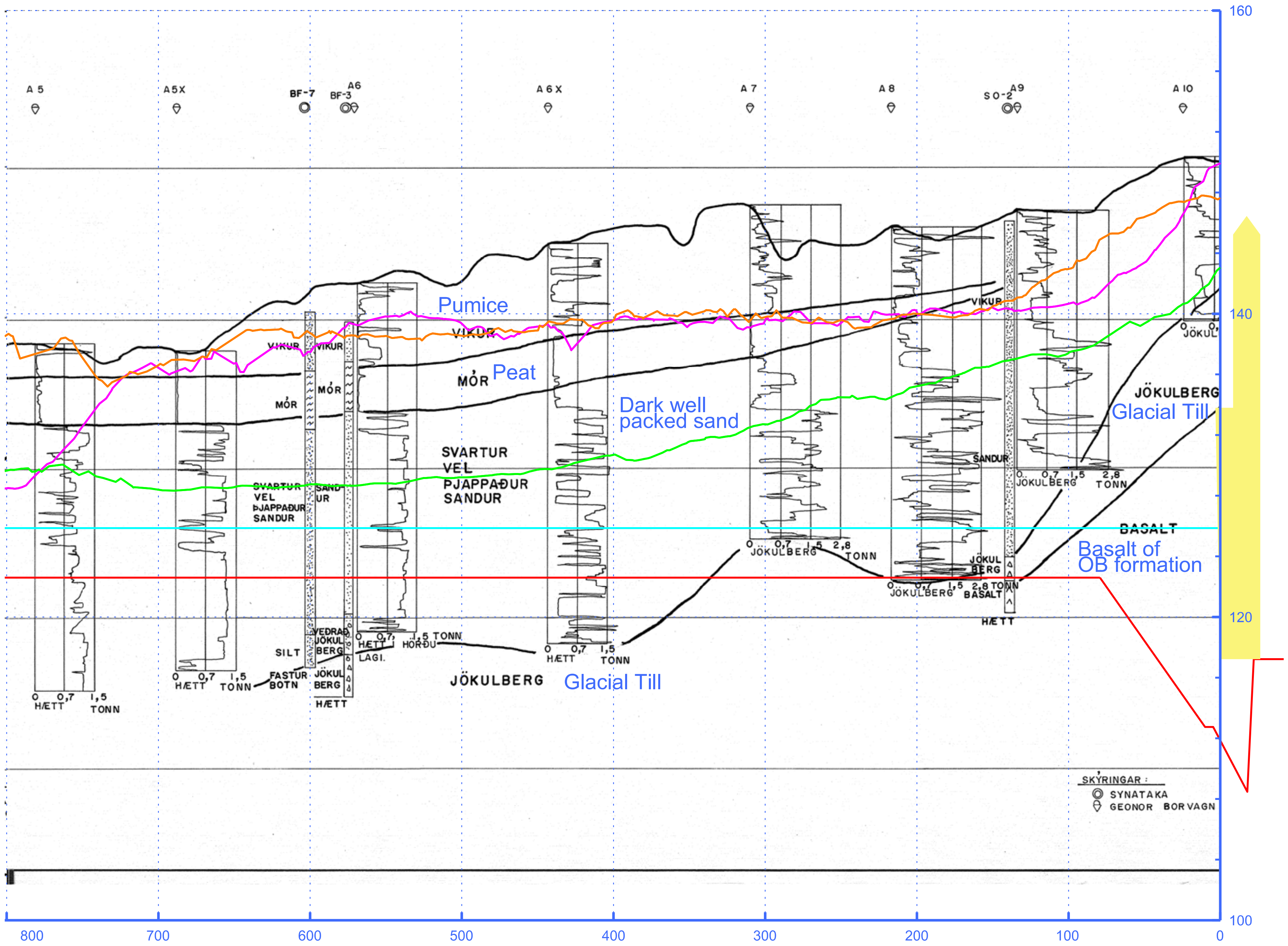
Project no: 1477.100	Drawing no: 12

Landsvirkjun
Almenna verkfræðistofan

BÚRFELL HEP EXTENSION

Geology



Section of Tailrace canal (Reference: Stækkun Búrfellsvirkjunnar - Rannsóknir á jarðlögum og byggingarefnum, Almenna verkfræðistofan og Jón Skúlason, Nóv. 1982.)

🟪	Section 45 m off the centerline north
🟩	Centerline of Tailrace canal
🟧	Section 45 m off the centerline south
🟦	Waterlevel
🟥	Bottom of designed Tailrace canal
🟨	Outlines of Powerhouse

Tailrace canal:
Longitudinal section of the present canal design superimposed
on similar section from 1982.
Showing the result of thrust/rotary soundings

▽	Thrust/rotary sounding
◎	Sampling hole

PROJECT
BÚRFELL HEP EXTENSION

Section of Tailrace canal
Geology and Boreholes
From 0 - 800 m

Designed: AKS	Date: NOV 2012
Drawn: AKS	Page size: A3
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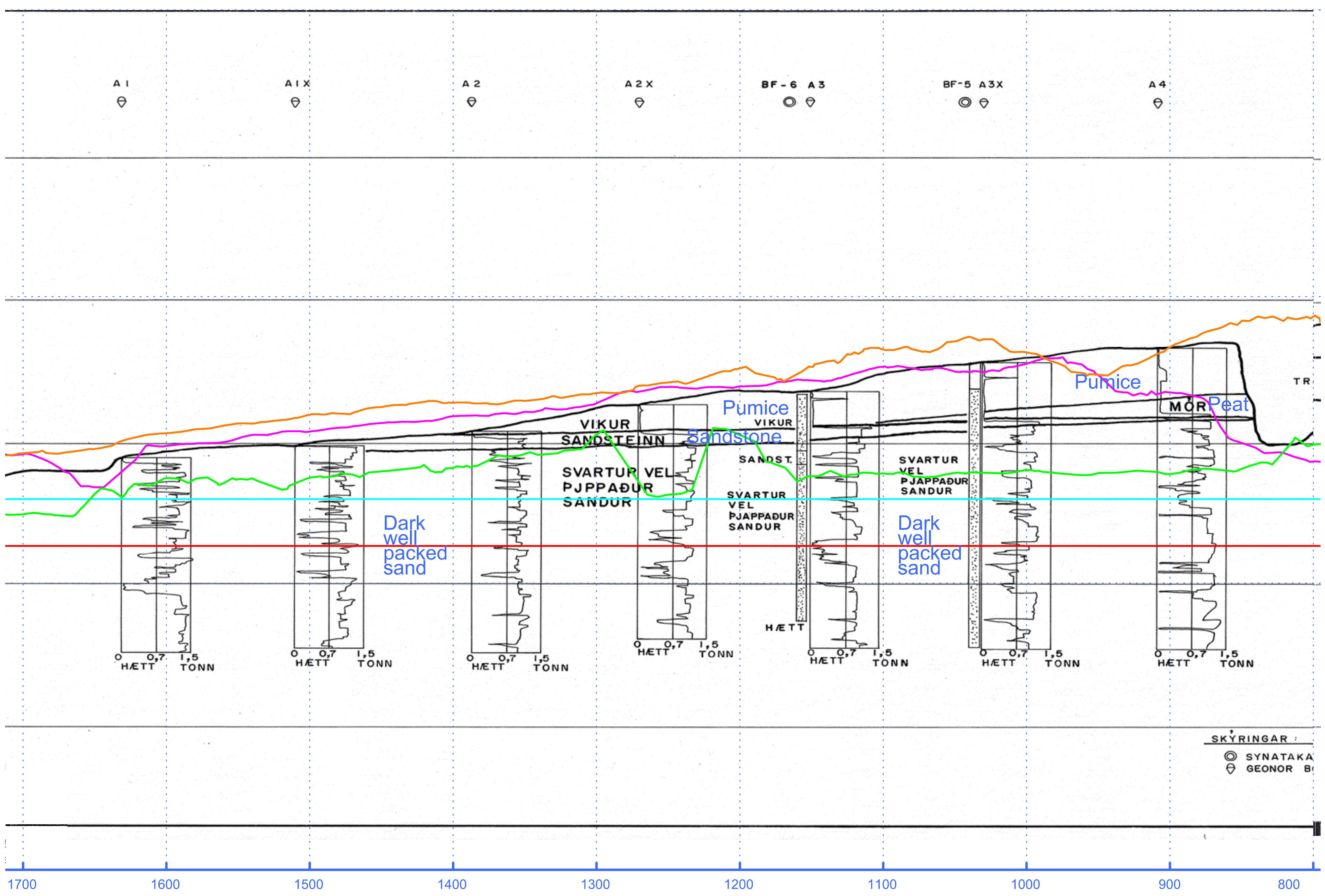
Project no: 1477.100	Drawing no: 13a

BÚRFELL HEP EXTENSION

Geology



Section of Tailrace canal (Reference: Stækkun Búrfellsvirkjunnar - Rannsóknir á jarðlögum og byggingarefnum, Almenna verkfræðistofan, Jón Skúlason, Nóv. 1982.)

▬ Section 45 m off the centerline north
▬ Centerline of Tailrace canal
▬ Section 45 m off the centerline south
▬ Waterlevel
▬ Bottom of designed Tailrace canal
▬ Outlines of Powerhouse

Tailrace canal:
Longitudinal section of the present canal design superimposed on similar section from 1982.
Showing the result of thrust/rotary soundings

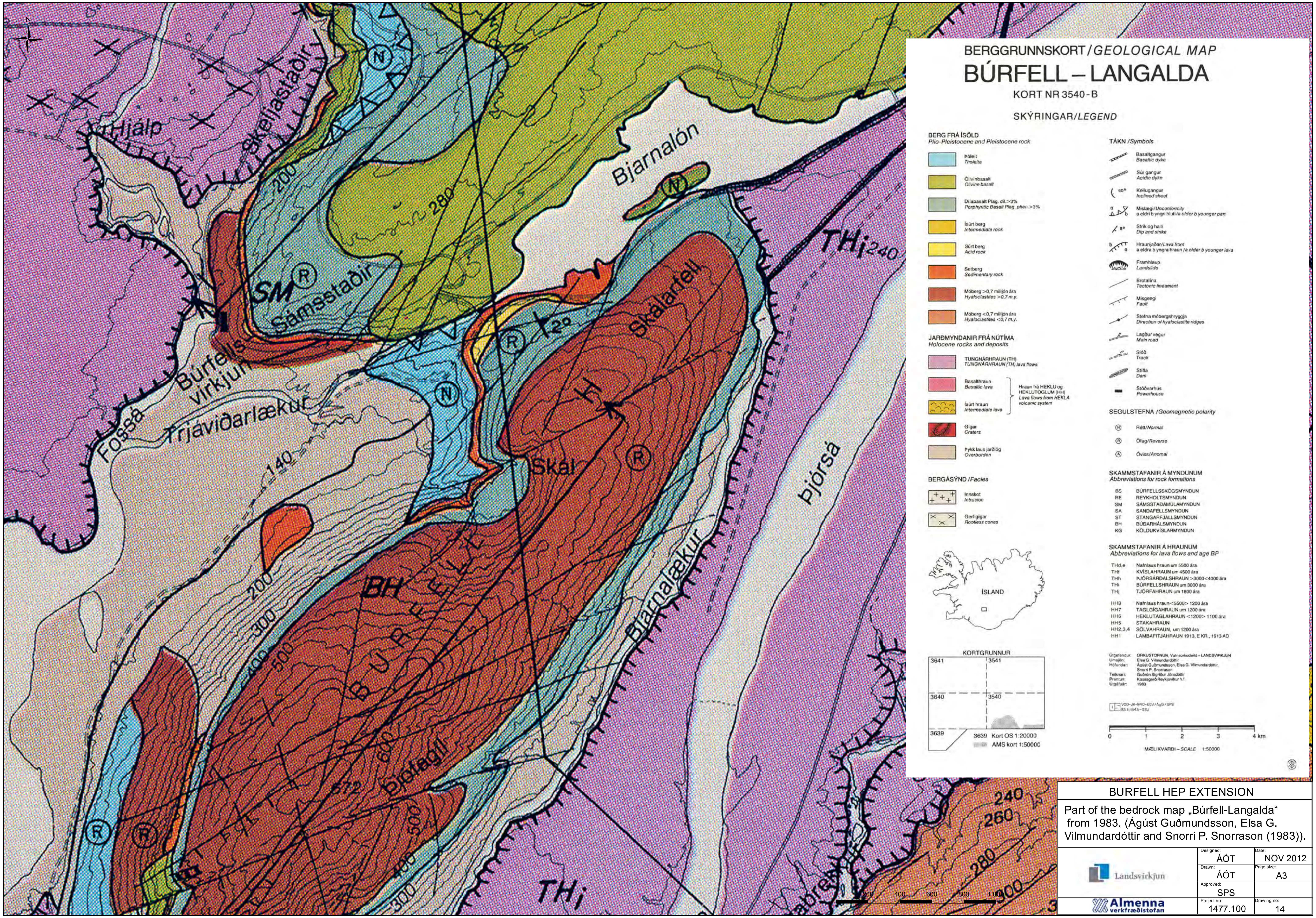
▽ Thrust/rotary sounding

◎ Sampling hole

PROJECT
BÚRFELL HEP EXTENSION

Section of Tailrace canal
Geology and Boreholes
From 800 - 1700 m

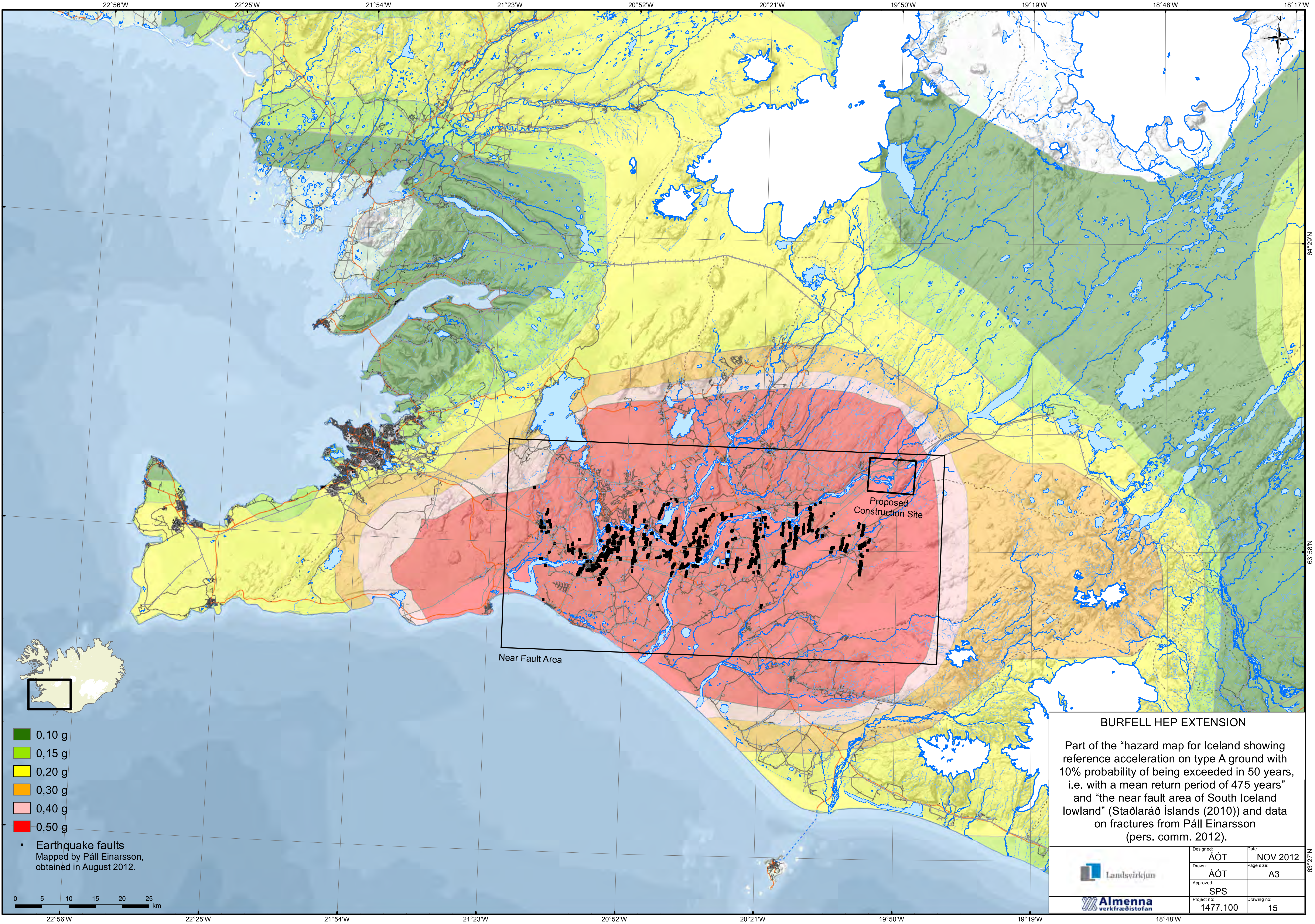
Landsvirkjun	Designed: AKS	Date: NOV 2012
	Drawn: AKS	Page size: A3
	Approved: SPS	
Almenna verkfræðistofan	Project no: 1477.100	Drawing no: 13b



BURFELL HEP EXTENSION

Part of the bedrock map „Búrfell-Langalda“ from 1983. (Ágúst Guðmundsson, Elsa G. Vilmundardóttir and Snorri P. Snorrason (1983)).

Landsvirkjun	Designed: ÁÓT	Date: NOV 2012
	Drawn: ÁÓT	Page size: A3
	Approved: SPS	
Almenna verkfræðistofan	Project no: 1477.100	Drawing no: 14



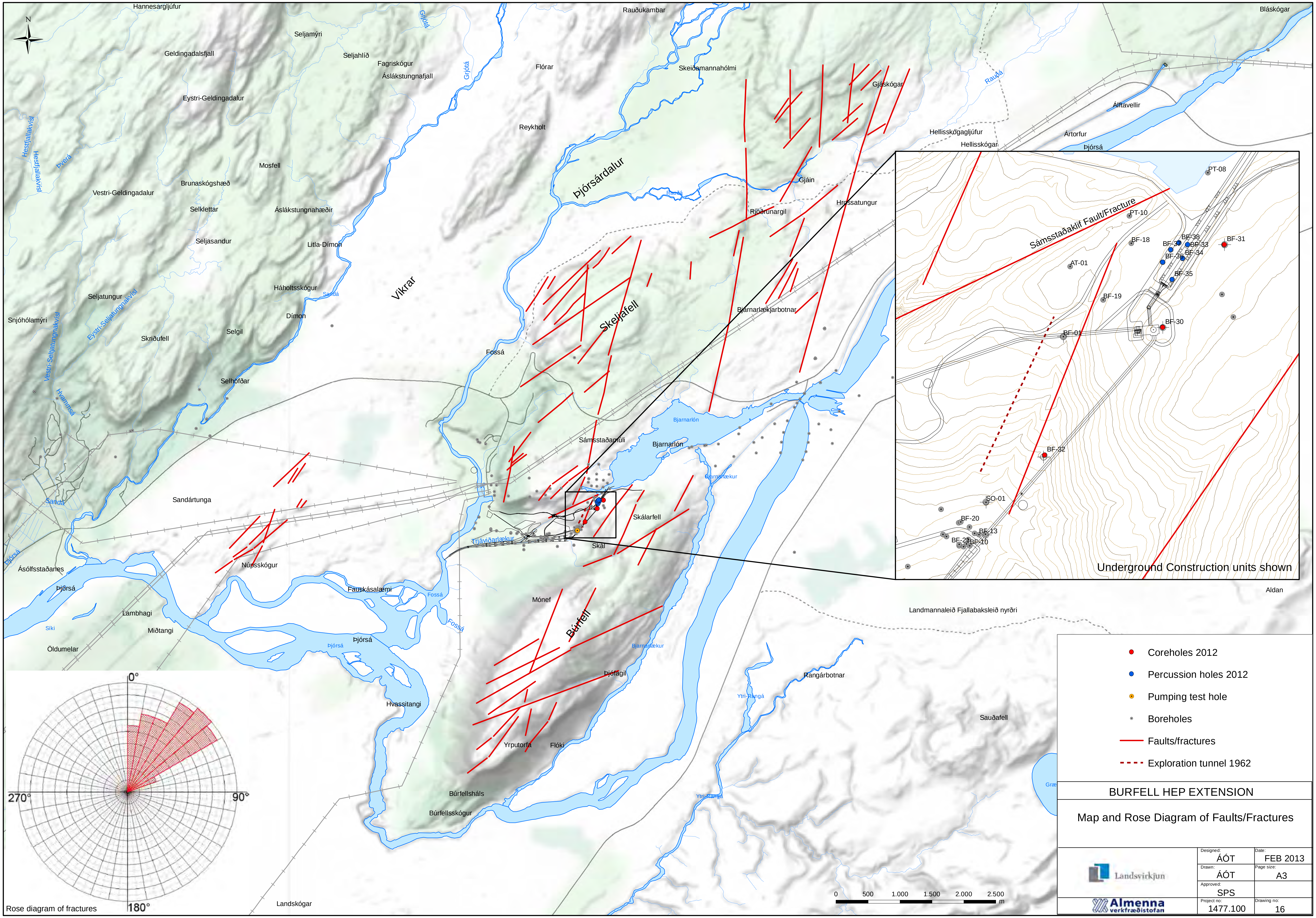
BURFELL HEP EXTENSION

Part of the “hazard map for Iceland showing reference acceleration on type A ground with 10% probability of being exceeded in 50 years, i.e. with a mean return period of 475 years” and “the near fault area of South Iceland lowland” (Staðlaráð Íslands (2010)) and data on fractures from Páll Einarsson (pers. comm. 2012).

Landsvirkjun

Almenna verkfræðistofan

Designed: ÁÓT
Date: NOV 2012
Drawn: ÁÓT
Page size: A3
Approved: SPS
Project no: 1477.100
Drawing no: 15



Rose diagram of fractures

● Coreholes 2012
● Percussion holes 2012
● Pumping test hole
● Boreholes
— Faults/fractures
--- Exploration tunnel 1962

BURFELL HEP EXTENSION

Map and Rose Diagram of Faults/Fractures

Landsvirkjun	Designed: ÁÓT	Date: FEB 2013
	Drawn: ÁÓT	Page size: A3
	Approved: SPS	
Almenna verkfræðistofan	Project no: 1477.100	Drawing no: 16

Appendices

Appendix A

Geology of Iceland and the Hreppar Block.

Appendix A Geology of Iceland and the Hreppar Block.

The Búrfellsvirkjun Hydroelectric Project Extension area is on the Hreppar Microplate (Hreppar Block), just west of the active Eastern Volcanic Zone including less than 10 km northwest of the very active volcano Hekla.

Below are some citations and maps from the general geology literature.

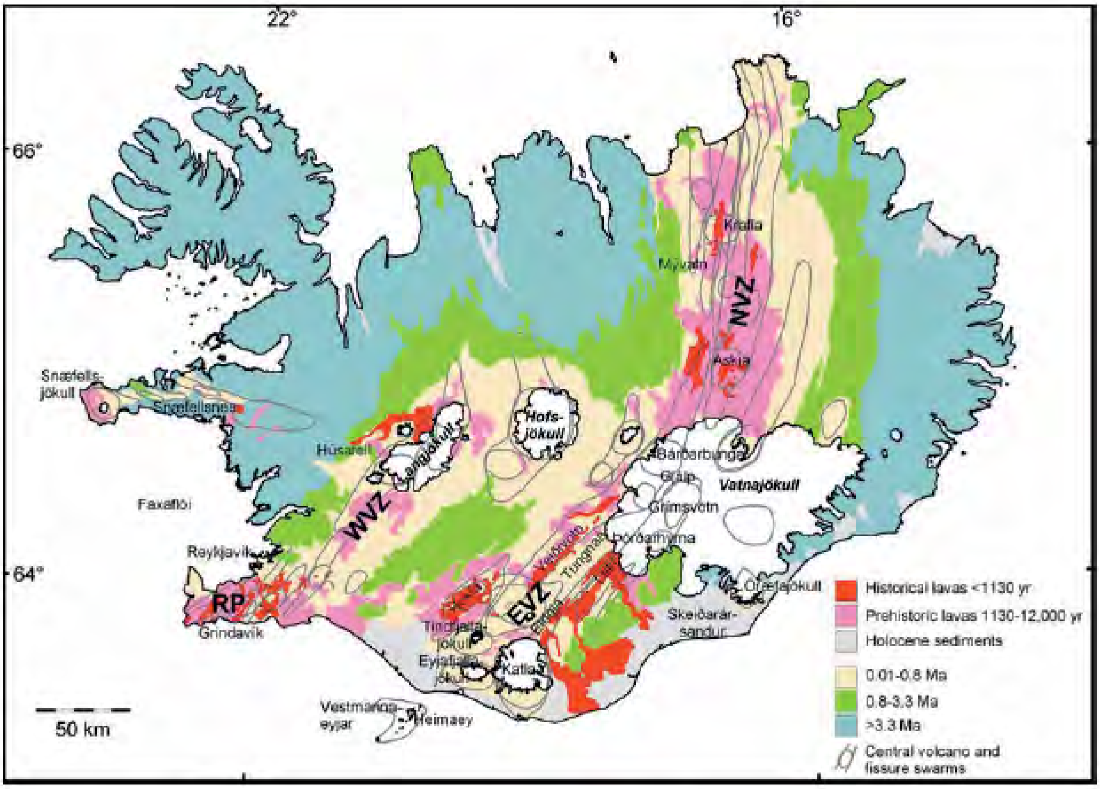


Figure 2. Simplified geological map of Iceland showing historical and Holocene lava flows, glaciers, and the main chronologically-defined units. Modified from Jóhannesson and Saemundsson (1998). – *Einfaldað jarðfræðikort af Íslandi. Á kortinu sjást nýleg hraun (rauð og bleik) og helstu jarðsögulegu einingar landsins.*

Figure 1. Geological map of Iceland. From Magnús Tumi Gudmundsson et al. (2008). WVZ = Western Volcanic Zone. EVZ = Eastern Volcanic Zone.

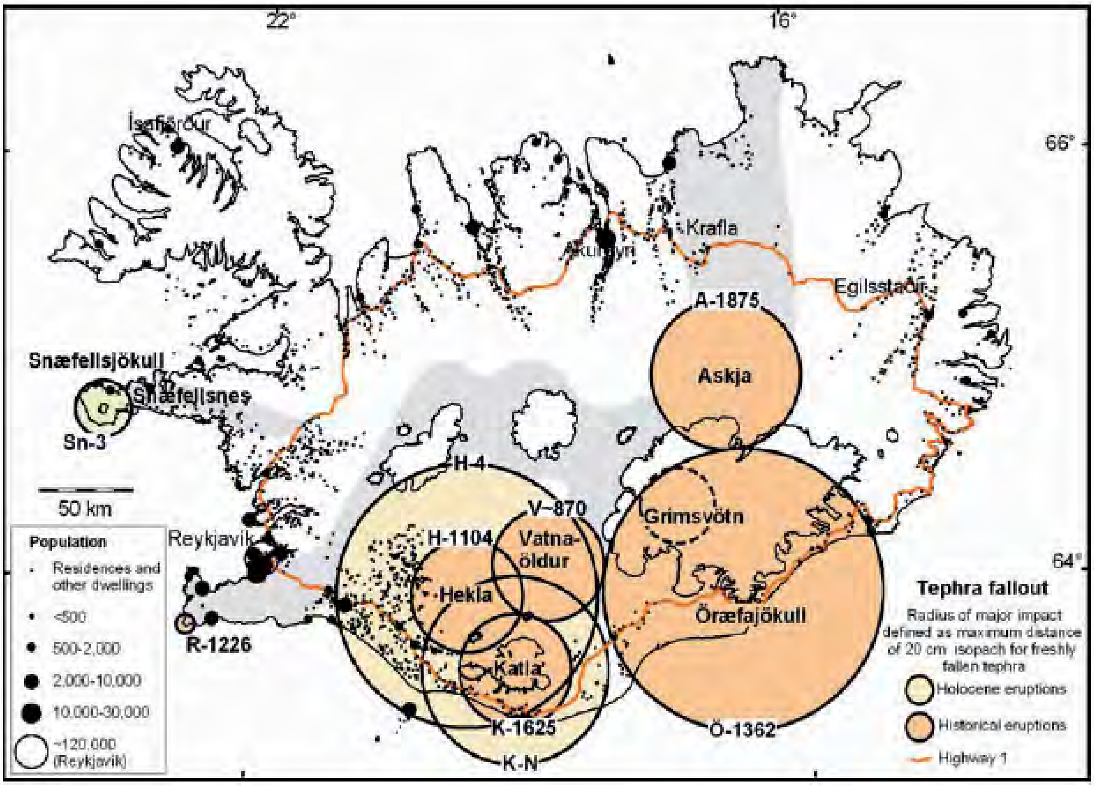


Figure 3. Areas that may receive over 20 cm of tephra fall in major explosive eruptions are indicated with circles around volcanoes or fissure swarms where explosive activity is common or the dominant mode of activity. The radius of each circle is defined as the distance to the 20 cm isopach along the axis of thickness for the largest historical and prehistoric explosive eruptions of each volcano. Also shown are populated areas and the main route, Highway 1. The volcanic zones are shown with a shade of gray. – *1. Svæði þar sem gjóskufall getur orðið 20 cm eða meira í miklum sprengigosum eru sýnd með hringjum utan um eldstöðvarnar. Geisli hvers hrings ákvarðast af mestu fjarlægð til 20 cm jafnþykktarlínu fyrir stærstu þekkt gos í hverri eldstöð á sögulegum og forsögulegum tíma. Á kortinu sjást einnig byggð svæði og þjóðvegur 1.*

Figure 2. Tephra-fall in Iceland in historical and prehistoric time. From Magnús Tumi Gudmundsson et al. (2008).

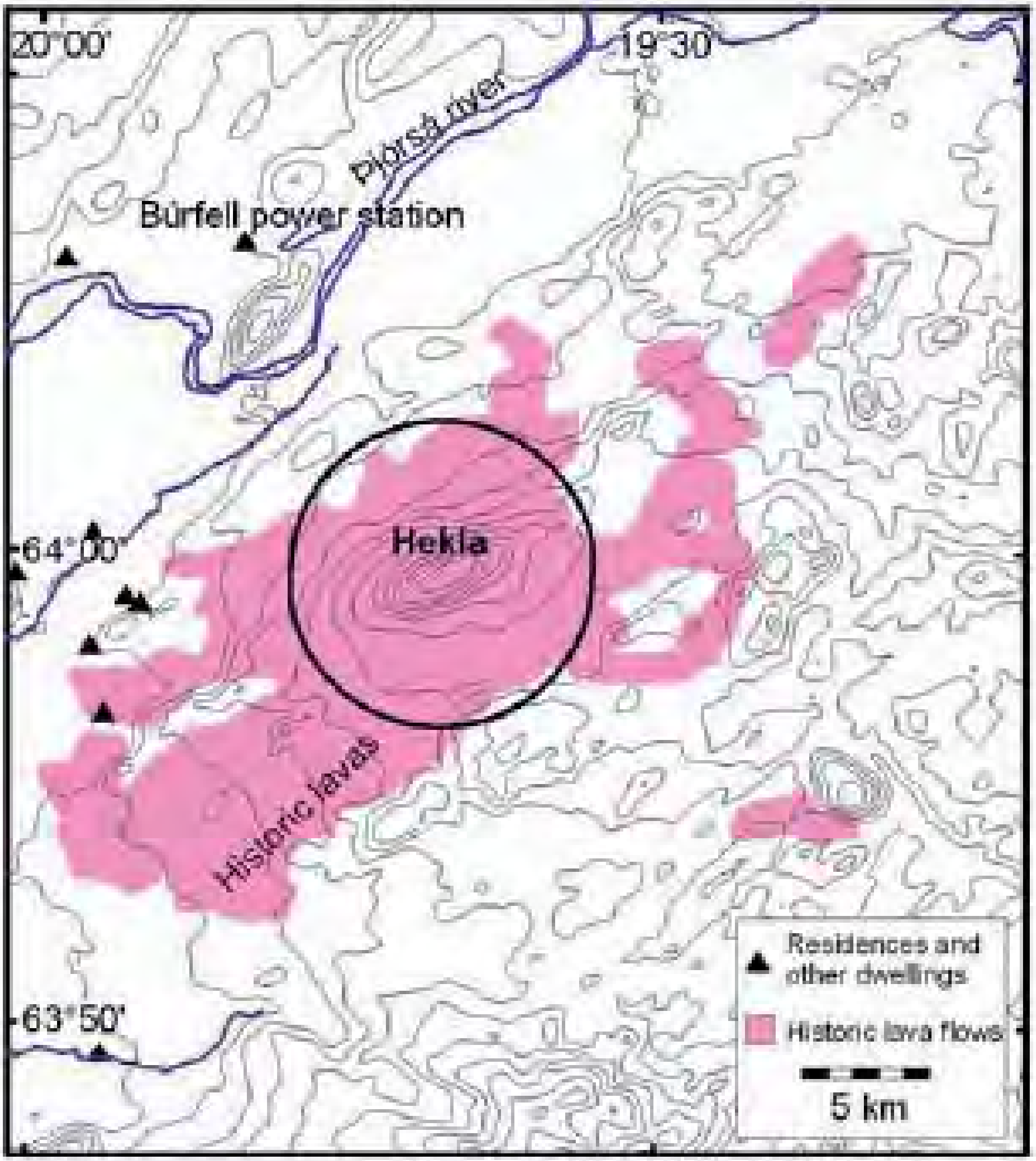


Figure 4. Hekla and surroundings. The extent of historical lavas and the maximum extent of pyroclastic flows during 20th century eruptions is shown (circle). – *Útbreiðsla hrauna frá Heklu á sögulegum tíma og mesta fjarlægð sem gjóskuflóð hafa náð út frá eldstöðinni á 20. öld (sýnd með hring).*

Figure 3. Lava-flows from mountain Hekla in historical time. From M.T. Gudmundsson et al. (2008).

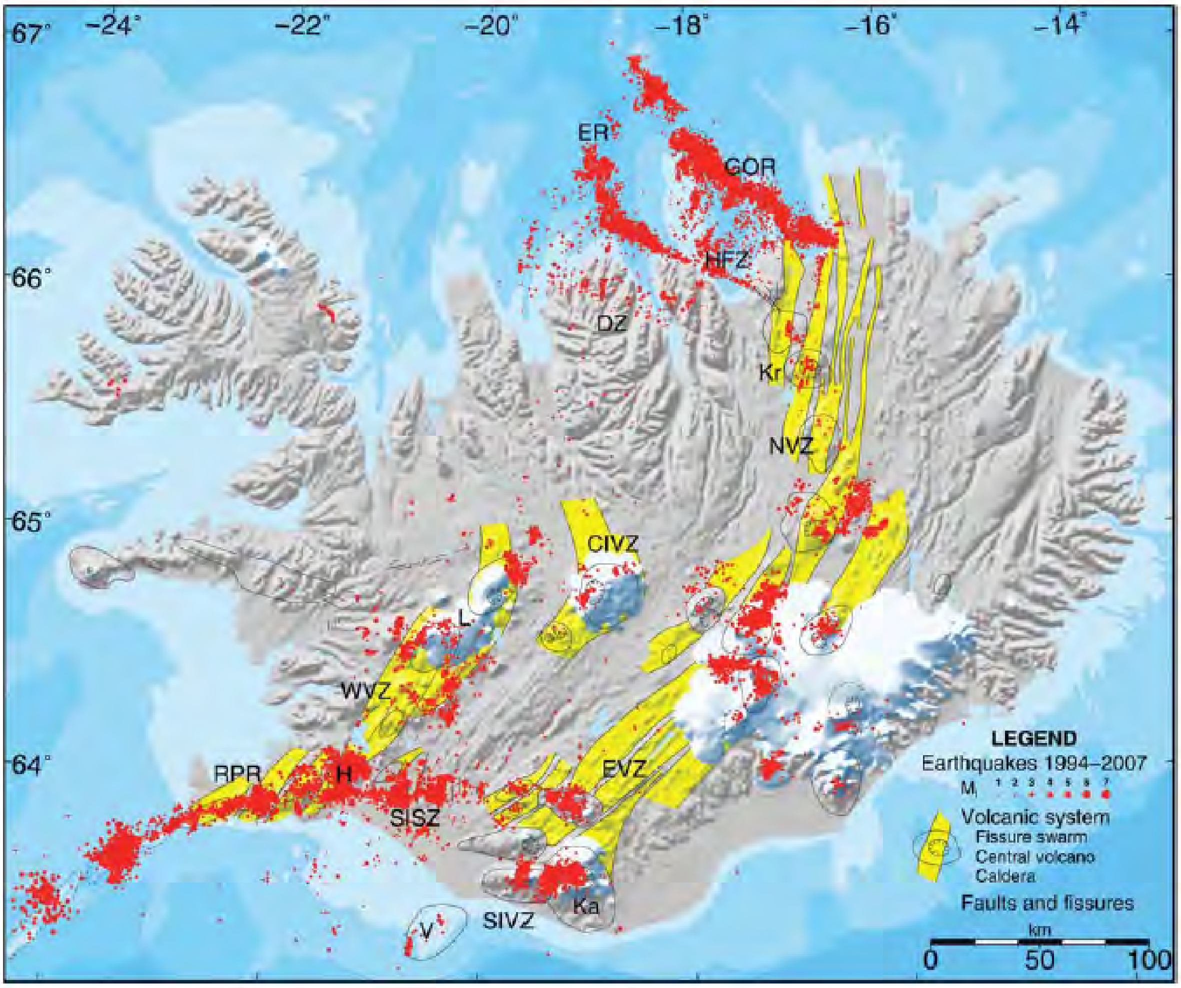


Figure 2. Earthquake epicenters 1994–2007 and volcanic systems of Iceland. Volcanic systems and active faults are from Einarsson and Sæmundsson (1987). Epicenters are from the data bank of the Icelandic Meteorological Office. Individual plate boundary segments are indicated: RPR Reykjanes Peninsula Rift, WVZ Western Volcanic Zone, SISZ South Iceland Seismic Zone, EVZ Eastern Volcanic Zone, CIVZ Central Iceland Volcanic Zone, NVZ Northern Volcanic Zone, GOR Grímsey Oblique Rift, HFZ Húsavík-Flatey Zone, ER Eyjafjarðaráll Rift, DZ Dalvík Zone. SIVZ South Iceland Volcanic Zone. Kr, Ka, H, L, V mark the central volcanoes of Krafla, Katla, Hengill, Langjökull, and Vestmannaeyjar. – *Upptök jarðskjálfta 1994–2007, misgengi og eldstöðvakerfi á Íslandi. Skjálftaupptök eru fengin frá Veðurstofu Íslands.*

Figure 4. Earthquakes in Iceland in the period 1994 to 2007. From Páll Einarsson (2008).

Iceland is a platform of dimensions 300x500 km situated astride a divergent plate boundary and on top of a hotspot presumed to be fed by a deep mantle plume … The eastern part of this mass sits on the European Plate and the western part sits on the North America Plate. …

The Iceland hotspot has a pronounced effect on the appearance and structure of the plate boundary … The thick crust produced by the excess magmatism of the hotspot leads to a wider and more complicated plate boundary deformation zone than is observed along normal oceanic plate boundaries. Furthermore, the relative movement of the boundary with respect to the roots of the hotspot leads to unstable boundaries and rift jumps, when crustal blocks or microplates are transferred *from one major plate to the other. The plate boundary zone can be divided into segments that are physiographically relatively homogeneous and possess distinct tectonic characteristics. The segments are more or less oblique to the relative spreading direction of the two major plates. The divergent component of the movements is taken up by diking and normal faulting and is usually concentrated in the fissure swarms of the volcanic systems. The transcurrent component of the movements is often accommodated by strike-slip faulting on faults that are transverse to the plate boundary segment, so-called bookshelf faults, witnessing to the transient nature of the segments. In highly oblique segments, such as the Reykjanes Peninsula Rift and the Grímsey Oblique Rift, both types of active structures occur superimposed on each other. In the South Iceland Seismic Zone, that is almost parallel to the local spreading direction, the bookshelf faults dominate the structure, producing earthquakes as large as magnitude 7. … A ridge-jump appears to be in progress in South Iceland, where rifting is occurring in two sub-parallel rift zones, the very active Eastern Volcanic Zone and the less active Western Volcanic Zone. The block between them is seismically and volcanically inert and may be defined as a microplate, the Hreppar Microplate. It is rotating in response to the southward propagation of the Eastern Volcanic Zone and corresponding recess of the Western Volcanic Zone. …*

In Southern Iceland the plate boundary has two branches and the block between them does not show evidence of active deformation or volcanism. Earthquake epicenters are almost completely lacking .... This block appears to fulfill the criteria of a microplate and has been termed the Hreppar Microplate. The southern boundary of the Hreppar Microplate is marked by the South Iceland Seismic Zone where large, strike-slip earthquakes occur. The northern boundary is marked by diffuse volcanism of the Central Iceland Volcanic Zone (CIVZ) and the relative movement across it seems to be slow.

(Páll Einarsson (2008)).

Sites west of the WVZ have velocities consistent with a location on stable North America, while sites east of the EVZ have velocities consistent with a location on stable Eurasia. Sites located on the Hreppar block, between the EVZ and WVZ, have velocities that are intermediate in rate and approximately parallel to the plate motion direction, and thus show no evidence of internal deformation of the block within uncertainties. …

Our surface velocity data are well fit by a simple model of dike injection and deformation on the EVZ and WVZ, with no permanent deformation in the intervening region, the Hreppar block. This suggests that the velocity data in the Hreppar block fit a rigid microplate or block

model, with the block deforming only by elastic strain accumulation on its edges. ...

Figure 16 shows site velocities for south Iceland relative to the Hreppar block. The coseismic corrected velocities are used here. The five sites used to define the Hreppar block fit the rigid block model to better than 1 mm/yr. Studies of propagating ridges and overlapping spreading

centers predict that the overlap region (e.g., the Hreppar Block) will act either as a rigid block or deform internally via shear ... Our data suggest that the Hreppar Block in fact is rigid, at least to the level of our data uncertainty.

(LaFemina et al. (2005))

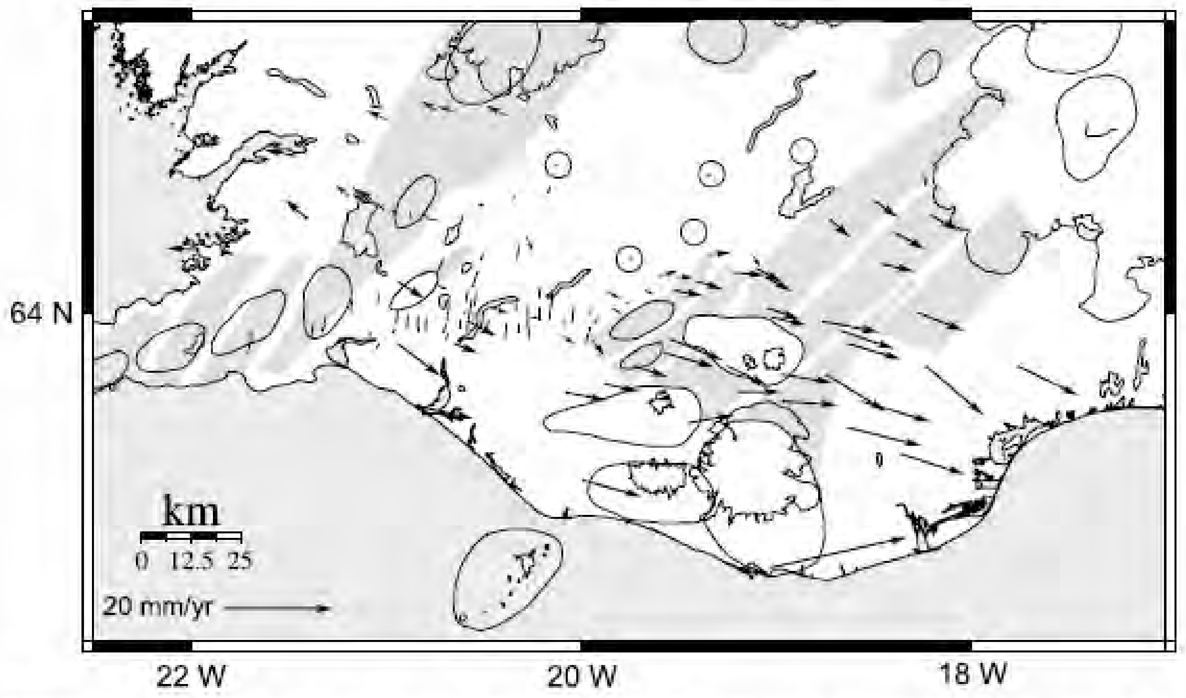


Figure 16. GPS velocity field relative to the Hreppar block, corrected for coseismic offsets from the 17 and 21 June 2000 SISZ earthquakes. Five sites used to define the Hreppar block are circled. This velocity field shows the slower divergence across the WVZ relative to the EVZ and strain accumulation across the SISZ. Deformation at sites near Hekla volcano can also be seen.

Figure 5. The Hreppar block or microplate in South-Iceland. From LaFemina et al. (2005).

Páll Einarsson argues "… that the South Iceland Seismic Zone is a transient feature, migrating sideways in response to propagation of the Eastern Volcanic Zone." (Einarsson (1991)). Khodayar and Franzson (2007) further add to this: "The transform zone of the SISZ is 20-30 km wide and some 80 km long, with typical shear fractures. Such fractures are also observed in the Thjórsárdalur volcano and throughout the Hreppar rift-jump block … We interpret the existence of a typical transform-zone fracture pattern far away from the present location of the zone implies to mean that the transform zone itself must have migrated southward by a distance corresponding to the current width of the SISZ … while Thjórsárdalur was forming in the Eastern Rift Zone and shifting away from this rift zone."

It believed that some northerly faults in the Hreppar Block connect to source faults of major earthquakes within the active SISZ (Khodayar et al. (2010)).

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Einarsson, P. (1991). *Earthquakes and present-day tectonism in Iceland.* Tectonophysics, volume 189, issues 1–4, 10 April 1991, pages 261–279.

Khodayar, M. and Hjalti Franzson (2007). *Fracture pattern of Thjórsárdalur central volcano with respect to rift-jump and a migrating transform zone in South Iceland.* Journal of Structural Geology, volume 29 (2007), pp. 898-912.

Khodayar, M., Sveinbjörn Björnsson, Páll Einarsson and Hjalti Franzson (2010). *Effect of tectonics and earthquakes on geothermal activity near plate boundaries: A case study from South Iceland.* Geothermics, volume 39, issue 3, September 2010, pages 207–219.

P. C. LaFemina, T. H. Dixon, R. Malservisi, T. Árnadóttir, E. Sturkell, F. Sigmundsson, and P. Einarsson (2005). *Geodetic GPS measurements in south Iceland: Strain accumulation and partitioning in a propagating ridge system.* Journal of Geophysical Research, vol. 110, B11405, doi:10.1029/2005JB003675, 2005.

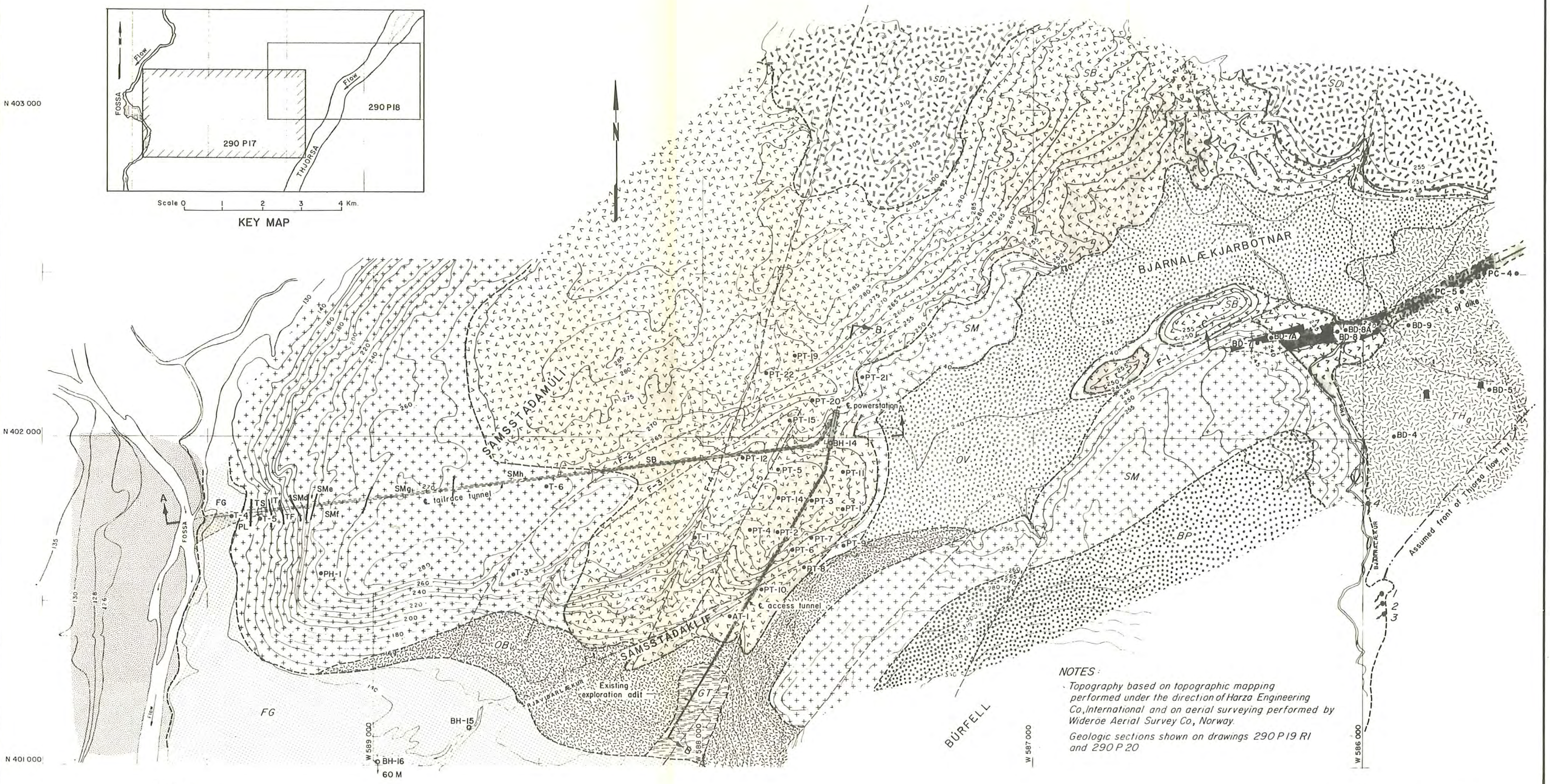
Magnús Tumi Gudmundsson, Guðrún Larsen, Ármann Höskuldsson and Ágúst Gunnar Gylfason (2008). *Volcanic hazards in Iceland*. Jökull, number 58, special issue: The dynamic geology of Iceland. pp. 251-268.

Páll Einarsson (2008). *Plate boundaries, rifts and transforms in Iceland.* Jökull, number 58, pp. 35-58.

Appendix B

Bedrock map of Búrfell-area from 1963 (Harza Engineering Company International (1963)).

EXHIBIT B-3



NOTES:

- Topography based on topographic mapping performed under the direction of Harza Engineering Co, International and on aerial surveying performed by Wideroe Aerial Survey Co, Norway.

Geologic sections shown on drawings 290 P 19 RI and 290 P 20

Scale 0 100 200 300 Meters

LEGEND:

▨	Overburden (OV) River alluvium Ash and lapilli
▨	Thjorsá flow (THg) Upper flow of Thjorsá group, consisting of porphyritic basalt flows with soil and ash interbeds
☐	Finiglacial (FG) Sand and gravel, unconsolidated
▤	Glacial till (GT) Moraine (boulder, clay)
▨	Skeljafell dolerite (SD) Dolerite and basalt
▨	Samsstaðaklif basalt (SB) Basalt and volcanic breccia
▨	Burfell pillow lava (BP) Pillow lava and volcanic breccia
+	Samsstaðamuli group (SM) Basalt flows (SM) interfingering with talus-fanglomerate (TF). Tuffaceous sandstone (TS) with tongues of pillow lava (PL)
▨	Older Burfell (OB) Basalt, andesite and rhyolite flows with clastic interbeds
▨	Outline of structures
- - -	Approximate geologic contact between groups
—	Approximate geologic contact between formations
— —	Fault
○	Exploration hole drilled under supervision of Harza Engineering Co, International 1961 during exploration for the "Lower Site"
●	Exploration hole drilled under supervision of Harza Engineering Co, International 1962 during exploration for the "Upper Site"
2 ●	Springs
▬	Trench

DATE	NO	DISTRIBUTION		
PRINTS				
	BY	DATE	CHKD	DATE
DSGN	PHD	12/21/62		
DWN.	NLS	1/4/63	RHD	1-11-63
DEPT.	GROUP LEADER	SECT HEAD	DEPT HEAD	
CIVIL		RJF	[illegible]	
MECH				
ELECT				
PLAN				
STAFF	CLW		CHENGR	

REV NO	DATE	NATURE OF REVISION	BY	CHKD	APPD
1	2-7-63	[illegible]	TLM	WGD	ARE

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

GEOLOGIC MAP-PROJECT AREA
SHEET 1 OF 2

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED

CHICAGO, ILLINOIS

DATE JAN. 1963

DWG. No. 290 P 17 RI

Appendix C

Logs of cored boreholes 2012.

Almenna verkfræðistofan
Landsvirkjun

Búrfell HEP Extension

Explanations
Corehole logging

Date: March 2013
Designed: AKS
Drawn by: AKS

▭	Overburden	▨	Hyaloclastite
▥	Basaltic Andesite	▤	Peat
▨	Scoria	▨	Tuff
▥	Olivine Basalt	▲	Moraine
▨	Conglomerate	▥	Tholeiite Basalt
▥	Porphyritic Olivine Basalt	▨	Sandstone

Explanations of symbols

Ⓝ / Ⓡ / Ⓐ	Rock magnetisation Normal / Reverse / Anomalous
—	Water level depth in meters (date)
15,5-24,7m >100 LU	Permeability Interval (in metres) and LU values
5,0 kN ⧗ 11,0 MPa	Point Load Test (PLT) kN = average readings from point load test MPa = point load strength index IS 50
I 3" ODEX I	Cuttings samples
▌	Casing

Explanations of formation

FG	Finiglacial
GT	Glacial till
SB	Sámsstaðarklif basalt
SM	Sámsstaðarmúli group
OB	Older Búrfell group

Q - system of rock mass quality

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

RQD (Rock Quality Designation)

Jn (joint set number)

Jr (joint roughness number)

Ja (joint alteration number)

Jw (joint water reduction factor)

SRF (Stress Reduction Factor)

$$Q_c = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Jw and SRF are evaluated as 1/1 in the boreholes

Q_c = Q evaluated from core sample from borehole

Almenna verkfræðistofan

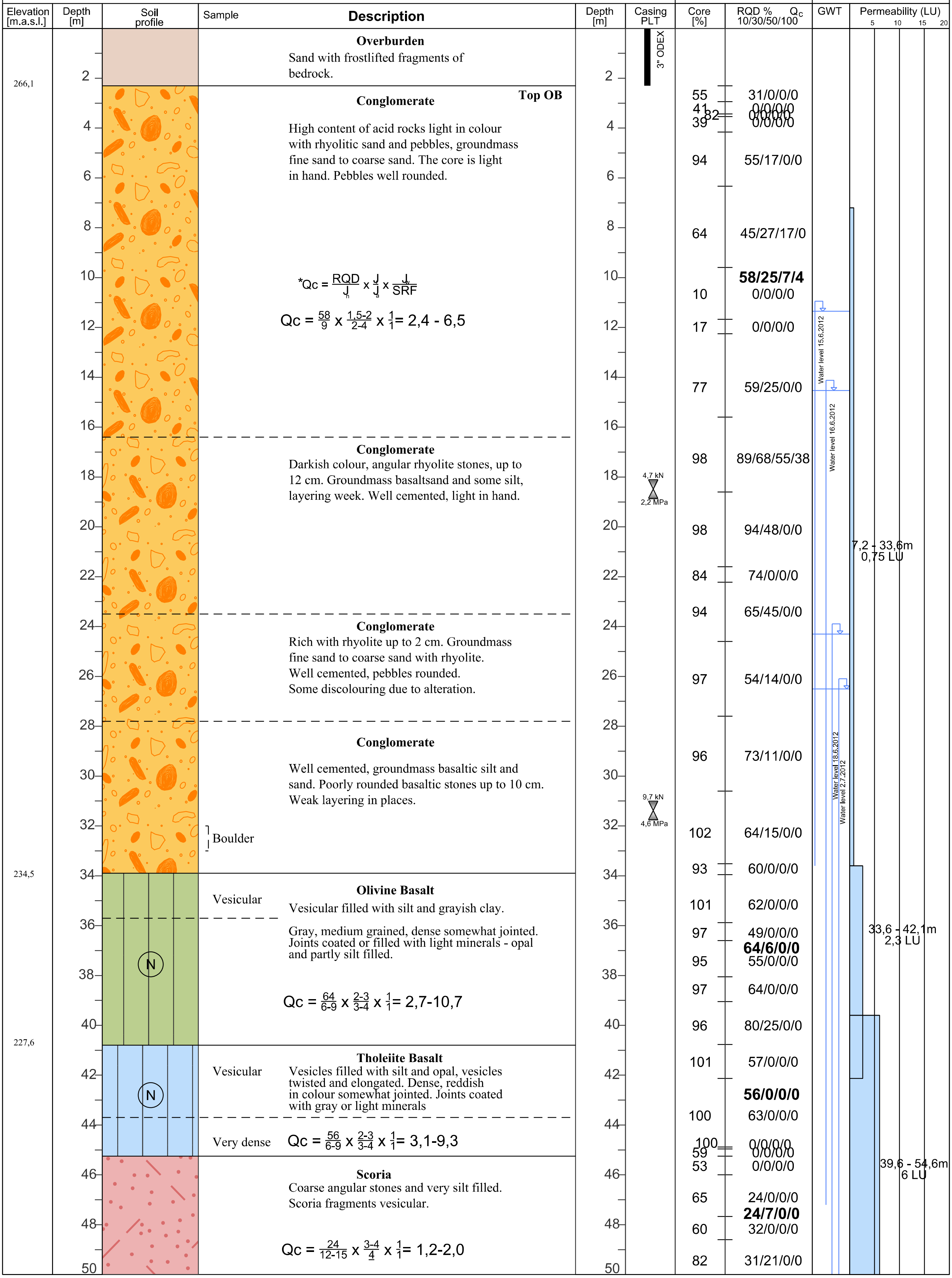
Landsvirkjun

Búrfell HEP Extension

BF-30
Cored hole

Contractor: RFS	Drill: Einráður/HMH		
Place: Sámsstaðaklif	Drill thickness: NQ/3" ODEX 45 mm core		
Date of drilling: June 2012	Drawn: ÁÓT/SPS		
Drawing nr.: 1 af 4	Approved: SPS		

Coordinates: ISN93 X: 460998,08 Y: 400336,45 Elev.: 268,39 m.a.s.l.



Overburden

Sand with frostlifted fragments of bedrock.

Top OB

Conglomerate

High content of acid rocks light in colour with rhyolitic sand and pebbles, groundmass fine sand to coarse sand. The core is light in hand. Pebbles well rounded.

$$^*Qc = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

$$Qc = \frac{58}{9} \times \frac{1,5\text{-}2}{2\text{-}4} \times \frac{1}{1} = 2,4 - 6,5$$

Conglomerate

Darkish colour, angular rhyolite stones, up to 12 cm. Groundmass basaltsand and some silt, layering week. Well cemented, light in hand.

Conglomerate

Rich with rhyolite up to 2 cm. Groundmass fine sand to coarse sand with rhyolite. Well cemented, pebbles rounded. Some discolouring due to alteration.

Conglomerate

Well cemented, groundmass basaltic silt and sand. Poorly rounded basaltic stones up to 10 cm. Weak layering in places.

Boulder

Olivine Basalt

Vesicular

Vesicular filled with silt and grayish clay.

Gray, medium grained, dense somewhat jointed. Joints coated or filled with light minerals - opal and partly silt filled.

$$Qc = \frac{64}{6\text{-}9} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 2,7\text{-}10,7$$

Tholeiite Basalt

Vesicular

Vesicles filled with silt and opal, vesicles twisted and elongated. Dense, reddish in colour somewhat jointed. Joints coated with gray or light minerals

Very dense

$$Qc = \frac{56}{6\text{-}9} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 3,1\text{-}9,3$$

Scoria

Coarse angular stones and very silt filled. Scoria fragments vesicular.

$$Qc = \frac{24}{12\text{-}15} \times \frac{3\text{-}4}{4} \times \frac{1}{1} = 1,2\text{-}2,0$$

Core [%]	RQD % 10/30/50/100 Qc
55	31/0/0/0
41	0/0/0/0
82	0/0/0/0
39	0/0/0/0
94	55/17/0/0
64	45/27/17/0
	58/25/7/4
10	0/0/0/0
17	0/0/0/0
77	59/25/0/0
98	89/68/55/38
98	94/48/0/0
84	74/0/0/0
94	65/45/0/0
97	54/14/0/0
96	73/11/0/0
102	64/15/0/0
93	60/0/0/0
101	62/0/0/0
97	49/0/0/0
	64/6/0/0
95	55/0/0/0
97	64/0/0/0
96	80/25/0/0
101	57/0/0/0
	56/0/0/0
100	63/0/0/0
100	0/0/0/0
59	0/0/0/0
53	0/0/0/0
65	24/0/0/0
	24/7/0/0
60	32/0/0/0
82	31/21/0/0

Almenna verkfræðistofan

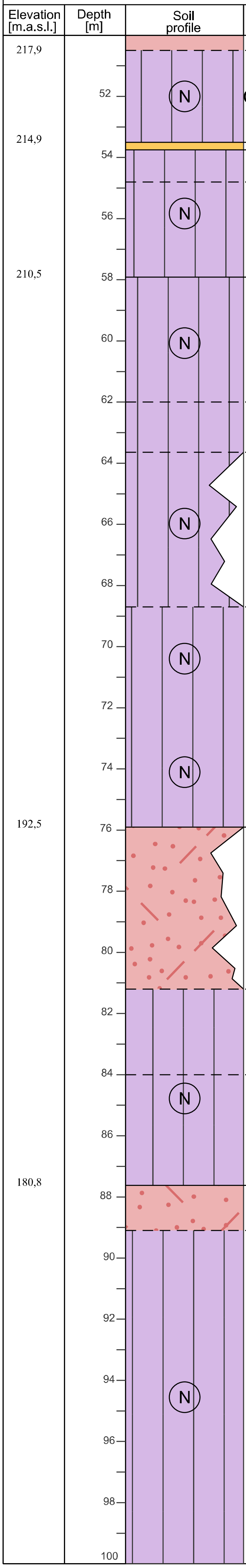
Landsvirkjun

Búrfell HEP Extension

BF-30
Cored hole

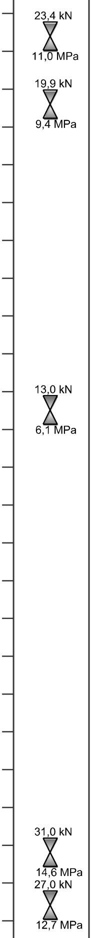
Contractor:	RFS
Drill	Einráður/HMH
Place:	Sámsstaðaklif
Drill thickness:	NQ/3" ODEX 45 mm core
Date of drilling:	June 2012
Drawn:	ÁÓT/SPS
Drawing nr.:	2 af 4
Approved:	SPS

Coordinates: ISN93 X: 460998,08 Y: 400336,45 Elev.: 268,39 m.a.s.l.



Depth [m]	Sample	Description
50,5–53,5	$Q_c = \frac{25}{12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} =$ 1,0-2,1	**Basaltic Andesite** Dark,fine grained groundmass, hard, strong and irregularly jointed, filled with silt.
53,5		**Conglomerate and Sandstone** Fine grained
53,5–57,9	Vesicular	**Basaltic Andesite** Hard, dark and fine grained, spotted in apperance. Dense, dark, joints discontinuous and rough. Heavily jointed, gray and light minerals coat joint surfaces. $Q_c = \frac{17}{12\text{-}15} \times \frac{2\text{-}3}{3} \times \frac{1}{1} =$ 0,8-1,4
57,9–62	Vesicular and reddish in colour	**Basaltic Andesite** Dard and fine grained, a few plg phenochrysts.
62–63,7	Dense	
63,7–68,7	Core loss 5cm band of silt Core loss Core loss	Scoracious and filled with silt, core recovery poor. $Q_c = \frac{21}{12\text{-}15} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} =$ 0,7-2,6
68,7–75,9	Vesicular and scoracious Core loss	**Basaltic Andesite** Dark, hard and fine grained, few plg phenochrysts spotty appearance. Dense and heavily jointed, joints coated with gray secondary minerals and silt. $Q_c = \frac{31}{12} \times \frac{2\text{-}3}{2\text{-}4} \times \frac{1}{1} =$ 1,3-3,9
75,9–81,2	Core loss probably Scoria	**Scoria filled with Silt/opal** $Q_c = \frac{10}{15\text{-}20} \times \frac{2\text{-}3}{2\text{-}4} \times \frac{1}{1} =$ 0,3-1,0
81,2–84	Vesicular large vesicles	**Basaltic Andesite** Dark, hard and fine grained, very jointed gray and green secondary minerals coat joint surfaces. Spotted appearance.
84–87,6	Core loss 87,47-87,62m	$Q_c = \frac{32}{12\text{-}15} \times \frac{2\text{-}3}{2\text{-}4} \times \frac{1}{1} =$ 1,1-4,0
87,6–89,1	60 cm Core recovery	**Scoria** Scoria partly filled with sandstone.
89,1–100		**Basaltic Andesite** Dark, hard, heavy and fine grained. Flow bands visible and joints form along the flow bands. Very jointed and joint surfaces coated with gray or light minerals. Joints rough and undulating. $Q_c = \frac{46}{12} \times \frac{2\text{-}3}{2\text{-}3} \times \frac{1}{1} =$ 2,6-5,8

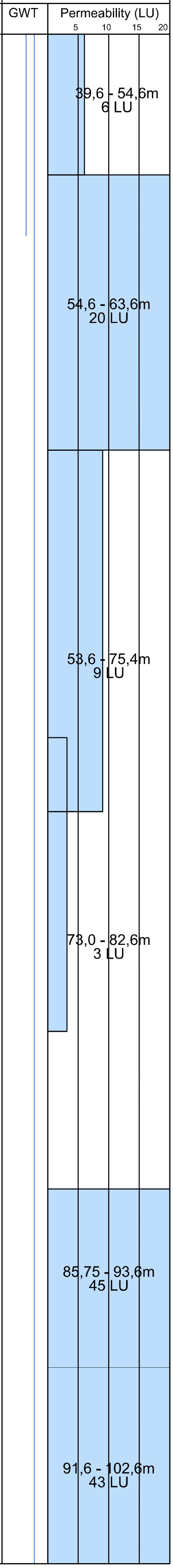
Casing PLT



Core [%]	RQD % 10/30/50/100	Q_c
96	29/0/0/0	
		25/0/0/0
100	16/0/0/0	
100	42/0/0/0	
100	41/0/0/0	
100	14/0/0/0	
107	38/0/0/0	
		17/0/0/0
100	0/0/0/0	
85	0/0/0/0	
100	17/0/0/0	
101	32/0/0/0	
51	0/0/0/0	
88	45/0/0/0	
86	0/0/0/0	
75	11/0/0/0	
81	36/0/0/0	
106	46/0/0/0	
		21/0/0/0
53	0/0/0/0	
48	0/0/0/0	
56	0/0/0/0	
59	59/0/0/0	
31	20/0/0/0	
136	56/27/0/0	
		31/0/0/0
20	9/0/0/0	
79	35/0/0/0	
93	38/0/0/0	
85	28/0/0/0	
86	0/0/0/0	
98	73/0/0/0	
7	4/0/0/0	
		10/0/0/0
34	19/0/0/0	
44	14	
62	29/0/0/0	
66	0/0/0/0	
92	37/0/0/0	
		32/0/0/0
65	22/0/0/0	
155	63/0/0/0	
75	17/0/0/0	
84	52/0/0/0	
62	37/0/0/0	
		46/0/0/0
95	49/20/0/0	
97	52/0/0/0	
90	71/0/0/0	
96	61/0/0/0	
96	34/0/0/0	
97	67/0/0/0	
90	26/0/0/0	

GWT

Permeability (LU)

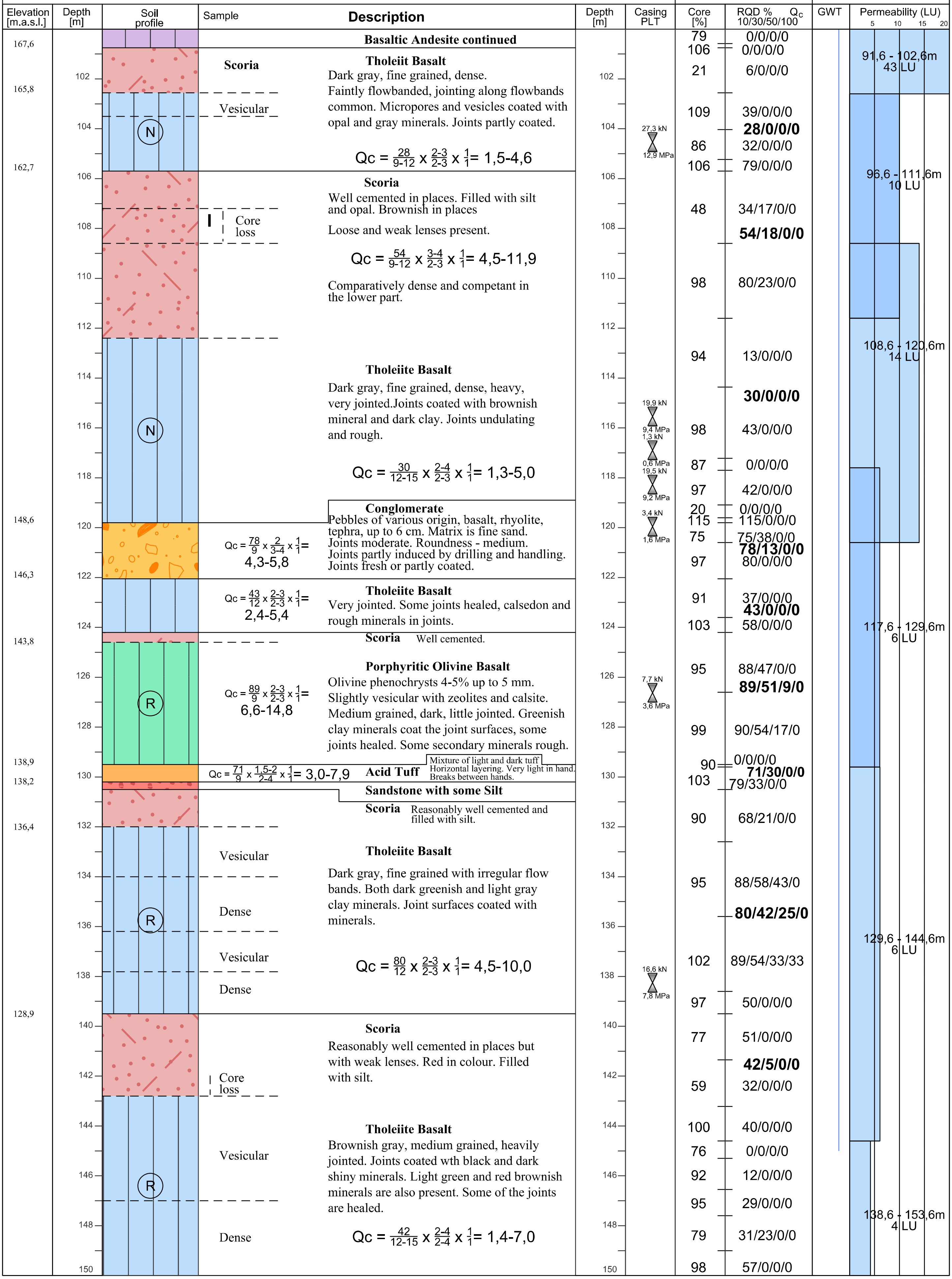


Búrfell HEP Extension

BF-30
Cored hole

Contractor:	RFS
Drill	Einráður/HMH
Place:	Sámsstaðaklif
Drill thickness:	NQ/3" ODEX 45 mm core
Date of drilling:	June 2012
Drawn:	ÁÓT/SPS
Drawing nr.:	3 af 4
Approved:	SPS

Coordinates: ISN93 X: 460998,08 Y: 400336,45 Elev.: 268,39 m.a.s.l.



Basaltic Andesite continued

Tholeiit Basalt
Dark gray, fine grained, dense. Faintly flowbanded, jointing along flowbands common. Micropores and vesicles coated with opal and gray minerals. Joints partly coated.

$$Qc = \frac{28}{9\text{-}12} \times \frac{2\text{-}3}{2\text{-}3} \times \frac{1}{1} = 1{,}5\text{-}4{,}6$$

Scoria
Well cemented in places. Filled with silt and opal. Brownish in places

Loose and weak lenses present.

$$Qc = \frac{54}{9\text{-}12} \times \frac{3\text{-}4}{2\text{-}3} \times \frac{1}{1} = 4{,}5\text{-}11{,}9$$

Comparatively dense and competant in the lower part.

Tholeiite Basalt
Dark gray, fine grained, dense, heavy, very jointed.Joints coated with brownish mineral and dark clay. Joints undulating and rough.

$$Qc = \frac{30}{12\text{-}15} \times \frac{2\text{-}4}{2\text{-}3} \times \frac{1}{1} = 1{,}3\text{-}5{,}0$$

Conglomerate
Pebbles of various origin, basalt, rhyolite, tephra, up to 6 cm. Matrix is fine sand. Joints moderate. Roundness - medium. Joints partly induced by drilling and handling. Joints fresh or partly coated.

$$Qc = \frac{78}{9} \times \frac{2}{3\text{-}4} \times \frac{1}{1} = 4{,}3\text{-}5{,}8$$

Tholeiite Basalt
Very jointed. Some joints healed, calsedon and rough minerals in joints.

$$Qc = \frac{43}{12} \times \frac{2\text{-}3}{2\text{-}3} \times \frac{1}{1} = 2{,}4\text{-}5{,}4$$

Scoria Well cemented.

Porphyritic Olivine Basalt
Olivine phenochrysts 4-5% up to 5 mm. Slightly vesicular with zeolites and calsite. Medium grained, dark, little jointed. Greenish clay minerals coat the joint surfaces, some joints healed. Some secondary minerals rough.

$$Qc = \frac{89}{9} \times \frac{2\text{-}3}{2\text{-}3} \times \frac{1}{1} = 6{,}6\text{-}14{,}8$$

Acid Tuff Mixture of light and dark tuff Horizontal layering. Very light in hand. Breaks between hands.

$$Qc = \frac{71}{9} \times \frac{1{,}5\text{-}2}{2\text{-}4} \times \frac{1}{1} = 3{,}0\text{-}7{,}9$$

Sandstone with some Silt

Scoria Reasonably well cemented and filled with silt.

Tholeiite Basalt
Dark gray, fine grained with irregular flow bands. Both dark greenish and light gray clay minerals. Joint surfaces coated with minerals.

$$Qc = \frac{80}{12} \times \frac{2\text{-}3}{2\text{-}3} \times \frac{1}{1} = 4{,}5\text{-}10{,}0$$

Scoria
Reasonably well cemented in places but with weak lenses. Red in colour. Filled with silt.

Tholeiite Basalt
Brownish gray, medium grained, heavily jointed. Joints coated wth black and dark shiny minerals. Light green and red brownish minerals are also present. Some of the joints are healed.

$$Qc = \frac{42}{12\text{-}15} \times \frac{2\text{-}4}{2\text{-}4} \times \frac{1}{1} = 1{,}4\text{-}7{,}0$$

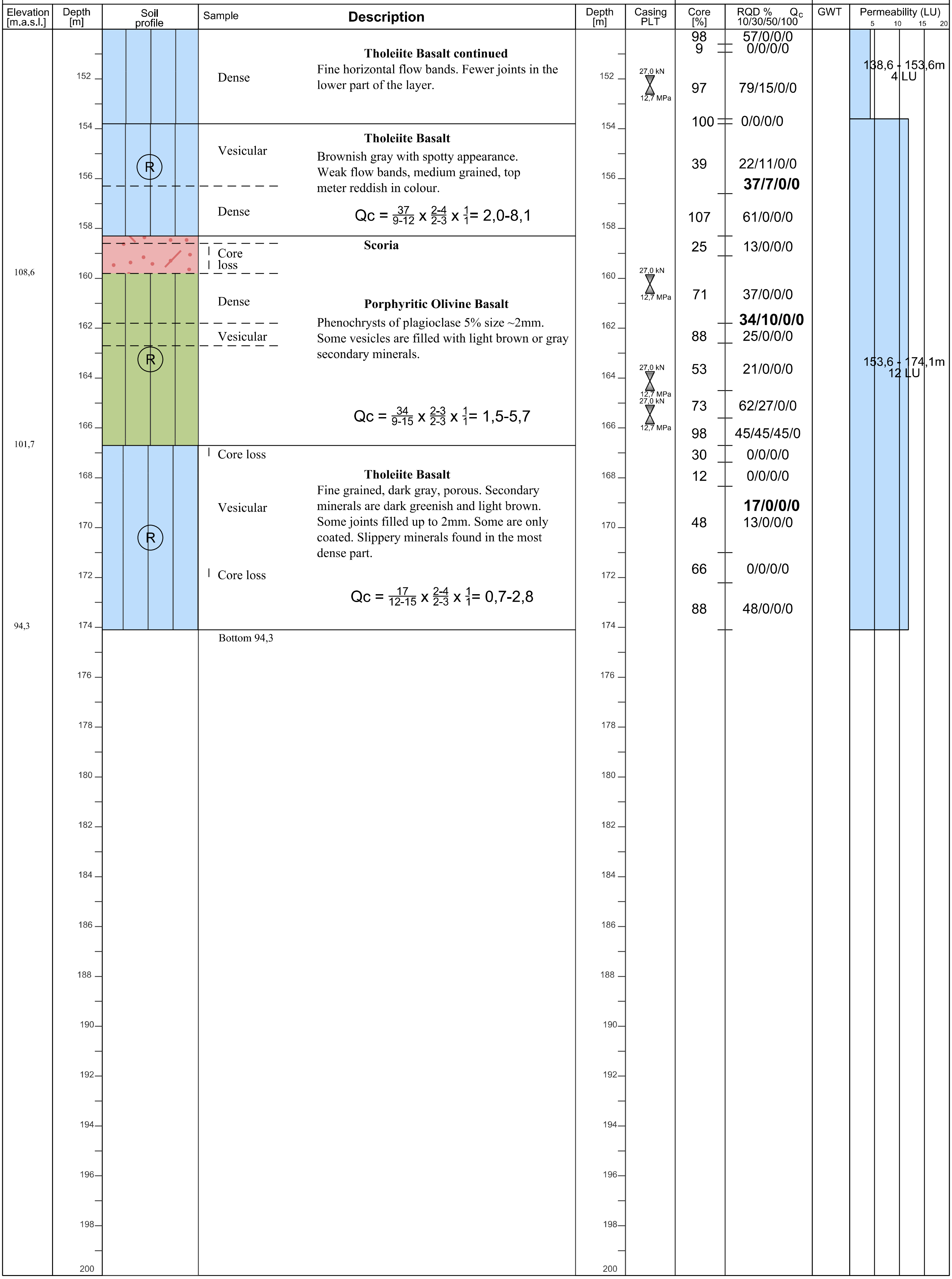
Core [%]	RQD % Qc 10/30/50/100
79	0/0/0/0
106	0/0/0/0
21	6/0/0/0
109	39/0/0/0
	28/0/0/0
86	32/0/0/0
106	79/0/0/0
48	34/17/0/0
	54/18/0/0
98	80/23/0/0
94	13/0/0/0
	30/0/0/0
98	43/0/0/0
87	0/0/0/0
97	42/0/0/0
20	0/0/0/0
115	115/0/0/0
75	75/38/0/0
	78/13/0/0
97	80/0/0/0
91	37/0/0/0
	43/0/0/0
103	58/0/0/0
95	88/47/0/0
	89/51/9/0
99	90/54/17/0
90	0/0/0/0
	71/30/0/0
103	79/33/0/0
90	68/21/0/0
95	88/58/43/0
	80/42/25/0
102	89/54/33/33
97	50/0/0/0
77	51/0/0/0
	42/5/0/0
59	32/0/0/0
100	40/0/0/0
76	0/0/0/0
92	12/0/0/0
95	29/0/0/0
79	31/23/0/0
98	57/0/0/0

Búrfell HEP Extension

BF-30
Cored hole

Contractor: RFS	Drill: Einráður/HMH		
Place: Sámsstaðaklif	Drill thickness: NQ/3" ODEX 45 mm core		
Date of drilling: June 2012	Drawn: ÁÓT/SPS		
Drawing nr.: 4 af 4	Approved: SPS		

Coordinates: ISN93 X: 460998,08 Y: 400336,45 Elev.: 268,39 m.a.s.l.



Tholeiite Basalt continued
Fine horizontal flow bands. Fewer joints in the lower part of the layer.

Tholeiite Basalt
Brownish gray with spotty appearance. Weak flow bands, medium grained, top meter reddish in colour.

$Qc = \frac{37}{9-12} x \frac{2-4}{2-3} x \frac{1}{1} = 2,0-8,1$

Scoria

Porphyritic Olivine Basalt
Phenochrysts of plagioclase 5% size ~2mm. Some vesicles are filled with light brown or gray secondary minerals.

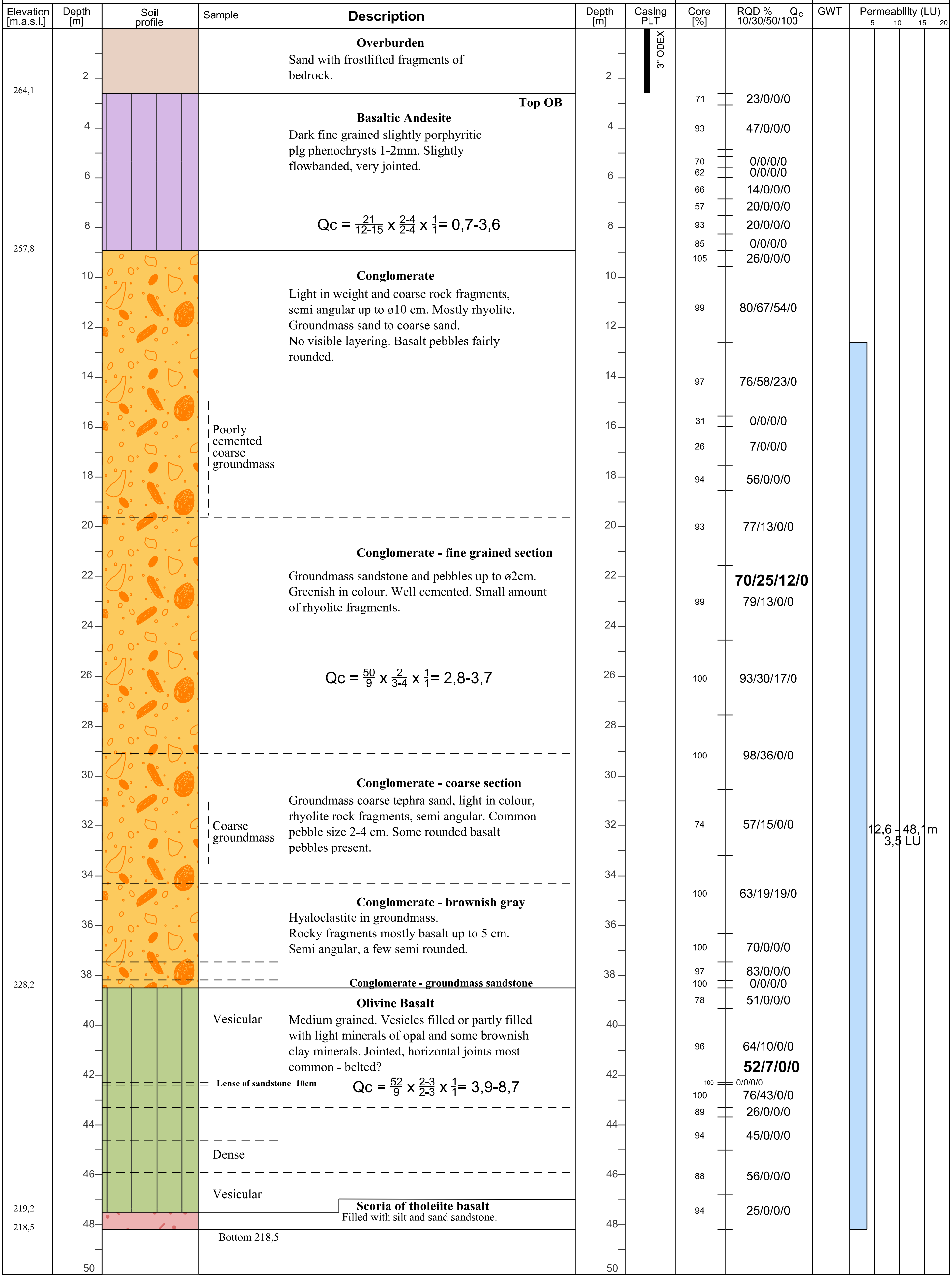
$Qc = \frac{34}{9-15} x \frac{2-3}{2-3} x \frac{1}{1} = 1,5-5,7$

Tholeiite Basalt
Fine grained, dark gray, porous. Secondary minerals are dark greenish and light brown. Some joints filled up to 2mm. Some are only coated. Slippery minerals found in the most dense part.

$Qc = \frac{17}{12-15} x \frac{2-4}{2-3} x \frac{1}{1} = 0,7-2,8$

Bottom 94,3

Almenna verkfræðistofan / Landsvirkjun	Búrfell HEP Extension	Contractor: RFS	Drill: Einráður/HMH
	BF-31 Cored hole	Place: Sámsstaðaklif	Drill thickness: NQ/3" ODEX 45 mm core
		Date of drilling: June 2012	Drawn: ÁÓT/SPS
Coordinates: ISN93	X: 461096,89 Y: 400469,09 Elev.: 266,71 m.a.s.l.	Drawing nr.: 1 af 1	Approved: SPS



Description

Overburden

Sand with frostlifted fragments of bedrock.

Top OB

Basaltic Andesite

Dark fine grained slightly porphyritic plg phenochrysts 1-2mm. Slightly flowbanded, very jointed.

$$Qc = \frac{21}{12\text{-}15} \times \frac{2\text{-}4}{2\text{-}4} \times \frac{1}{1} = 0{,}7\text{-}3{,}6$$

Conglomerate

Light in weight and coarse rock fragments, semi angular up to ø10 cm. Mostly rhyolite. Groundmass sand to coarse sand. No visible layering. Basalt pebbles fairly rounded.

Poorly cemented coarse groundmass

Conglomerate - fine grained section

Groundmass sandstone and pebbles up to ø2cm. Greenish in colour. Well cemented. Small amount of rhyolite fragments.

$$Qc = \frac{50}{9} \times \frac{2}{3\text{-}4} \times \frac{1}{1} = 2{,}8\text{-}3{,}7$$

Conglomerate - coarse section

Coarse groundmass

Groundmass coarse tephra sand, light in colour, rhyolite rock fragments, semi angular. Common pebble size 2-4 cm. Some rounded basalt pebbles present.

Conglomerate - brownish gray

Hyaloclastite in groundmass. Rocky fragments mostly basalt up to 5 cm. Semi angular, a few semi rounded.

Conglomerate - groundmass sandstone

Olivine Basalt

Vesicular

Medium grained. Vesicles filled or partly filled with light minerals of opal and some brownish clay minerals. Jointed, horizontal joints most common - belted?

Lense of sandstone 10cm

$$Qc = \frac{52}{9} \times \frac{2\text{-}3}{2\text{-}3} \times \frac{1}{1} = 3{,}9\text{-}8{,}7$$

Dense

Vesicular

Scoria of tholeiite basalt

Filled with silt and sand sandstone.

Bottom 218,5

Core [%]	RQD % 10/30/50/100
71	23/0/0/0
93	47/0/0/0
70	0/0/0/0
62	0/0/0/0
66	14/0/0/0
57	20/0/0/0
93	20/0/0/0
85	0/0/0/0
105	26/0/0/0
99	80/67/54/0
97	76/58/23/0
31	0/0/0/0
26	7/0/0/0
94	56/0/0/0
93	77/13/0/0
	70/25/12/0
99	79/13/0/0
100	93/30/17/0
100	98/36/0/0
74	57/15/0/0
100	63/19/19/0
100	70/0/0/0
97	83/0/0/0
100	0/0/0/0
78	51/0/0/0
96	64/10/0/0
	52/7/0/0
100	0/0/0/0
100	76/43/0/0
89	26/0/0/0
94	45/0/0/0
88	56/0/0/0
94	25/0/0/0

Almenna verkfræðistofan

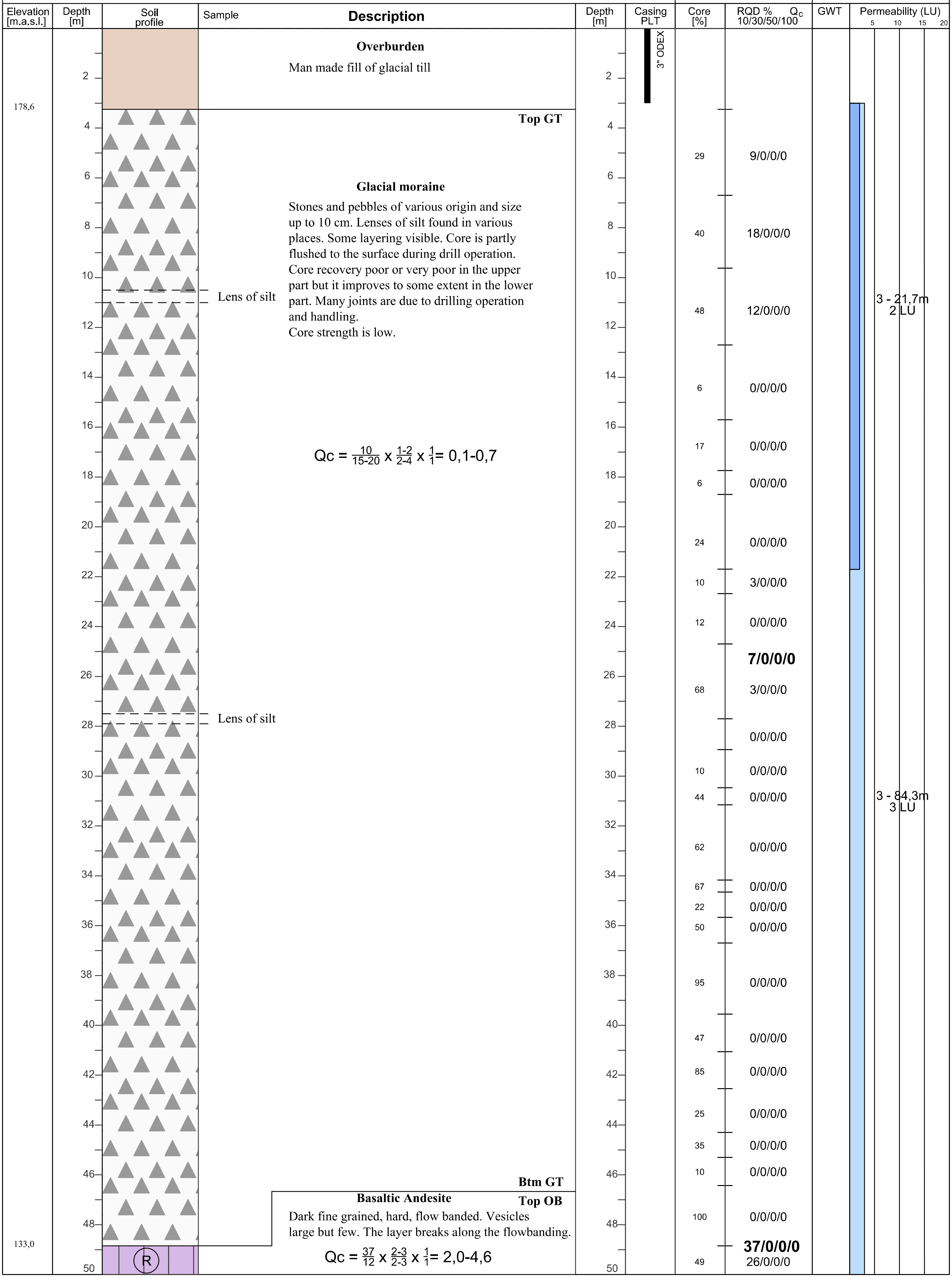
Landsvirkjun

Búrfell HEP Extension

BF-32
Cored hole

Contractor:	RFS
Drill	Einráður/HMH
Place:	Sámsstaðaklif
Drill thickness:	NQ/3" ODEX 45 mm core
Date of drilling:	July 2012
Drawn:	ÁÓT/SPS
Drawing nr.:	1 af 2
Approved:	SPS

Coordinates: ISN93 X: 460809,06 Y: 400131,84 Elev.: 181,87 m.a.s.l.



Overburden

Man made fill of glacial till

Top GT

Glacial moraine

Stones and pebbles of various origin and size up to 10 cm. Lenses of silt found in various places. Some layering visible. Core is partly flushed to the surface during drill operation. Core recovery poor or very poor in the upper part but it improves to some extent in the lower part. Many joints are due to drilling operation and handling.
Core strength is low.

$$Qc = \frac{10}{15\text{-}20} \times \frac{1\text{-}2}{2\text{-}4} \times \frac{1}{1} = 0{,}1\text{-}0{,}7$$

Btm GT

Basaltic Andesite

Top OB

Dark fine grained, hard, flow banded. Vesicles large but few. The layer breaks along the flowbanding.

$$Qc = \frac{37}{12} \times \frac{2\text{-}3}{2\text{-}3} \times \frac{1}{1} = 2{,}0\text{-}4{,}6$$

Core [%]	RQD % 10/30/50/100
29	9/0/0/0
40	18/0/0/0
48	12/0/0/0
6	0/0/0/0
17	0/0/0/0
6	0/0/0/0
24	0/0/0/0
10	3/0/0/0
12	0/0/0/0
	7/0/0/0
68	3/0/0/0
	0/0/0/0
10	0/0/0/0
44	0/0/0/0
62	0/0/0/0
67	0/0/0/0
22	0/0/0/0
50	0/0/0/0
95	0/0/0/0
47	0/0/0/0
85	0/0/0/0
25	0/0/0/0
35	0/0/0/0
10	0/0/0/0
100	0/0/0/0
	37/0/0/0
49	26/0/0/0

Almenna verkfræðistofan

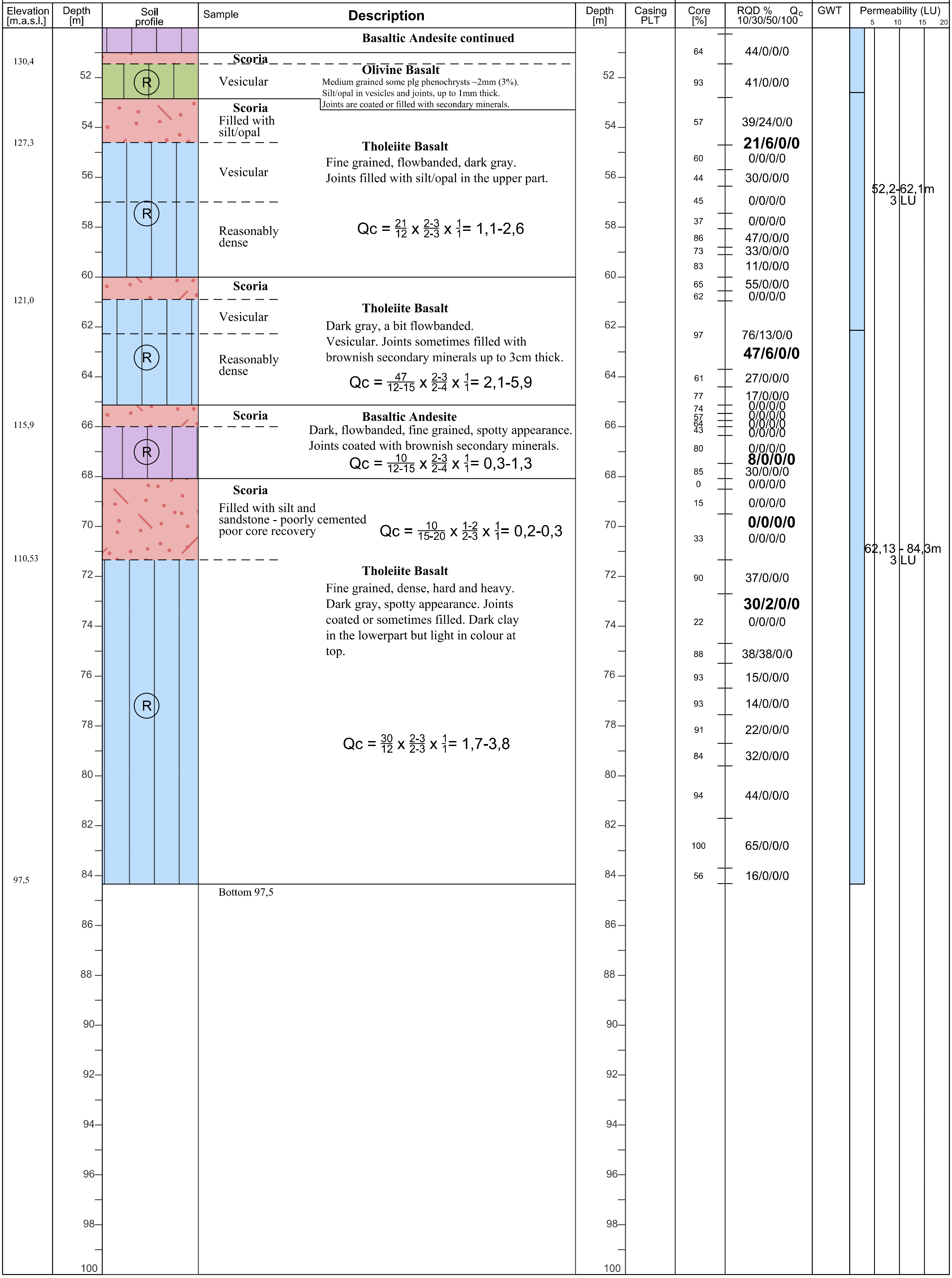
Landsvirkjun

Búrfell HEP Extension

BF-32
Cored hole

Contractor:	RFS
Drill	Einráður/HMH
Place:	Sámsstaðaklif
Drill thickness:	NQ/3" ODEX 45 mm core
Date of drilling:	July 2012
Drawn:	ÁÓT/SPS
Drawing nr.:	2 af 2
Approved:	SPS

Coordinates: ISN93 X: 460809,06 Y: 400131,84 Elev.: 181,87 m.a.s.l.



Description

Basaltic Andesite continued

Scoria

Olivine Basalt

Vesicular

Medium grained some plg phenochrysts ~2mm (3%).
Silt/opal in vesicles and joints, up to 1mm thick.
Joints are coated or filled with secondary minerals.

Scoria
Filled with silt/opal

Tholeiite Basalt

Vesicular

Fine grained, flowbanded, dark gray.
Joints filled with silt/opal in the upper part.

Reasonably dense

$Qc = \frac{21}{12} x \frac{2\text{-}3}{2\text{-}3} x \frac{1}{1} = 1,1\text{-}2,6$

Scoria

Tholeiite Basalt

Vesicular

Dark gray, a bit flowbanded.
Vesicular. Joints sometimes filled with brownish secondary minerals up to 3cm thick.

Reasonably dense

$Qc = \frac{47}{12\text{-}15} x \frac{2\text{-}3}{2\text{-}4} x \frac{1}{1} = 2,1\text{-}5,9$

Scoria

Basaltic Andesite

Dark, flowbanded, fine grained, spotty appearance.
Joints coated with brownish secondary minerals.

$Qc = \frac{10}{12\text{-}15} x \frac{2\text{-}3}{2\text{-}4} x \frac{1}{1} = 0,3\text{-}1,3$

Scoria
Filled with silt and sandstone - poorly cemented poor core recovery

$Qc = \frac{10}{15\text{-}20} x \frac{1\text{-}2}{2\text{-}3} x \frac{1}{1} = 0,2\text{-}0,3$

Tholeiite Basalt

Fine grained, dense, hard and heavy.
Dark gray, spotty appearance. Joints coated or sometimes filled. Dark clay in the lowerpart but light in colour at top.

$Qc = \frac{30}{12} x \frac{2\text{-}3}{2\text{-}3} x \frac{1}{1} = 1,7\text{-}3,8$

Bottom 97,5

Core [%]	RQD % 10/30/50/100	Q_c
64	44/0/0/0	
93	41/0/0/0	
57	39/24/0/0	
		21/6/0/0
60	0/0/0/0	
44	30/0/0/0	
45	0/0/0/0	
37	0/0/0/0	
86	47/0/0/0	
73	33/0/0/0	
83	11/0/0/0	
65	55/0/0/0	
62	0/0/0/0	
97	76/13/0/0	
		47/6/0/0
61	27/0/0/0	
77	17/0/0/0	
74	0/0/0/0	
57	0/0/0/0	
64	0/0/0/0	
43	0/0/0/0	
80	0/0/0/0	
		8/0/0/0
85	30/0/0/0	
0	0/0/0/0	
15	0/0/0/0	
		0/0/0/0
33	0/0/0/0	
90	37/0/0/0	
		30/2/0/0
22	0/0/0/0	
88	38/38/0/0	
93	15/0/0/0	
93	14/0/0/0	
91	22/0/0/0	
84	32/0/0/0	
94	44/0/0/0	
100	65/0/0/0	
56	16/0/0/0	

Appendix D

Logs of cored boreholes from previous investigations.

Almenna verkfræðistofan	# Búrfell HEP Extension	Date: March 2013
Landsvirkjun	Explanations Corehole logging	Designed: AKS Drawn by: AKS

🟫	Overburden	▨	Hyaloclastite
🟪	Basaltic Andesite	🟩	Peat
🟥	Scoria	🟧	Tuff
🟩	Olivine Basalt	▲	Moraine
🟨	Conglomerate	🟦	Tholeiite Basalt
🟩	Porphyritic Olivine Basalt	🟥	Sandstone

Explanations of symbols

Ⓝ / Ⓡ / Ⓐ	Rock magnetisation Normal / Reverse / Anomalous
—	Water level depth in meters (date)
15,5-24,7m >100 LU	Permeability Interval (in metres) and LU values
5,0 kN ⧗ 11,0 MPa	Point Load Test (PLT) kN = average readings from point load test MPa = point load strength index IS 50
I 3" ODEX I	Cuttings samples
▌	Casing

Explanations of formation

FG	Finiglacial
GT	Glacial till
SB	Sámsstaðarklif basalt
SM	Sámsstaðarmúli group
OB	Older Búrfell group

Q - system of rock mass quality

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

RQD (Rock Quality Designation)

Jn (joint set number)

Jr (joint roughness number)

Ja (joint alteration number)

Jw (joint water reduction factor)

SRF (Stress Reduction Factor)

$$Q_c = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Jw and SRF are evaluated as 1/1 in the boreholes

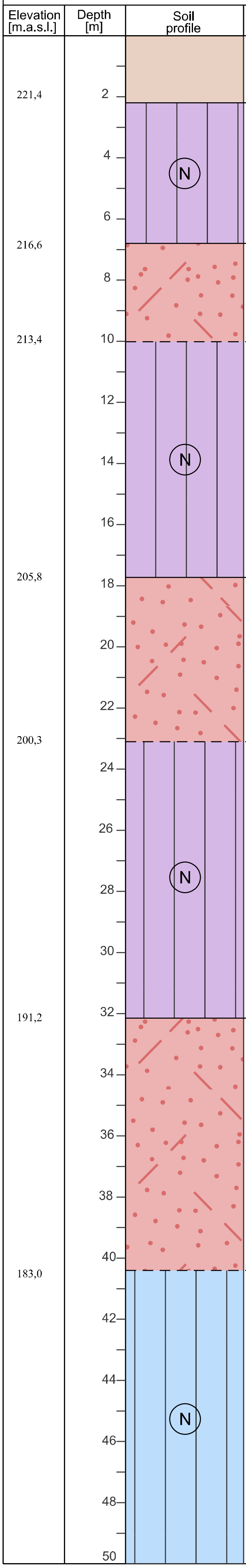
Q_c = Q evaluated from core sample from borehole

Búrfell HEP Extension

BF-1
Cored Hole

Contractor:	Jarðboranir
Drill	Niðandi (S5)
Place:	Sámsstaðir
Drill thickness:	55 mm/BQ 36,5 mm core
Date of drilling:	2/6 - 8/7 1980
Drawn:	AKS
Drawing nr.:	1 of 4
Approved:	SPS

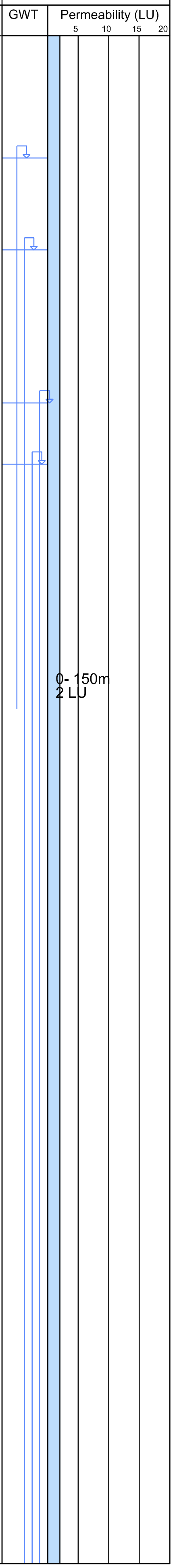
Coordinates: ISN93 X: 460838,804 Y: 400321,516 Elev.: 223,40 m.a.s.l.



Depth [m]	Sample	Description
0–2,2		**Overburden** Rock fragments and pebbles, from the bedrock below.
2,2–6,8	Vesicular Dense	**Basaltic Andesite** **Top OB** Strongly flowbanded, breaks along flowbanding. Dark, very fine grained, hard and heavy, flowbanding irregular in the top, almost horizontal below 4 m. Secondary mineral mostly opal. 3 joint directions, joints coated/filled with opal and/or light colored secondary minerals. $Qc = \frac{27}{9\text{-}12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 1,1\text{-}3$
6,8–10	**Scoria**	Reddish in color, vesicular, filled with silt/opal. Highly jointed, slightly denser toward bottom. $Qc = \frac{10}{12\text{-}15} \times \frac{3\text{-}4}{3\text{-}4} \times \frac{1}{1} = 0,5\text{-}1,1$
10–17,6	Vesicular Dense	**Basaltic Andesite** Dark, very fine grained, joints coated. $Qc = \frac{27}{12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 1,1\text{-}2,3$
17,6–23,1	**Scoria**	Core recovery poor, irregular fragments of scoria filled with silt. $Qc = \frac{10}{12\text{-}15} \times \frac{3}{3\text{-}4} \times \frac{1}{1} = 0,5\text{-}0,8$
23,1–32,2	Scoracious Vesicular Slightly vesicular	**Basaltic Andesite** Spotty appearance, dark, very fine grained, flowbanded. Elongated vesicles, very jointed, joints break along flowband direction. Upperpart very jointed. Joints partly filled with opal/silt. $Qc = \frac{10}{12} \times \frac{3}{3\text{-}4} \times \frac{1}{1} = 0,6\text{-}0,8$
32,2–40,4	**Scoria** Very jointed Vesicular Very jointed	Vesicular, filled with opal/silt, thick fillings. Very jointed, light in hand. $Qc = \frac{17}{12\text{-}15} \times \frac{3}{3\text{-}4} \times \frac{1}{1} = 0,9\text{-}1,4$
40,4–50	Slightly vesicular fine vesicles Dense	**Tholeiite Basalt** Micro phenocrysts present, joints coated or filled with light colored secondary minerals. $Qc = \frac{19}{12\text{-}15} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 0,6\text{-}1,6$

Casing PLT: Casing probably down to 5m

Core [%]	RQD % 10/30/50/100
7	0/0/0/0
17	0/0/0/0
25	0/0/0/0
75	0/0/0/0
124	0/0/0/0
88	23/0/0/0
87	70/0/0/0
96	62/0/0/0
108	34/0/0/0
	27/6/0/0
93	47/19/0/0
85	0/0/0/0
60	0/0/0/0
	0/0/0/0
79	
91	39/0/0/0
90	43/0/0/0
	27/0/0/0
82	26/0/0/0
250	0/0/0/0
94	23/0/0/0
87	0/0/0/0
39	0/0/0/0
	0/0/0/0
16	0/0/0/0
8	0/0/0/0
33	0/0/0/0
50	0/0/0/0
62	9/0/0/0
21	0/0/0/0
56	0/0/0/0
66	22/0/0/0
67	0/0/0/0
	7/0/0/0
85	21/0/0/0
62	0/0/0/0
70	0/0/0/0
82	0/0/0/0
67	0/0/0/0
40	0/0/0/0
40	
61	0/0/0/0
28	0/0/0/0
38	0/0/0/0
55	0/0/0/0
52	11/0/0/0
71	28/0/0/0
	17/0/0/0
85	47/0/0/0
73	0/0/0/0
93	0/0/0/0
60	18/0/0/0
86	58/0/0/0
64	22/0/0/0
35	0/0/0/0
74	17/0/0/0
	19/0/0/0
69	0/0/0/0
82	12/0/0/0
100	0/0/0/0
42	0/0/0/0
15	0/0/0/0



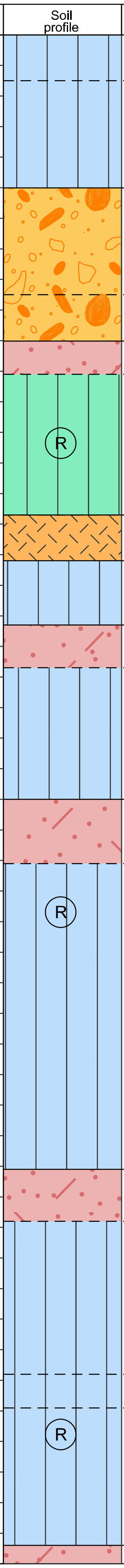
Reference: Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-80/02.
Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-81/01.

Búrfell HEP Extension

BF-1
Cored Hole

Contractor:	Jarðboranir	Drill	Niðandi (S5)
Place:	Sámsstaðir	Drill thickness:	BQ 36,5 mm core
Date of drilling:	2/6 - 8/7 1980	Drawn:	AKS
Drawing nr.:	2 of 4	Approved:	SPS

Coordinates: ISN93 X: 460838,804 Y: 400321,516 Elev.: 223,40 m.a.s.l.

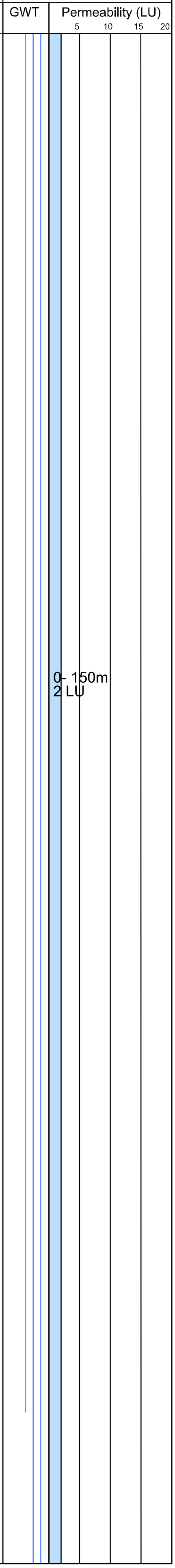


Elevation [m.a.s.l.]	Sample	Description
171,9	Dense	
168,4	Fine	**Conglomerate** Groundmass sandy, zeolites in micropores, pebbles 2-4 cm of various origin. Blend of rounded or subrounded pebbles. Layer is jointed some core loss. Upper part well cemented. $Qc = \frac{30}{9\text{-}12} \times \frac{1\text{-}1{,}5}{3} \times \frac{1}{1} = 0{,}8\text{-}1{,}7$
164,9	Coarse Hole collapsed after drilling	Pebbles more angular, rock fragments 5-25 cm. Silt lenses present, lower part seems to be more fragile.
163,4	**Scoria**	Filled with reddish colored sand.
162,3	Sound Very jointed	**Porphyritic Basalt** **4-6%** Phenochrysts 1-2 mm plg. Variably vesicular, zeolites, joints coated or filled, sand lenses toward bottom. $Qc = \frac{36}{9} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 2\text{-}4$
157,7		**Acid Tuff** $Qc = \frac{23}{9\text{-}12} \times \frac{1\text{-}1{,}5}{3\text{-}4} \times \frac{1}{1} = 0{,}5\text{-}1{,}3$ Light in hand, dark and light grains in upper part, vague layering, 40 cm weak layering. Bottom 30 cm sandstone. Poorly cemented, breaks in hand.
156,2	Vesicular	**Tholeiite Basalt** Dark brownish in color and very fine grained. Vesicles up to 15 mm, joints coated with opal and brownish secondary minerals.
154,1	**Scoria**	Sandy fillings, light in hand, poorly cemented. $Qc = \frac{18}{12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 0{,}8\text{-}1{,}5$
152,7	Core eroded	**Tholeiite Basalt** Poor core recovery. Layer breaks up. Vesicular, jointed, core is eroded 73,8-74,1m. Coated/filled joints, light colored secondary minerals.
148,4	**Scoria**	Well consolidated, jointed, core eroded during drilling. Vesicular, vesicles half filled with opal and light secondary minerals. Light in hand. $Qc = \frac{44}{9\text{-}12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 1{,}9\text{-}4{,}9$
145,7	Vesicular	**Tholeiite Basalt** Fine to medium grained, dark gray. A bit brownish, vesicular, with medium to fine vesicles, vesicles coated with opal and some zeolites or calsedony. $Qc = \frac{21}{12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 0{,}9\text{-}1{,}8$
136,3	**Scoria**	Poorly cemented, fine vesicles, coated/filled joints, reddish in color. Large vesicles in the lower part, vesicles filled/coated. $Qc = \frac{12}{12\text{-}15} \times \frac{3}{3\text{-}4} \times \frac{1}{1} = 0{,}6\text{-}1{,}0$
134,6	Vesicular	**Tholeiite Basalt** Jointed, joints coated/filled with opal and brownish secondary clay minerals. Fine grained, gray in color. $Qc = \frac{15}{12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 0{,}6\text{-}1{,}3$
129,6	Scoracious	
128,5	Vesicular	**Tholeiite Basalt** Fine grained, very jointed.
124,0	**Scoria**	Reddish filled with silt. Core loss. Breaks in hand.

Depth [m]: 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100

Casing PLT

Core [%]	RQD % Qc 10/30/50/100
15	0/0/0/0
50	0/0/0/0
50	0/0/0/0
53	37/0/0/0
35	0/0/0/0
6	0/0/0/0
92	38/0/0/0
102	43/0/0/0
90	64/0/0/0
	30/0/0/0
92	23/0/0/0
99	23/0/0/0
100	0/0/0/0
84	0/0/0/0
85	60/52/0/0
	36/17/0/0
71	47/15/0/0
64	17/0/0/0
87	38/0/0/0
	23/0/0/0
83	23/0/0/0
65	0/0/0/0
74	51/17/0/0
62	14/0/0/0
	18/4/0/0
11	0/0/0/0
17	0/0/0/0
92	26/0/0/0
110	27/0/0/0
	44/0/0/0
93	44/0/0/0
93	34/15/0/0
93	37/14/0/0
	21/0/0/0
50	0/0/0/0
74	0/0/0/0
97	10/0/0/0
52	8/0/0/0
82	0/0/0/0
67	0/0/0/0
27	0/0/0/0
	12/0/0/0
70	35/0/0/0
88	29/0/0/0
50	0/0/0/0
93	0/0/0/0
90	13/0/0/0
62	18/0/0/0
55	0/0/0/0
	15/0/0/0
89	21/0/0/0
79	0/0/0/0
91	0/0/0/0

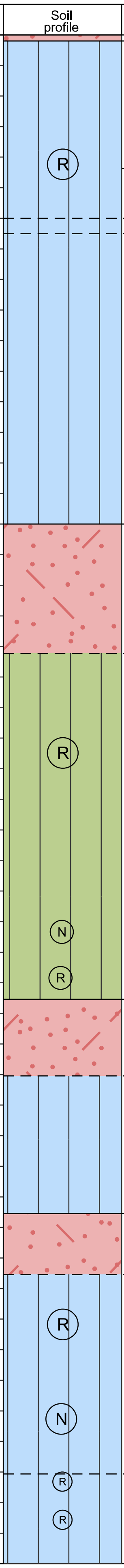


Reference: Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-80/02.
Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-81/01.

Almenna verkfræðistofan	# Búrfell HEP Extension
Landsvirkjun	BF-1 Cored Hole

Contractor: Jarðboranir	Drill: Niðandi (S5)
Place: Sámsstaðir	Drill thickness: BQ 36,5 mm core
Date of drilling: 2/6 - 8/7 1980	Drawn: AKS
Drawing nr.: 3 of 4	Approved: SPS

Coordinates: ISN93 X: 460838,804 Y: 400321,516 Elev.: 223,40 m.a.s.l.

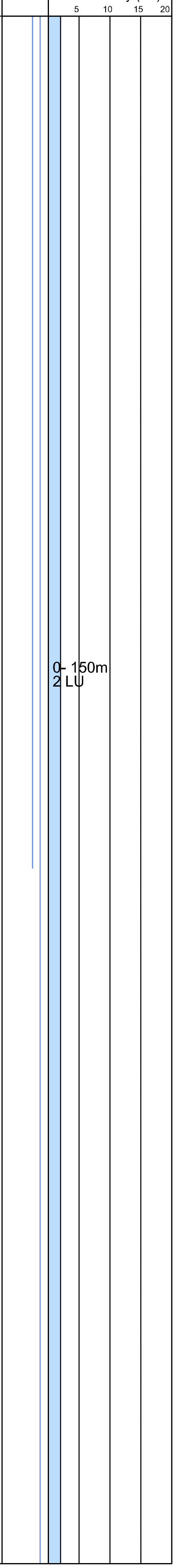


Elevation [m.a.s.l.]	Sample	Description
123,2		**Scoria**
121,9	Vesicular Dense	**Tholeiite Basalt** Gray, joints coated, the dense part is heavy, fine to small grained.
117,4		**Scoria**
116,9		**Tholeiite Basalt** Medium grained, flow banded, dark gray, bit brownish. Joints coated/filled with light or brownish secondary minerals. Considerably jointed. $Qc = \frac{37}{12} x \frac{2-3}{3-4} x \frac{1}{1} = 1,5-3,1$
107,4	**Scoria**	Reddish, vesicular, breaks between hands. Joints filled with silt. $Qc = \frac{28}{12-15} x \frac{3}{3-4} x \frac{1}{1} = 1,4-2,2$
103,2	Slightly flow banded Dense	**Olivine Basalt** Slightly porphyritic, phenochrysts plg, max 1mm. Medium grained. Joints coated to filled with clay minerals. Light brownish secondary minerals. Gray in color. Joint fillings up to 1mm. $Qc = \frac{33}{12} x \frac{2-3}{3-4} x \frac{1}{1} = 1,4-2,8$
91,9	**Scoria**	Breaks between hands, filled with silt. $Qc = \frac{62}{12} x \frac{3}{3-4} x \frac{1}{1} = 3,9-5,2$
87,9	Scoracious	**Tholeiite Basalt** Fine grained, flow banded. $Qc = \frac{37}{9-12} x \frac{3}{3-4} x \frac{1}{1} = 2,3-4,1$
84,9	**Scoria**	Very jointed, filled with silt, basaltic stones up to 10cm, joints coated/filled with thick silt fillings in places. $Qc = \frac{14}{12} x \frac{3}{3-4} x \frac{1}{1} = 0,9-1,2$
82,9	Sparsly vesicular	**Tholeiite Basalt** Dark gray, fine to medium grained. Slightly flowbanded, coated/filled joints. $Qc = \frac{28}{12} x \frac{2-3}{3-4} x \frac{1}{1} = 1,2-2,3$
76,3	Scoracious	**Scoracious Tholeiite Basalt**

Depth [m]: 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126, 128, 130, 132, 134, 136, 138, 140, 142, 144, 146, 148, 150

Core [%]	RQD % 10/30/50/100 Qc
91	0/0/0/0
85	39/0/0/0
92	62/21/0/0
100	97/0/0/0
17	0/0/0/0
60	0/0/0/0
96	38/0/0/0
	37/12/0/0
93	42/23/0/0
90	20/0/0/0
91	44/36/0/0
92	48/0/0/0
	28/0/0/0
74	27/0/0/0
77	0/0/0/0
86	22/0/0/0
93	0/0/0/0
89	0/0/0/0
78	25/0/0/0
86	36/0/0/0
84	17/0/0/0
88	30/0/0/0
	33/3/0/0
70	12/0/0/0
95	75/0/0/0
60	0/0/0/0
93	45/0/0/0
92	41/0/0/0
218	93/52/0/0
	62/14/0/0
92	60/15/0/0
100	100/0/0/0
96	46/0/0/0
	37/15/0/0
81	29/14/0/0
76	0/0/0/0
20	0/0/0/0
	14/0/0/0
85	20/0/0/0
94	20/0/0/0
92	35/0/0/0
	28/0/0/0
88	17/0/0/0
40	0/0/0/0
87	34/0/0/0
58	0/0/0/0
76	14/0/0/0
25	0/0/0/0
52	12/0/0/0
97	59/0/0/0

GWT | Permeability (LU)



Reference: Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-80/02.
Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-81/01.

Almenna verkfræðistofan

Landsvirkjun

Búrfell HEP Extension

BF-1
Cored Hole

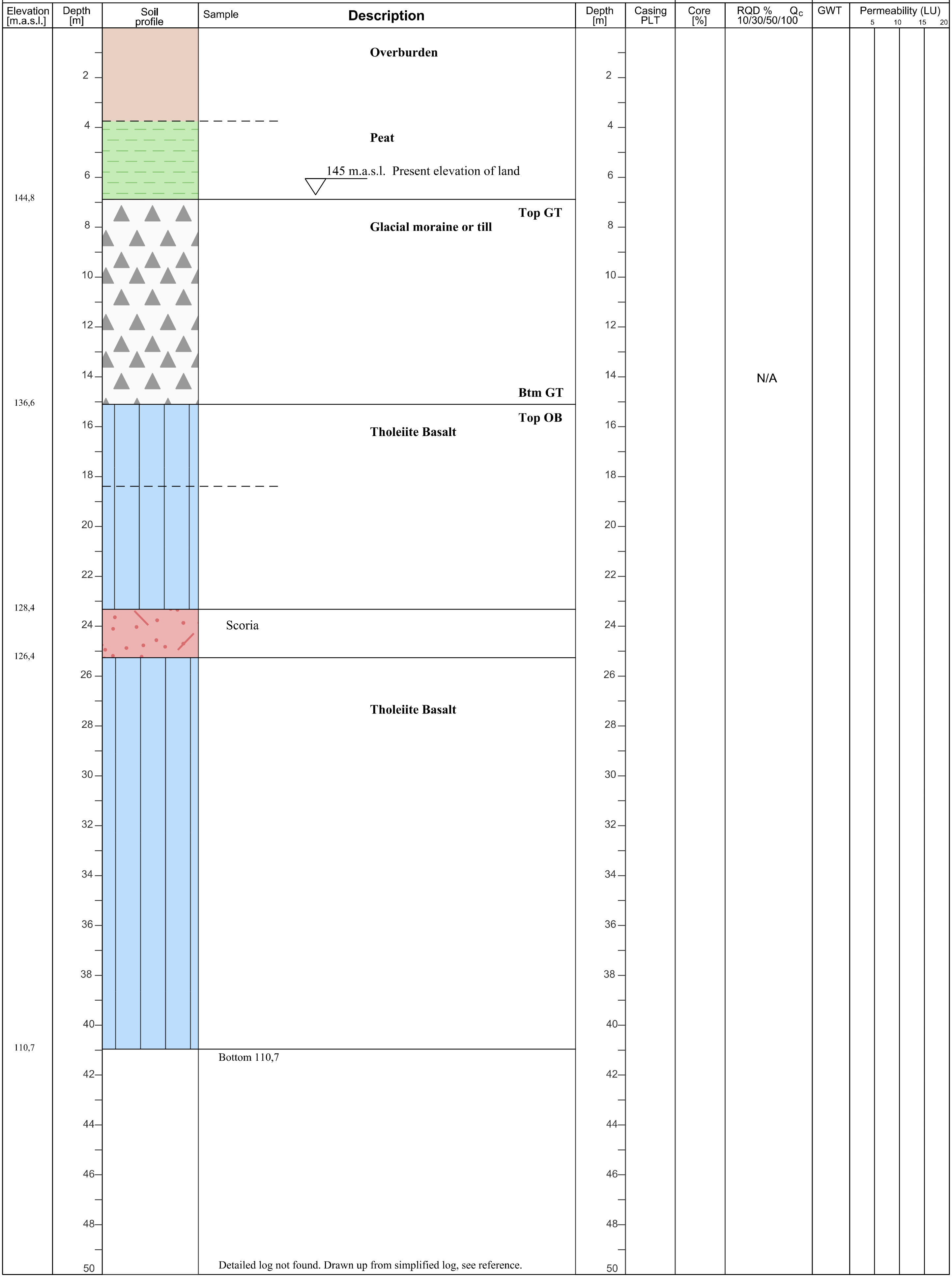
Contractor: Jarðboranir	Drill Niðandi (S5)		
Place: Sámsstaðir	Drill thickness: BQ 36,5 mm core		
Date of drilling: 2/6 - 8/7 1980	Drawn: AKS		
Drawing nr.: 4 of 4	Approved: SPS		

Coordinates: ISN93 X: 460838,804 Y: 400321,516 Elev.: 223,40 m.a.s.l.

Elevation [m.a.s.l.]	Depth [m]	Soil profile	Sample	Description	Depth [m]	Casing PLT	Core [%]	RQD % 10/30/50/100 Q_c	GWT	Permeability (LU) 5 10 15 20
				Tholeiite Basalt continued Vesicular, coated/filled with light colored secondary minerals. Slightly flowbanded.			97	59/0/0/0		
71,9										
	152			Bottom 71,9	152					
	154				154					
	156				156					
	158				158					
	160				160					
	162				162					
	164				164					
	166				166					
	168				168					
	170				170					
	172				172					
	174				174					
	176				176					
	178				178					
	180				180					
	182				182					
	184				184					
	186				186					
	188				188					
	190				190					
	192				192					
	194				194					
	196				196					
	198				198					
	200				200					

Reference: Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-80/02.
Jarðfræði Sámstaðaklifs, Snorri Páll Snorrason, SPS-81/01.

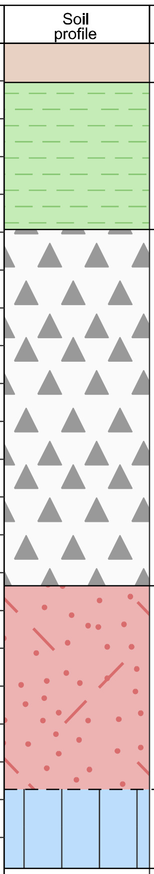
Almenna verkfræðistofan Landsvirkjun	Búrfell HEP Extension BF-02 Cored Hole	Contractor: Jarðboranir ríkisins	Drill: Drífandi (C1)
		Place: Sámsstaðir	Drill thickness: NQ 47,6 mm
		Date of drilling: 13/10 - 18/10 1981	Drawn: AKS
Coordinates: ISN93 X: 460714,32 Y: 400005,24 Elev.: 151,7 m.a.s.l.		Drawing nr.: 1 af 1	Approved: SPS



Detailed log not found. Drawn up from simplified log, see reference.

Reference: Búrfell II, Bjarni Bjarnason, OS-83059/VOD-29, July 1983.

Almenna verkfræðistofan	Búrfell HEP Extension	Contractor: Jarðboranir ríkisins	Drill Percussion
Landsvirkjun	BF-10 Percussion Hole	Place: Sámsstaðir	Drill thickness:
		Date of drilling: 30/9 - 13/10 1982	Drawn: AKS
Coordinates: ISN93 X: 460688,28 Y: 399988,09 Elev.: 148,1 m.a.s.l.		Drawing nr.: 1 af 1	Approved: SPS



Elevation [m.a.s.l.]	Depth [m]	Soil profile	Sample	Description	Depth [m]	Casing PLT	Core [%]	RQD % Q_C 10/30/50/100	GWT	Permeability (LU) 5 10 15 20
147,1				**Overburden**						
143,2	2 4			**Peat** 143 m.a.s.l. Present elevation of land	2 4					
133,8	6 8 10 12 14			**Top GT** **Glacial moraine or till** **Btm GT**	6 8 10 12 14			N/A		
128,4	16 18 20		Scoria	**Top OB**	16 18 20					
126,3	22			**Tholeiite Basalt**	22					
	24 26 28 30 32 34 36 38 40 42 44 46 48 50			Bottom 126,3 Detailed log not found. Drawn up from simplified log, see reference.	24 26 28 30 32 34 36 38 40 42 44 46 48 50					

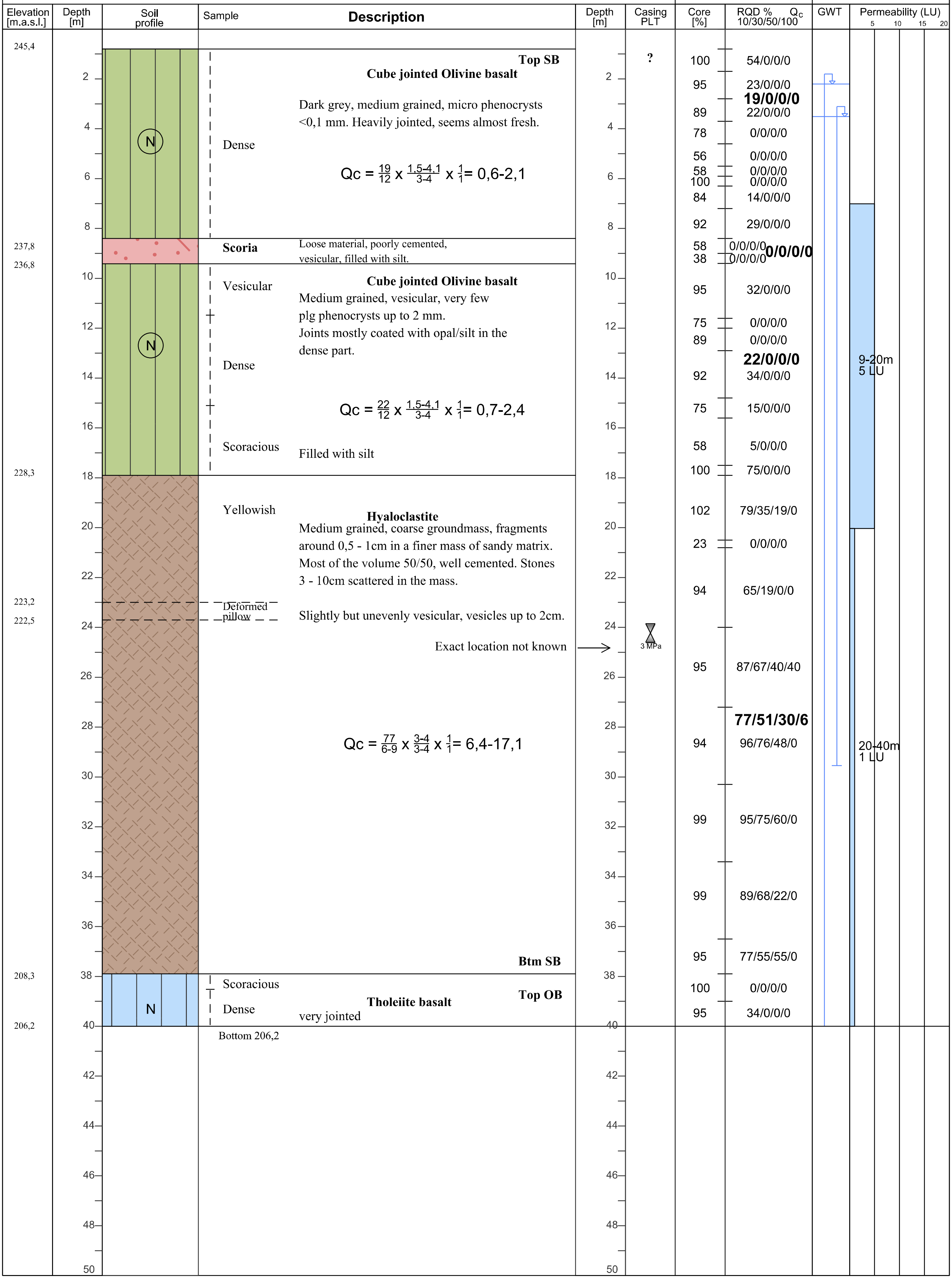
Reference: Búrfell II, Bjarni Bjarnason, OS-83059/VOD-29, July 1983.

Búrfell HEP Extension

BF-18
Cored Hole

Contractor: Jarðboranir ríkisins	Drill: Dugandi (C2)
Place: Sámsstaðir	Drill thickness: NQ 47,6 mm core
Date of drilling: 3/6 - 7/6 1983	Drawn: AKS
Drawing nr.: 1 af 1	Approved: SPS

Coordinates: ISN93 X: 460947,63 Y: 400471,32 Elev.: 246,24 m.a.s.l.



Top SB

Cube jointed Olivine basalt

Dense

Dark grey, medium grained, micro phenocrysts <0,1 mm. Heavily jointed, seems almost fresh.

$$Qc = \frac{19}{12} \times \frac{1,5\text{-}4,1}{3\text{-}4} \times \frac{1}{1} = 0,6\text{-}2,1$$

Scoria

Loose material, poorly cemented, vesicular, filled with silt.

Vesicular

Cube jointed Olivine basalt

Medium grained, vesicular, very few plg phenocrysts up to 2 mm. Joints mostly coated with opal/silt in the dense part.

Dense

$$Qc = \frac{22}{12} \times \frac{1,5\text{-}4,1}{3\text{-}4} \times \frac{1}{1} = 0,7\text{-}2,4$$

Scoracious

Filled with silt

Yellowish

Hyaloclastite

Medium grained, coarse groundmass, fragments around 0,5 - 1cm in a finer mass of sandy matrix. Most of the volume 50/50, well cemented. Stones 3 - 10cm scattered in the mass.

Deformed pillow

Slightly but unevenly vesicular, vesicles up to 2cm.

Exact location not known →

$$Qc = \frac{77}{6\text{-}9} \times \frac{3\text{-}4}{3\text{-}4} \times \frac{1}{1} = 6,4\text{-}17,1$$

Btm SB

Scoracious

Top OB

Tholeiite basalt

Dense

very jointed

Bottom 206,2

Reference: Búrfell II, Bjarni Bjarnason, OS-83059/VOD-29, July 1983.

Almenna verkfræðistofan

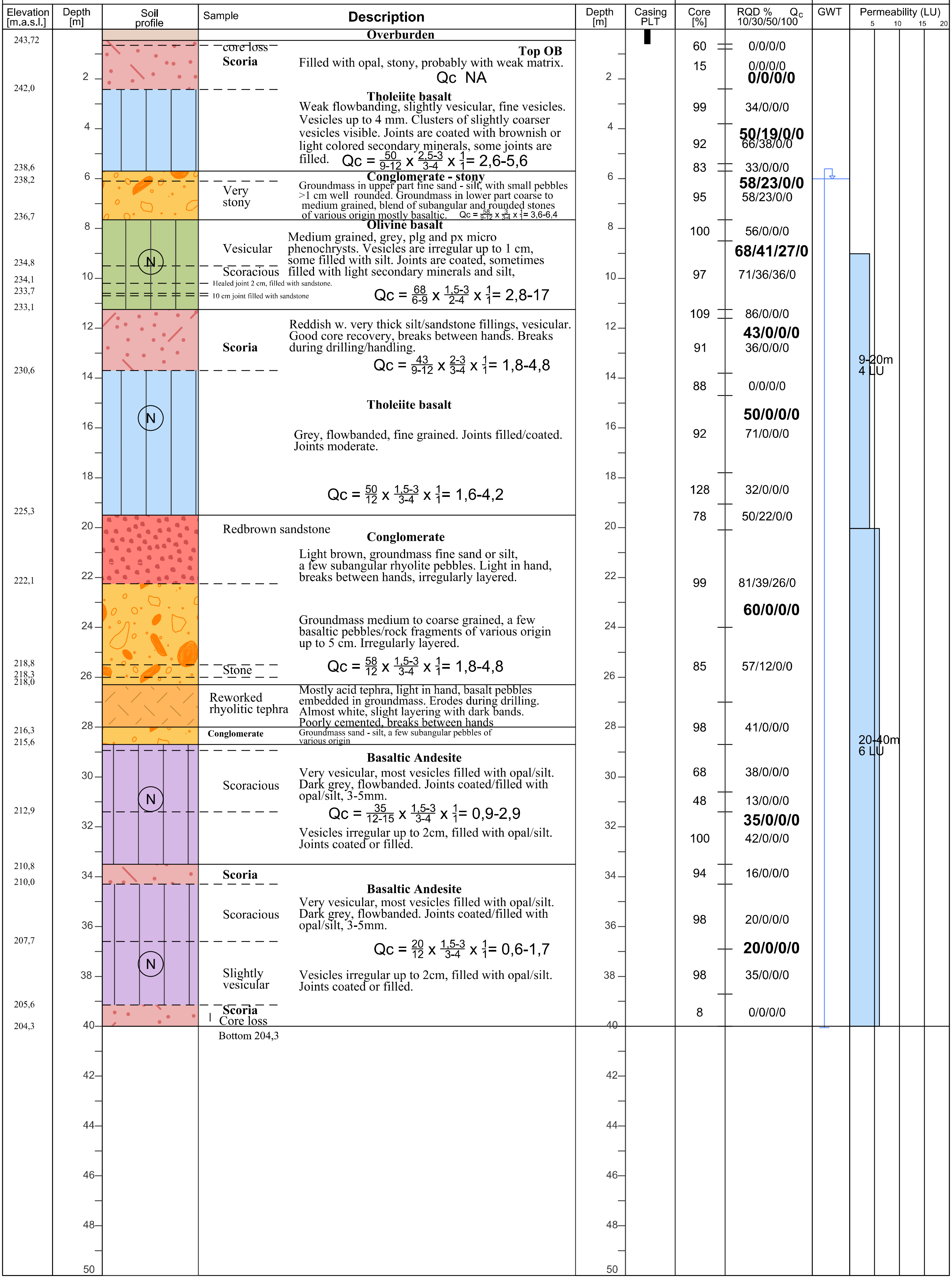
Landsvirkjun

Búrfell HEP Extension

BF-19
Cored Hole

Contractor: Jarðboranir ríkisins	Drill: Dugandi (C2)		
Place: Sámsstaðir	Drill thickness: NQ 47,6 mm core		
Date of drilling: 26/5 - 2/6 1983	Drawn: AKS		
Drawing nr.: 1 af 1	Approved: SPS		

Coordinates: ISN93 X: 460902,62 Y: 400380,69 Elev.: 244,32 m.a.s.l.



Overburden

core loss

Scoria — **Top OB**
Filled with opal, stony, probably with weak matrix.
Qc NA

Tholeiite basalt
Weak flowbanding, slightly vesicular, fine vesicles. Vesicles up to 4 mm. Clusters of slightly coarser vesicles visible. Joints are coated with brownish or light colored secondary minerals, some joints are filled. $Qc = \frac{50}{9\text{-}12} \times \frac{2{,}5\text{-}3}{3\text{-}4} \times \frac{1}{1} = 2{,}6\text{-}5{,}6$

Very stony — **Conglomerate - stony**
Groundmass in upper part fine sand - silt, with small pebbles >1 cm well rounded. Groundmass in lower part coarse to medium grained, blend of subangular and rounded stones of various origin mostly basaltic. $Qc = \frac{58}{9\text{-}12} \times \frac{3}{3\text{-}4} \times \frac{1}{1} = 3{,}6\text{-}6{,}4$

Olivine basalt
Vesicular
Scoracious
Medium grained, grey, plg and px micro phenochrysts. Vesicles are irregular up to 1 cm, some filled with silt. Joints are coated, sometimes filled with light secondary minerals and silt,
Healed joint 2 cm, filled with sandstone.
10 cm joint filled with sandstone
$Qc = \frac{68}{6\text{-}9} \times \frac{1{,}5\text{-}3}{2\text{-}4} \times \frac{1}{1} = 2{,}8\text{-}17$

Scoria
Reddish w. very thick silt/sandstone fillings, vesicular. Good core recovery, breaks between hands. Breaks during drilling/handling.
$Qc = \frac{43}{9\text{-}12} \times \frac{2\text{-}3}{3\text{-}4} \times \frac{1}{1} = 1{,}8\text{-}4{,}8$

Tholeiite basalt
Grey, flowbanded, fine grained. Joints filled/coated. Joints moderate.
$Qc = \frac{50}{12} \times \frac{1{,}5\text{-}3}{3\text{-}4} \times \frac{1}{1} = 1{,}6\text{-}4{,}2$

Redbrown sandstone — **Conglomerate**
Light brown, groundmass fine sand or silt, a few subangular rhyolite pebbles. Light in hand, breaks between hands, irregularly layered.

Groundmass medium to coarse grained, a few basaltic pebbles/rock fragments of various origin up to 5 cm. Irregularly layered.
$Qc = \frac{58}{12} \times \frac{1{,}5\text{-}3}{3\text{-}4} \times \frac{1}{1} = 1{,}8\text{-}4{,}8$

Stone

Reworked rhyolitic tephra
Mostly acid tephra, light in hand, basalt pebbles embedded in groundmass. Erodes during drilling. Almost white, slight layering with dark bands. Poorly cemented, breaks between hands

Conglomerate
Groundmass sand - silt, a few subangular pebbles of various origin

Scoracious — **Basaltic Andesite**
Very vesicular, most vesicles filled with opal/silt. Dark grey, flowbanded. Joints coated/filled with opal/silt, 3-5mm.
$Qc = \frac{35}{12\text{-}15} \times \frac{1{,}5\text{-}3}{3\text{-}4} \times \frac{1}{1} = 0{,}9\text{-}2{,}9$
Vesicles irregular up to 2cm, filled with opal/silt. Joints coated or filled.

Scoria

Scoracious — **Basaltic Andesite**
Very vesicular, most vesicles filled with opal/silt. Dark grey, flowbanded. Joints coated/filled with opal/silt, 3-5mm.
$Qc = \frac{20}{12} \times \frac{1{,}5\text{-}3}{3\text{-}4} \times \frac{1}{1} = 0{,}6\text{-}1{,}7$
Slightly vesicular
Vesicles irregular up to 2cm, filled with opal/silt. Joints coated or filled.

Scoria
Core loss
Bottom 204,3

Core [%]	RQD % Q_c 10/30/50/100
60	0/0/0/0
15	0/0/0/0
	0/0/0/0
99	34/0/0/0
	50/19/0/0
92	66/38/0/0
83	33/0/0/0
	58/23/0/0
95	58/23/0/0
100	56/0/0/0
	68/41/27/0
97	71/36/36/0
109	86/0/0/0
	43/0/0/0
91	36/0/0/0
88	0/0/0/0
	50/0/0/0
92	71/0/0/0
128	32/0/0/0
78	50/22/0/0
99	81/39/26/0
	60/0/0/0
85	57/12/0/0
98	41/0/0/0
68	38/0/0/0
48	13/0/0/0
	35/0/0/0
100	42/0/0/0
94	16/0/0/0
98	20/0/0/0
	20/0/0/0
98	35/0/0/0
8	0/0/0/0

Reference: Búrfell II, Bjarni Bjarnason, OS-83059/VOD-29, July 1983.

Almenna verkfræðistofan

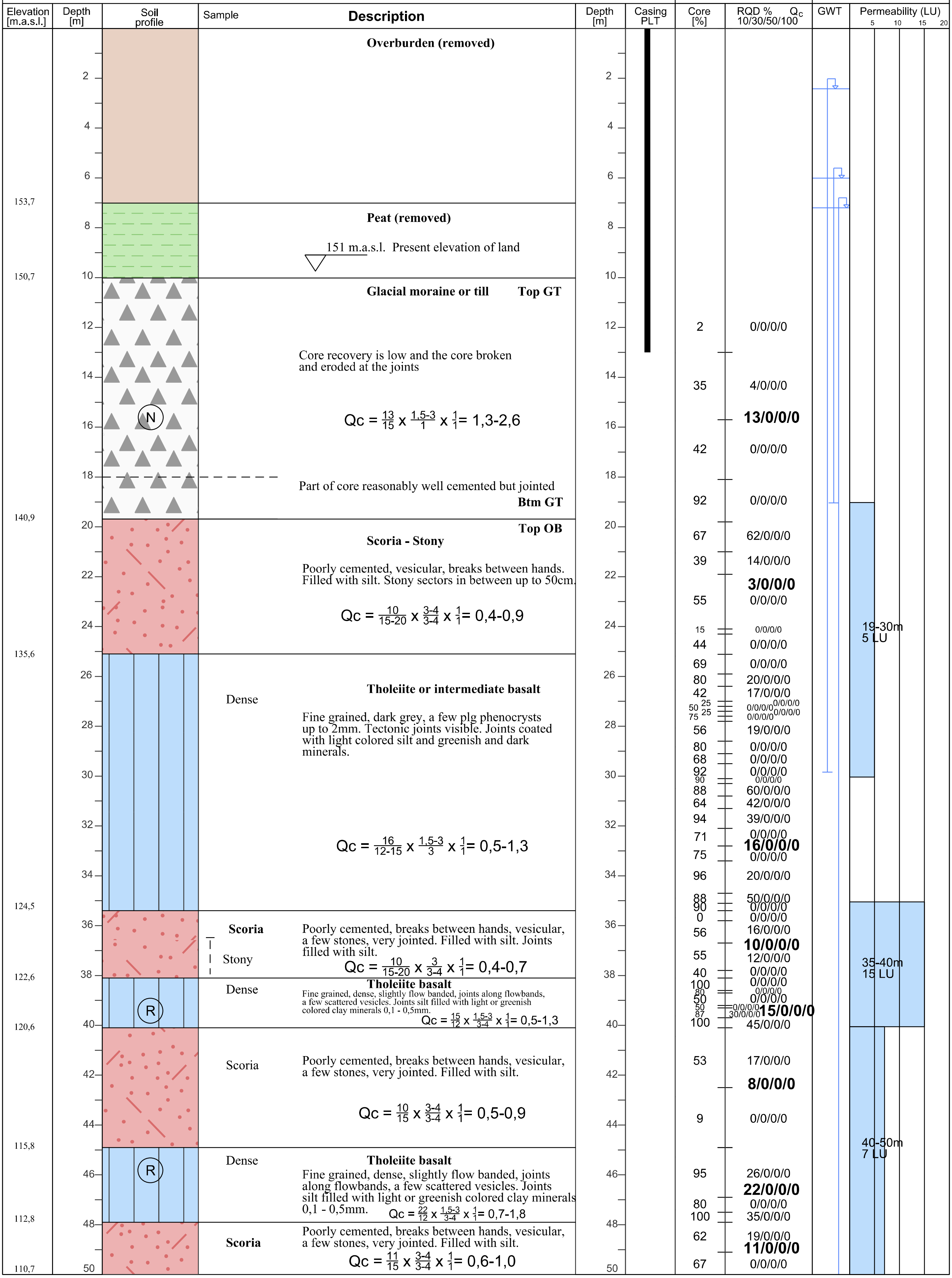
Landsvirkjun

Búrfell HEP Extension

BF-20
Cored Hole

Contractor:	Jarðboranir ríkisins
Drill	Dugandi (C2)
Place:	Sámsstaðir
Drill thickness:	NQ 47,6 mm core
Date of drilling:	8/6 - 19/6 1983
Drawn:	AKS
Drawing nr.:	1 af 1
Approved:	SPS

Coordinates: ISN93 X: 460674,67 Y: 400024,83 Elev.: 160,74 m.a.s.l.



Overburden (removed)

Peat (removed)

151 m.a.s.l. Present elevation of land

Glacial moraine or till **Top GT**

Core recovery is low and the core broken and eroded at the joints

$Qc = \frac{13}{15} \mathrm{x} \frac{1,5\text{-}3}{1} \mathrm{x} \frac{1}{1} = 1,3\text{-}2,6$

Part of core reasonably well cemented but jointed

Btm GT

Top OB

Scoria - Stony

Poorly cemented, vesicular, breaks between hands. Filled with silt. Stony sectors in between up to 50cm.

$Qc = \frac{10}{15\text{-}20} \mathrm{x} \frac{3\text{-}4}{3\text{-}4} \mathrm{x} \frac{1}{1} = 0,4\text{-}0,9$

Dense

Tholeiite or intermediate basalt

Fine grained, dark grey, a few plg phenocrysts up to 2mm. Tectonic joints visible. Joints coated with light colored silt and greenish and dark minerals.

$Qc = \frac{16}{12\text{-}15} \mathrm{x} \frac{1,5\text{-}3}{3} \mathrm{x} \frac{1}{1} = 0,5\text{-}1,3$

Scoria

Stony

Poorly cemented, breaks between hands, vesicular, a few stones, very jointed. Filled with silt. Joints filled with silt.

$Qc = \frac{10}{15\text{-}20} \mathrm{x} \frac{3}{3\text{-}4} \mathrm{x} \frac{1}{1} = 0,4\text{-}0,7$

Dense

Tholeiite basalt

Fine grained, dense, slightly flow banded, joints along flowbands, a few scattered vesicles. Joints silt filled with light or greenish colored clay minerals 0,1 - 0,5mm.

$Qc = \frac{15}{12} \mathrm{x} \frac{1,5\text{-}3}{3\text{-}4} \mathrm{x} \frac{1}{1} = 0,5\text{-}1,3$

Scoria

Poorly cemented, breaks between hands, vesicular, a few stones, very jointed. Filled with silt.

$Qc = \frac{10}{15} \mathrm{x} \frac{3\text{-}4}{3\text{-}4} \mathrm{x} \frac{1}{1} = 0,5\text{-}0,9$

Dense

Tholeiite basalt

Fine grained, dense, slightly flow banded, joints along flowbands, a few scattered vesicles. Joints silt filled with light or greenish colored clay minerals 0,1 - 0,5mm.

$Qc = \frac{22}{12} \mathrm{x} \frac{1,5\text{-}3}{3\text{-}4} \mathrm{x} \frac{1}{1} = 0,7\text{-}1,8$

Scoria

Poorly cemented, breaks between hands, vesicular, a few stones, very jointed. Filled with silt.

$Qc = \frac{11}{15} \mathrm{x} \frac{3\text{-}4}{3\text{-}4} \mathrm{x} \frac{1}{1} = 0,6\text{-}1,0$

Core [%]	RQD % Qc 10/30/50/100
2	0/0/0/0
35	4/0/0/0
	13/0/0/0
42	0/0/0/0
92	0/0/0/0
67	62/0/0/0
39	14/0/0/0
	3/0/0/0
55	0/0/0/0
15	0/0/0/0
44	0/0/0/0
69	0/0/0/0
80	20/0/0/0
42	17/0/0/0
25	0/0/0/0
50	0/0/0/0
25	0/0/0/0
75	0/0/0/0
56	19/0/0/0
80	0/0/0/0
68	0/0/0/0
92	0/0/0/0
90	0/0/0/0
88	60/0/0/0
64	42/0/0/0
94	39/0/0/0
71	0/0/0/0
	16/0/0/0
75	0/0/0/0
96	20/0/0/0
88	50/0/0/0
90	0/0/0/0
0	0/0/0/0
56	16/0/0/0
	10/0/0/0
55	12/0/0/0
40	0/0/0/0
100	0/0/0/0
80	0/0/0/0
50	0/0/0/0
50	0/0/0/0
87	30/0/0/0
	15/0/0/0
100	45/0/0/0
53	17/0/0/0
	8/0/0/0
9	0/0/0/0
95	26/0/0/0
	22/0/0/0
80	0/0/0/0
100	35/0/0/0
62	19/0/0/0
	11/0/0/0
67	0/0/0/0

Reference: Búrfell II, Bjarni Bjarnason, OS-83059/VOD-29, July 1983.

Almenna verkfræðistofan

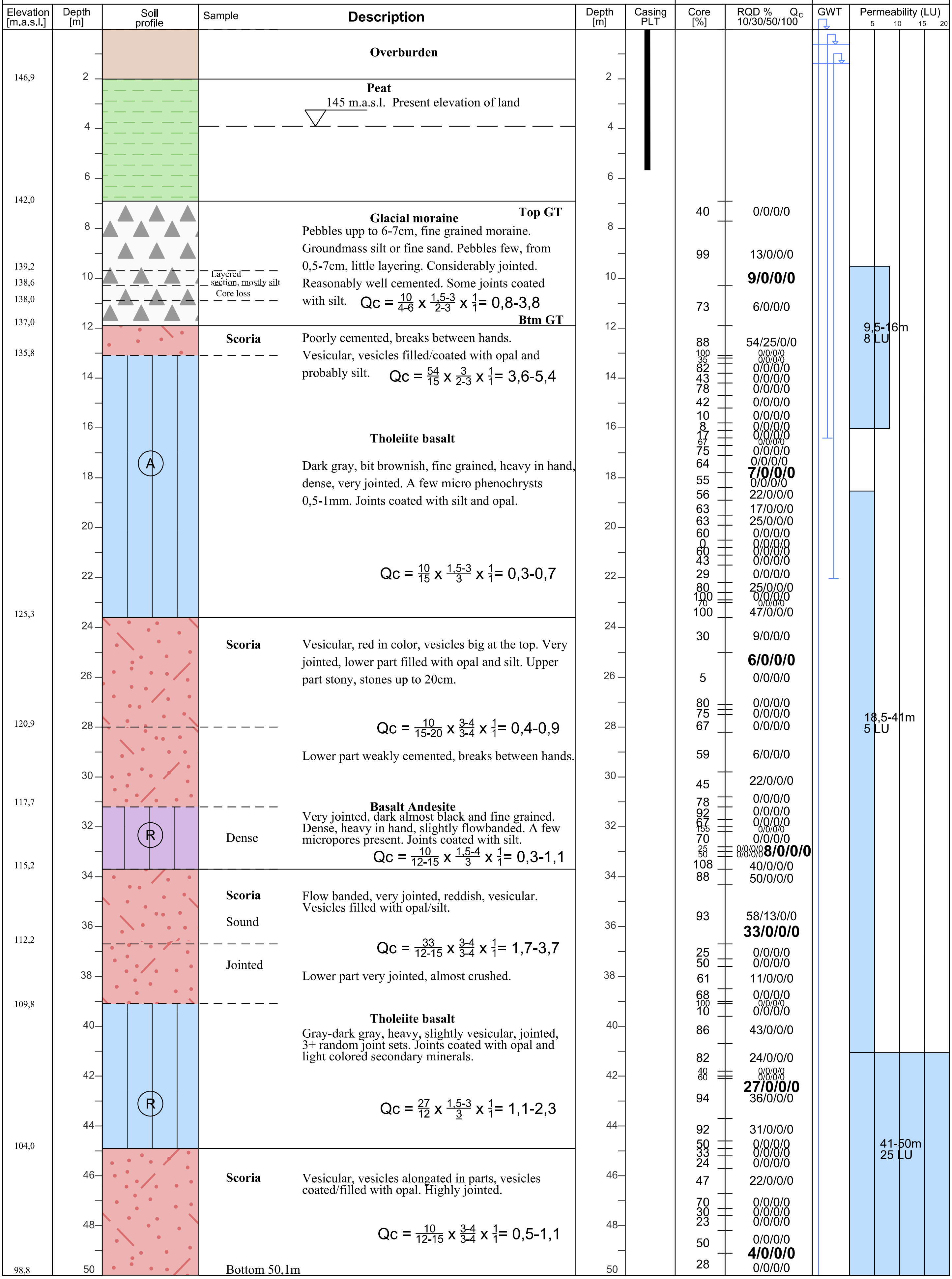
Landsvirkjun

Búrfell HEP Extension

BF-21
Cored Hole

Contractor:	Jarðboranir ríkisins
Drill	Dugandi (C2)
Place:	Sámsstaðir
Drill thickness:	NQ 47,6 mm core
Date of drilling:	20/6 - 2/7 1983
Drawn:	AKS/ÁÓT
Drawing nr.:	1 af 1
Approved:	SPS

Coordinates: ISN93 X: 460683,71 Y: 399989,942 Elev.: 148,90 m.a.s.l.



Overburden

Peat

145 m.a.s.l. Present elevation of land

Glacial moraine **Top GT**

Pebbles upp to 6-7cm, fine grained moraine. Groundmass silt or fine sand. Pebbles few, from 0,5-7cm, little layering. Considerably jointed. Reasonably well cemented. Some joints coated with silt. $Qc = \frac{10}{4\text{-}6} \times \frac{1,5\text{-}3}{2\text{-}3} \times \frac{1}{1} = 0,8\text{-}3,8$

Layered section, mostly silt

Core loss

Btm GT

Scoria

Poorly cemented, breaks between hands. Vesicular, vesicles filled/coated with opal and probably silt. $Qc = \frac{54}{15} \times \frac{3}{2\text{-}3} \times \frac{1}{1} = 3,6\text{-}5,4$

Tholeiite basalt

Dark gray, bit brownish, fine grained, heavy in hand, dense, very jointed. A few micro phenochrysts 0,5-1mm. Joints coated with silt and opal.

$Qc = \frac{10}{15} \times \frac{1,5\text{-}3}{3} \times \frac{1}{1} = 0,3\text{-}0,7$

Scoria

Vesicular, red in color, vesicles big at the top. Very jointed, lower part filled with opal and silt. Upper part stony, stones up to 20cm.

$Qc = \frac{10}{15\text{-}20} \times \frac{3\text{-}4}{3\text{-}4} \times \frac{1}{1} = 0,4\text{-}0,9$

Lower part weakly cemented, breaks between hands.

Basalt Andesite

Dense

Very jointed, dark almost black and fine grained. Dense, heavy in hand, slightly flowbanded. A few micropores present. Joints coated with silt.

$Qc = \frac{10}{12\text{-}15} \times \frac{1,5\text{-}4}{3} \times \frac{1}{1} = 0,3\text{-}1,1$

Scoria

Sound

Flow banded, very jointed, reddish, vesicular. Vesicles filled with opal/silt.

$Qc = \frac{33}{12\text{-}15} \times \frac{3\text{-}4}{3\text{-}4} \times \frac{1}{1} = 1,7\text{-}3,7$

Jointed

Lower part very jointed, almost crushed.

Tholeiite basalt

Gray-dark gray, heavy, slightly vesicular, jointed, 3+ random joint sets. Joints coated with opal and light colored secondary minerals.

$Qc = \frac{27}{12} \times \frac{1,5\text{-}3}{3} \times \frac{1}{1} = 1,1\text{-}2,3$

Scoria

Vesicular, vesicles alongated in parts, vesicles coated/filled with opal. Highly jointed.

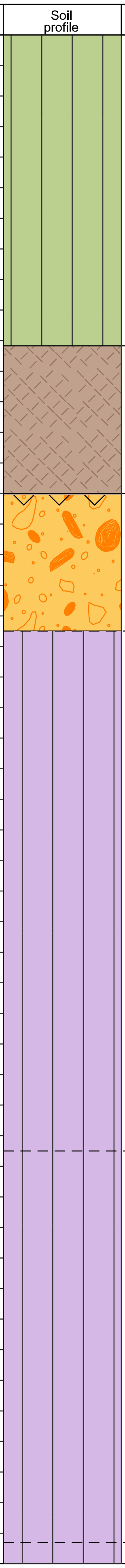
$Qc = \frac{10}{12\text{-}15} \times \frac{3\text{-}4}{3\text{-}4} \times \frac{1}{1} = 0,5\text{-}1,1$

Bottom 50,1m

Core [%]	RQD % 10/30/50/100
40	0/0/0/0
99	13/0/0/0
	9/0/0/0
73	6/0/0/0
88	54/25/0/0
100	0/0/0/0
35	0/0/0/0
82	0/0/0/0
43	0/0/0/0
78	0/0/0/0
42	0/0/0/0
10	0/0/0/0
8	0/0/0/0
17	0/0/0/0
67	0/0/0/0
75	0/0/0/0
64	0/0/0/0
	7/0/0/0
55	0/0/0/0
56	22/0/0/0
63	17/0/0/0
63	25/0/0/0
60	0/0/0/0
0	0/0/0/0
60	0/0/0/0
43	0/0/0/0
29	0/0/0/0
80	25/0/0/0
100	0/0/0/0
70	0/0/0/0
100	47/0/0/0
30	9/0/0/0
	6/0/0/0
5	0/0/0/0
80	0/0/0/0
75	0/0/0/0
67	0/0/0/0
59	6/0/0/0
45	22/0/0/0
78	0/0/0/0
92	0/0/0/0
67	0/0/0/0
155	0/0/0/0
70	0/0/0/0
25	0/0/0/0
50	0/0/0/0
	8/0/0/0
108	40/0/0/0
88	50/0/0/0
93	58/13/0/0
	33/0/0/0
25	0/0/0/0
50	0/0/0/0
61	11/0/0/0
68	0/0/0/0
100	0/0/0/0
10	0/0/0/0
86	43/0/0/0
82	24/0/0/0
40	0/0/0/0
60	0/0/0/0
	27/0/0/0
94	36/0/0/0
92	31/0/0/0
50	0/0/0/0
33	0/0/0/0
24	0/0/0/0
47	22/0/0/0
70	0/0/0/0
30	0/0/0/0
23	0/0/0/0
50	0/0/0/0
	4/0/0/0
28	0/0/0/0

Reference: Búrfell II, Bjarni Bjarnason, OS-83059/VOD-29, July 1983.

Almenna verkfræðistofan Landsvirkjun	**Búrfell HEP Extension**	Contractor: Jarðboranir ríkisins	Drill Sullivan 1
	AT-1 Cored Hole	Place: Sámsstaðir	Drill thickness: 55 mm ?
		Date of drilling: 7/10 - 13/11 1962	Drawn: AKS
Coordinates: ISN93 X: 460849 Y: 400434	Elev.: 241,9 m.a.s.l.	Drawing nr.: 1 af 2	Approved: SPS



Elevation [m.a.s.l.]	Description	RQD % Qc 10/30/50/100
	Top SB **Olivine Basalt**	
226,9	**Hyaloclastite** **Btm SB**	N/A
222,4	**Conglomerate** **Top OB** Slight Hydrothermal Alteration	
205,4	**Basalt Andesite** Scoriaceous Slight Hydrothermal Alteration	
192,6	**Basalt Andesite** Scoriaceous Slight Hydrothermal Alteration	
	Scoriaceous Hydrothermal Alteration	

Elevation [m.a.s.l.] | Depth [m] | Soil profile | Sample | Description | Depth [m] | Casing PLT | Core [%] | RQD % Qc 10/30/50/100 | GWT | Permeability (LU) 5 10 15 20

Reference: Búrfell Project, Project Planning Report Vol. 2., Harza Engineering Company International, February 1963.

Almenna verkfræðistofan

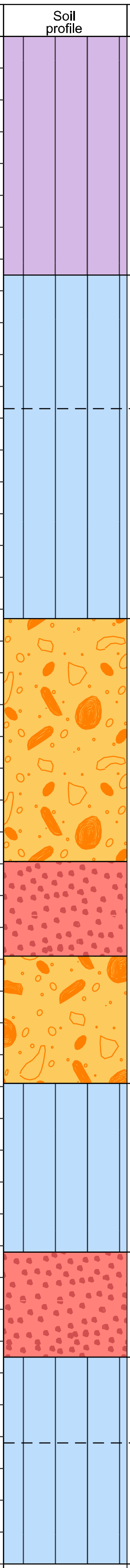
Landsvirkjun

Búrfell HEP Extension

AT-1
Cored Hole

Contractor:	Jarðboranir ríkisins
Drill	Sullivan 1
Place:	Sámsstaðir
Drill thickness:	55 mm ?
Date of drilling:	7/10 - 13/11 1962
Drawn:	AKS
Drawing nr.:	2 af 2
Approved:	SPS

Coordinates: ISN93 X: 460849 Y: 400434 Elev.: 241,9 m.a.s.l.



Elevation [m.a.s.l.]	Depth [m]	Soil profile	Sample	Description	Depth [m]	Casing PLT	Core [%]	RQD % 10/30/50/100 Qc	GWT	Permeability (LU) 5 10 15 20
	52 54 56			**Basalt Andesite**	52 54 56			N/A		
184,4	58 60			**Tholeiite Basalt** Scoriaceous Slight Hydrothermal Alteration	58 60					
180,2	62 64 66 68			**Tholeiite Basalt** Hydrothermal Alteration	62 64 66 68					
173,6	70 72 74 76			**Conglomerate** (Sedimentary Breccia in original log) (Probably angular or subangular rock fragments) Slight Hydrothemal Alteration	70 72 74 76					
	78			**Tuffaceous Sandstone**	78					
163,0	80 82			**Conglomerate** (Sedimentary Breccia in original log) (Probably angular or subangular rock fragments)	80 82					
159,0	84 86 88			**Tholeiite Basalt**	84 86 88					
153,7	90			**Sandstone** Slight Hydrothermal Alteration	90					
150,4	92 94			**Tholeiite Basalt**	92 94					
147,7	96 98			**Tholeiite Basalt** Scoriaceous Slight Hydrothermal Alteration	96 98					
143,9	100			Bottom 143,9	100					

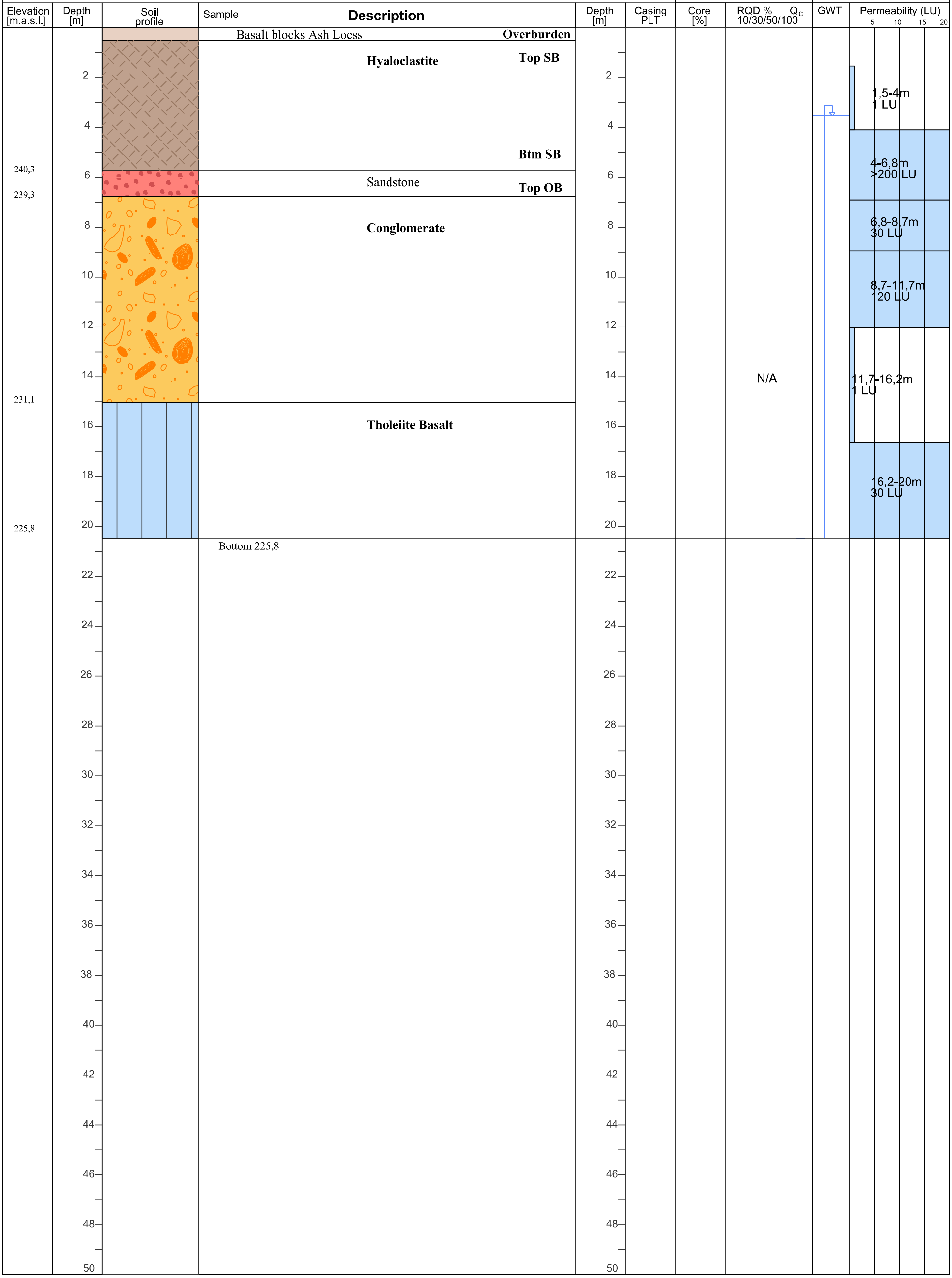
Reference: Búrfell Project, Project Planning Report Vol. 2., Harza Engineering Company International, February 1963.

Búrfell HEP Extension

PT-8
Cored Hole

Contractor: Jarðboranir ríkisins
Drill: Sullivan 2
Place: Sámsstaðir
Drill thickness: 55 mm ?
Date of drilling: 4/6 - 6/6 1962
Drawn: AKS
Drawing nr.: 1 af 1
Approved: SPS

Coordinates: ISN93 X: 461070,4 Y: 400584,1 Elev.: 245,9 m.a.s.l.



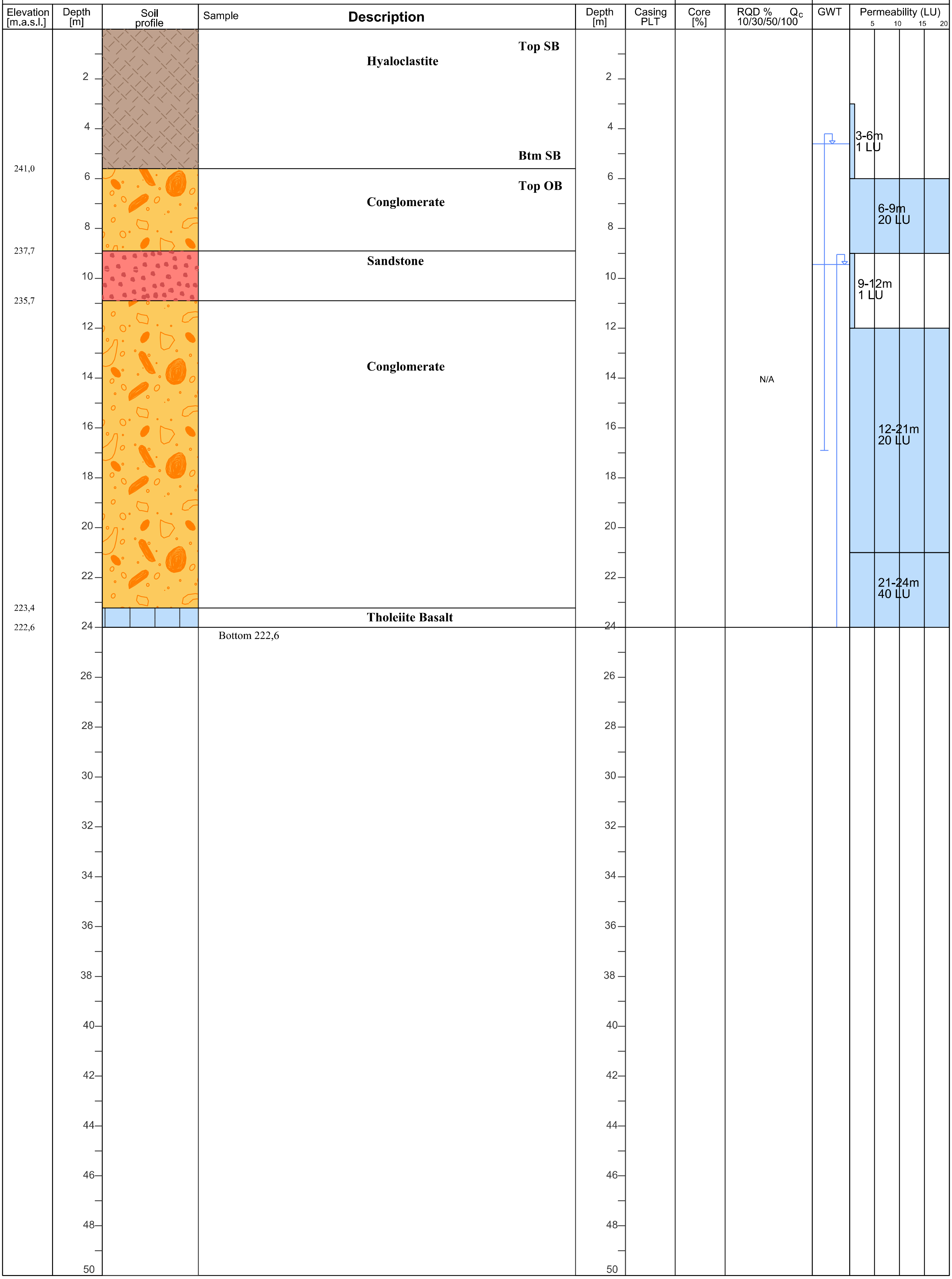
Reference: Búrfell Project, Project Planning Report Vol. 2., Harza Engineering Company International, February 1963.

Búrfell HEP Extension

PT-9
Cored Hole

Contractor: Jarðboranir ríkisins	Drill Sullivan 2
Place: Sámsstaðir	Drill thickness: 55 mm ?
Date of drilling: 7/6 - 14/6 1962	Drawn: AKS
Drawing nr.: 1 af 1	Approved: SPS

Coordinates: ISN93 X: 461189,8 Y: 400651,7 Elev.: 246,6 m.a.s.l.



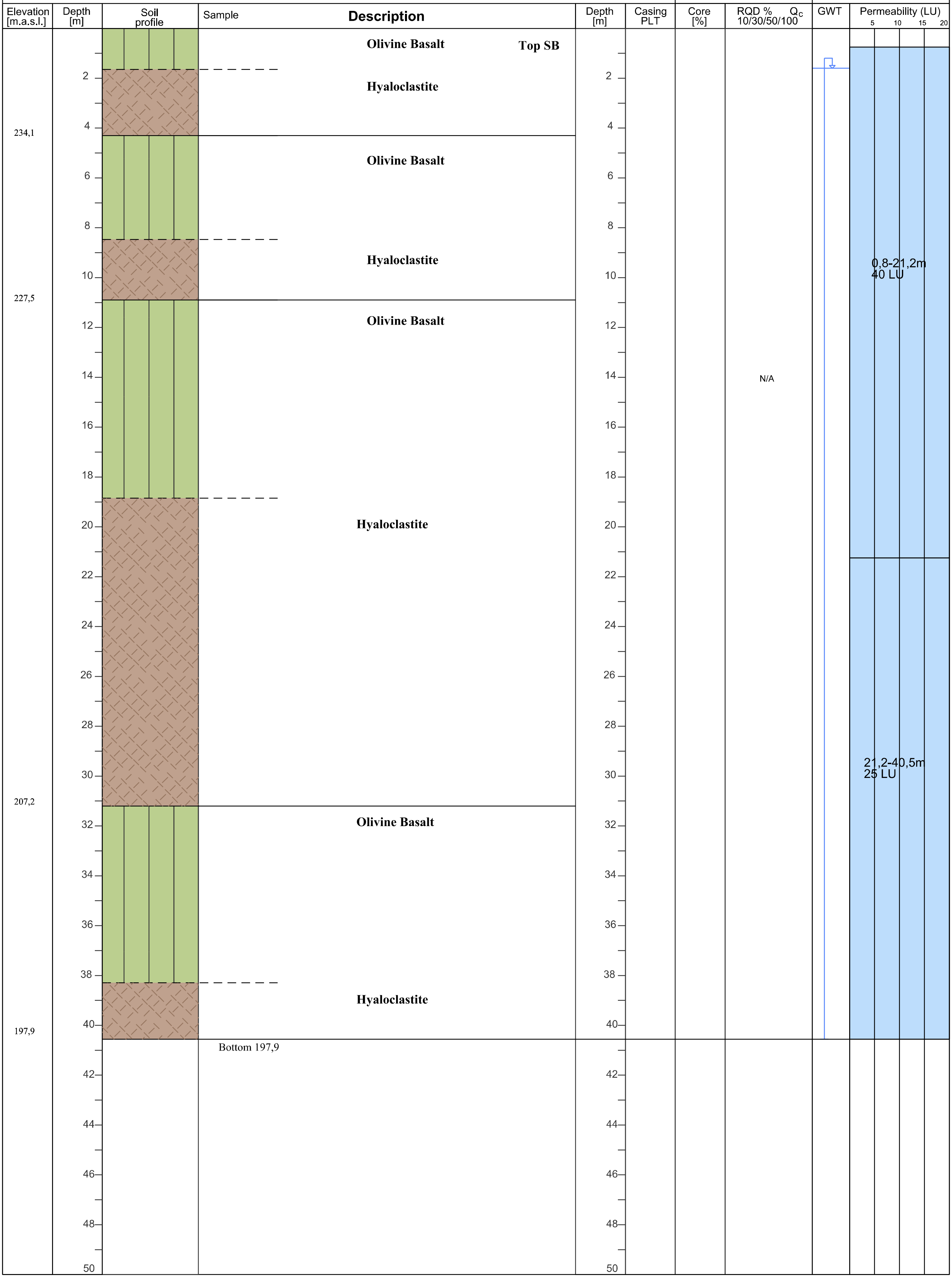
Reference: Búrfell Project, Project Planning Report Vol. 2., Harza Engineering Company International, February 1963.

Búrfell HEP Extension

PT-10
Cored Hole

Contractor:	Jarðboranir ríkisins	Drill	Sullivan 2
Place:	Sámsstaðir	Drill thickness:	55 mm ?
Date of drilling:	15/6 - 29/6 1962	Drawn:	AKS
Drawing nr.:	1 af 1	Approved:	SPS

Coordinates: ISN93 X: 460944,8 Y: 400515,4 Elev.: 238,4 m.a.s.l.



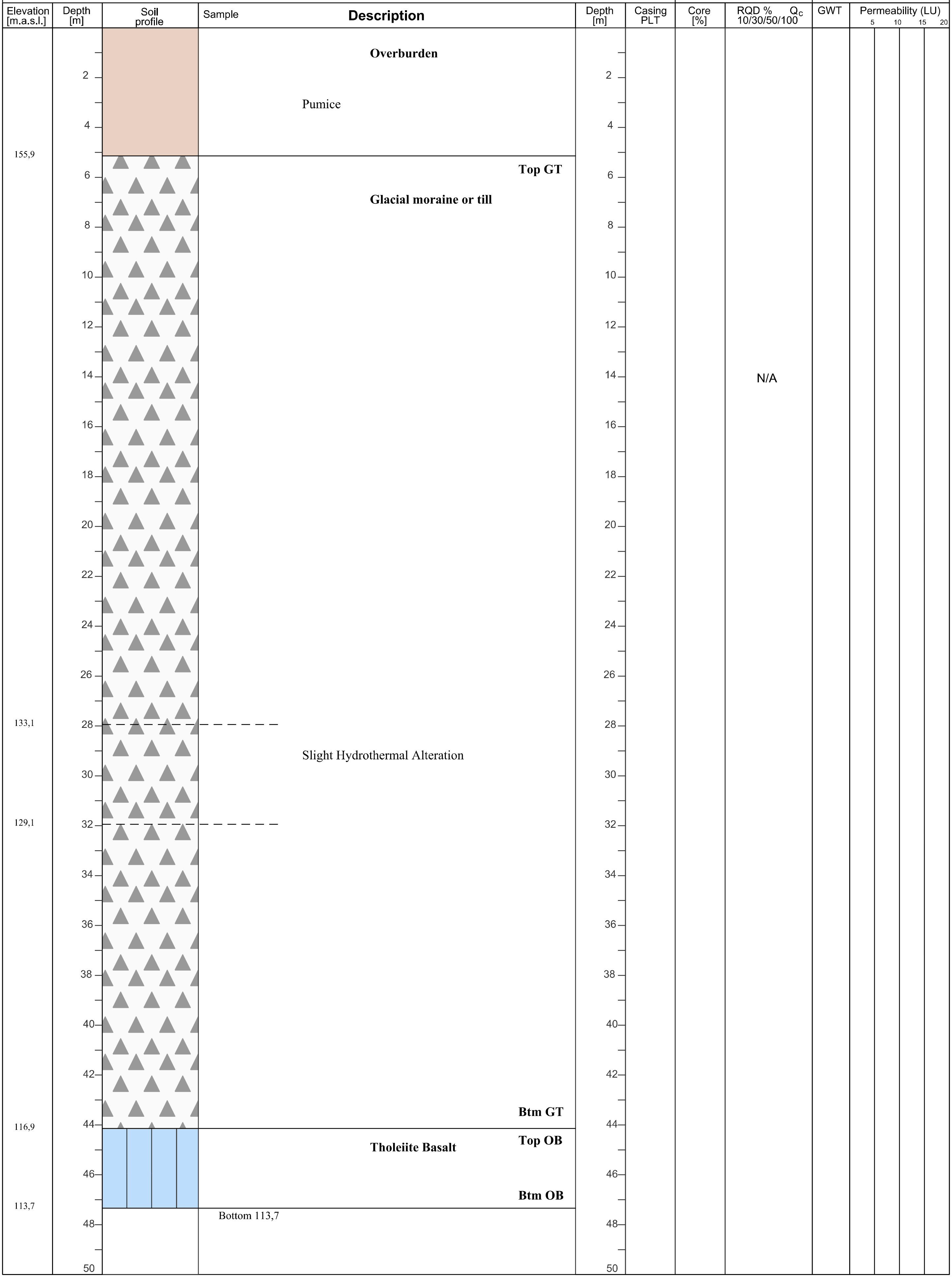
Reference: Búrfell Project, Project Planning Report Vol. 2., Harza Engineering Company International, February 1963.

Búrfell HEP Extension

SO-01
Cored Hole

Contractor: Jarðboranir ríkisins
Drill: Sullivan 1
Place: Sámsstaðir
Drill thickness:
Date of drilling: 1964
Drawn: AKS
Drawing nr.: 1 af 1
Approved: SPS

Coordinates: ISN93 X: 460715,00 Y: 400056,75 Elev.: 161,1 m.a.s.l.

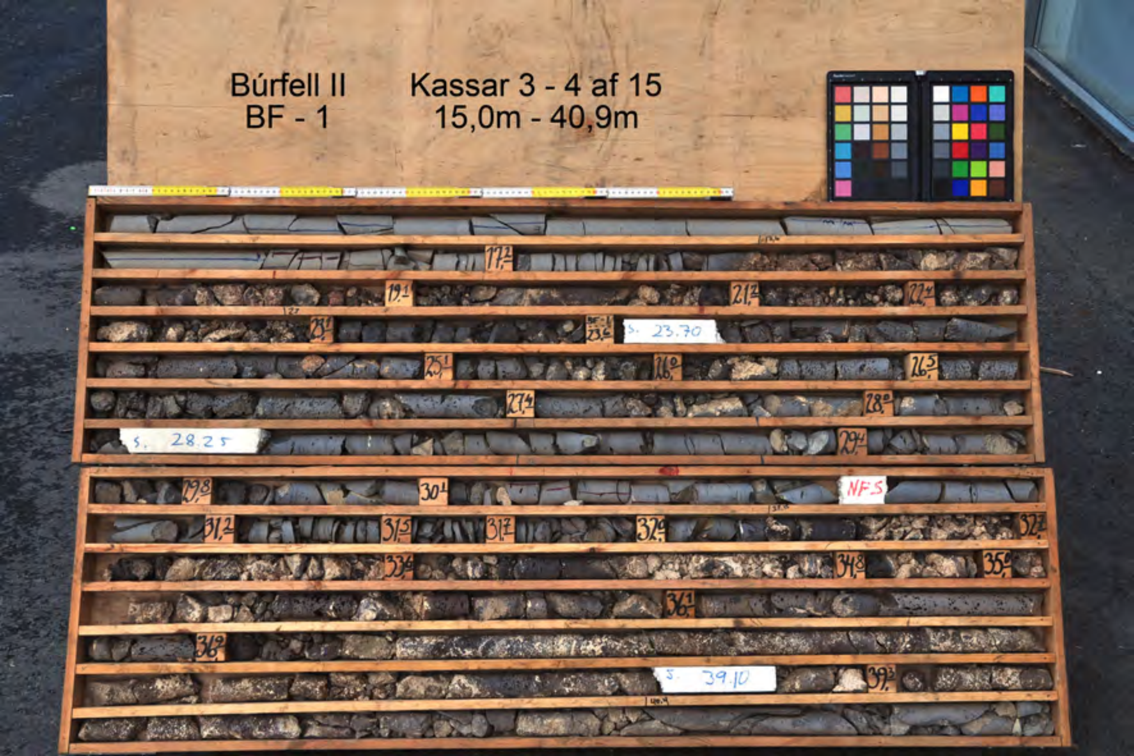


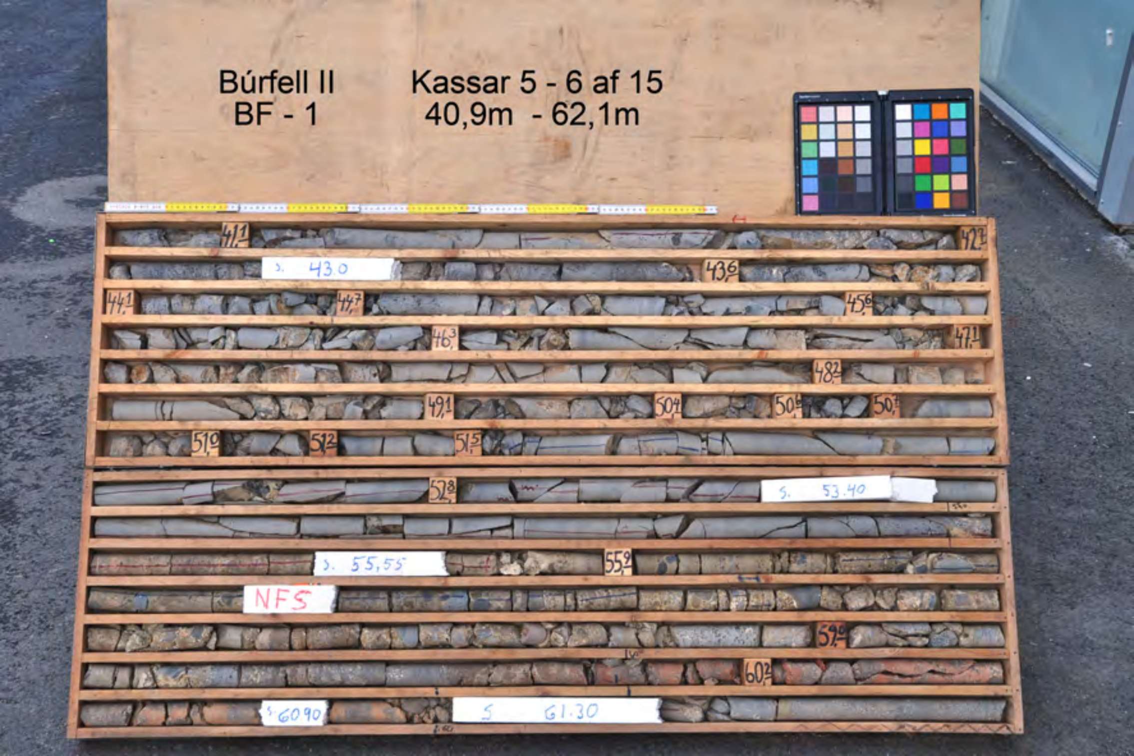
Reference: Búrfell Project, The Modified Saetersmoen Scheme, December 1964.

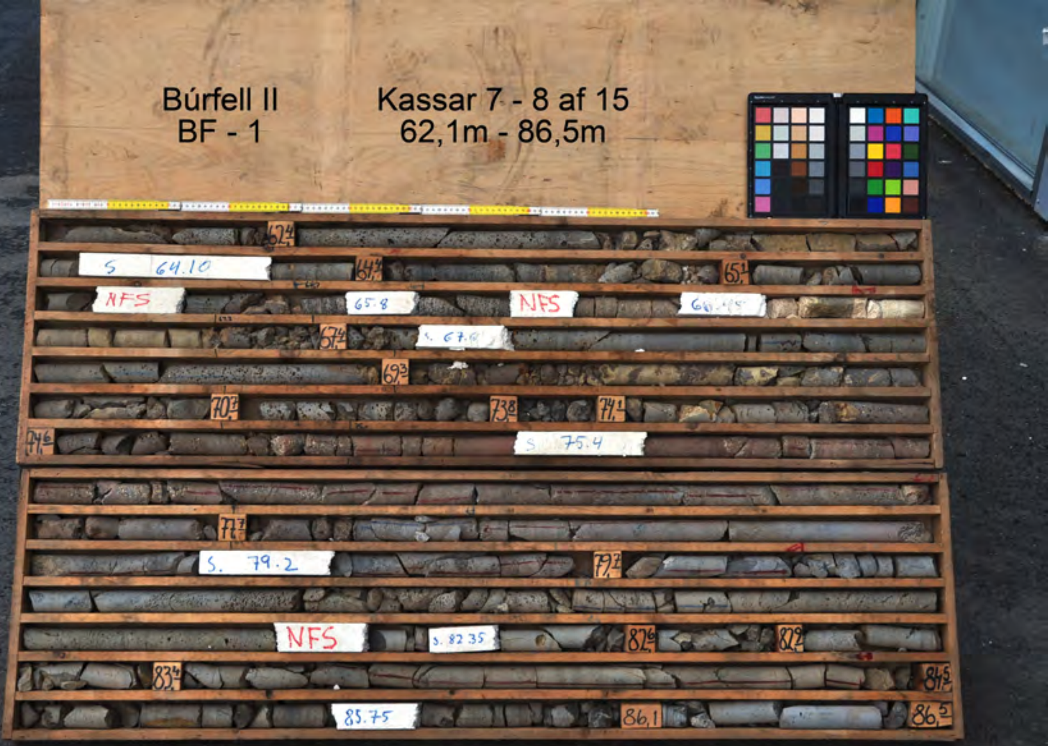
Appendix E

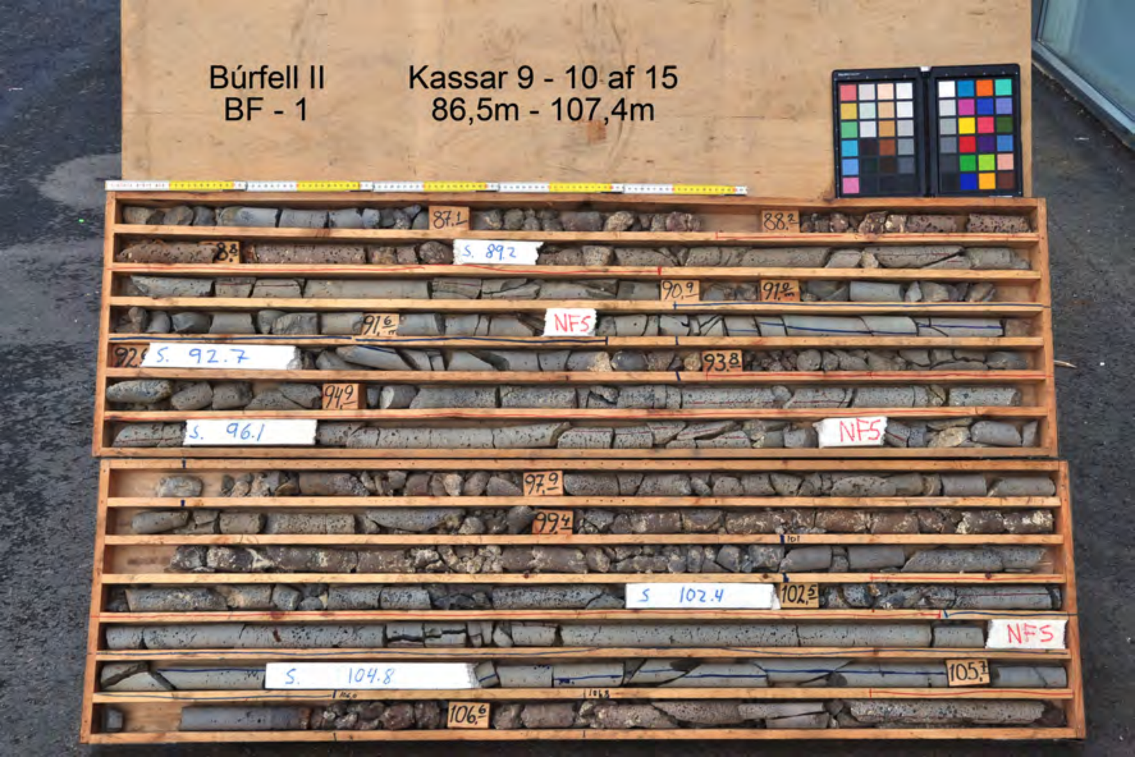
Pictures of cores.

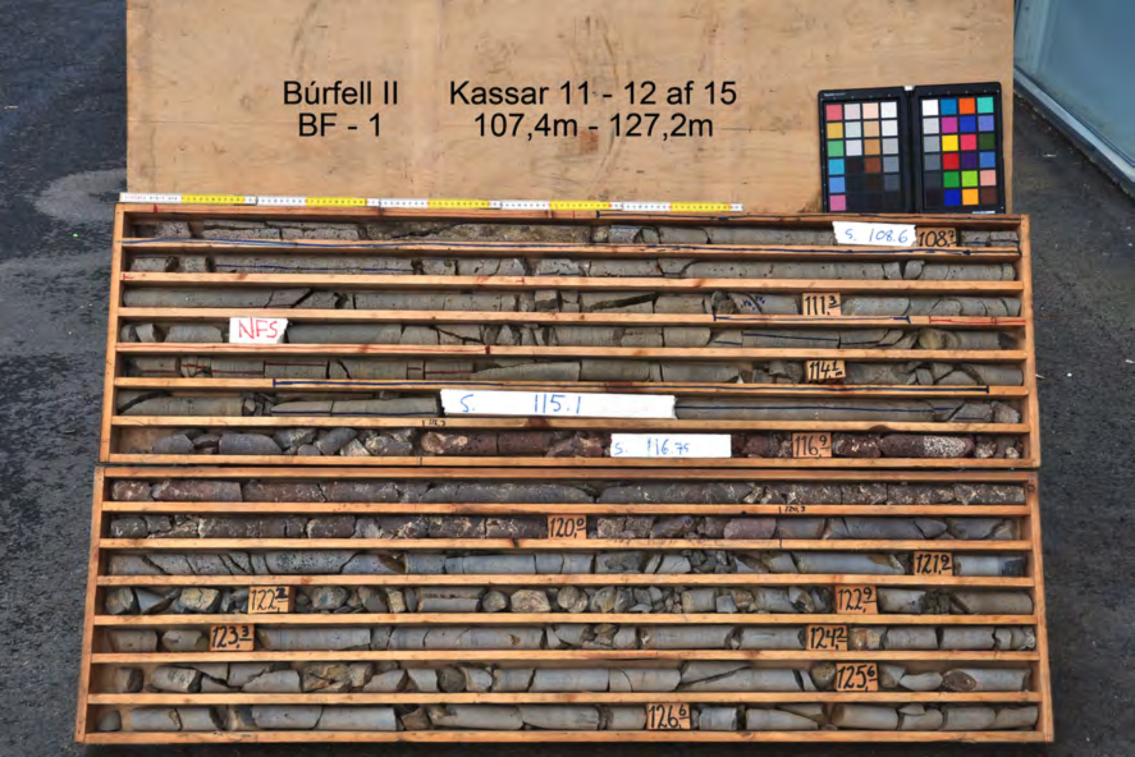
Búrfell II	Kassar 1 - 2 af 15
BF - 1	0,7m - 15,0m

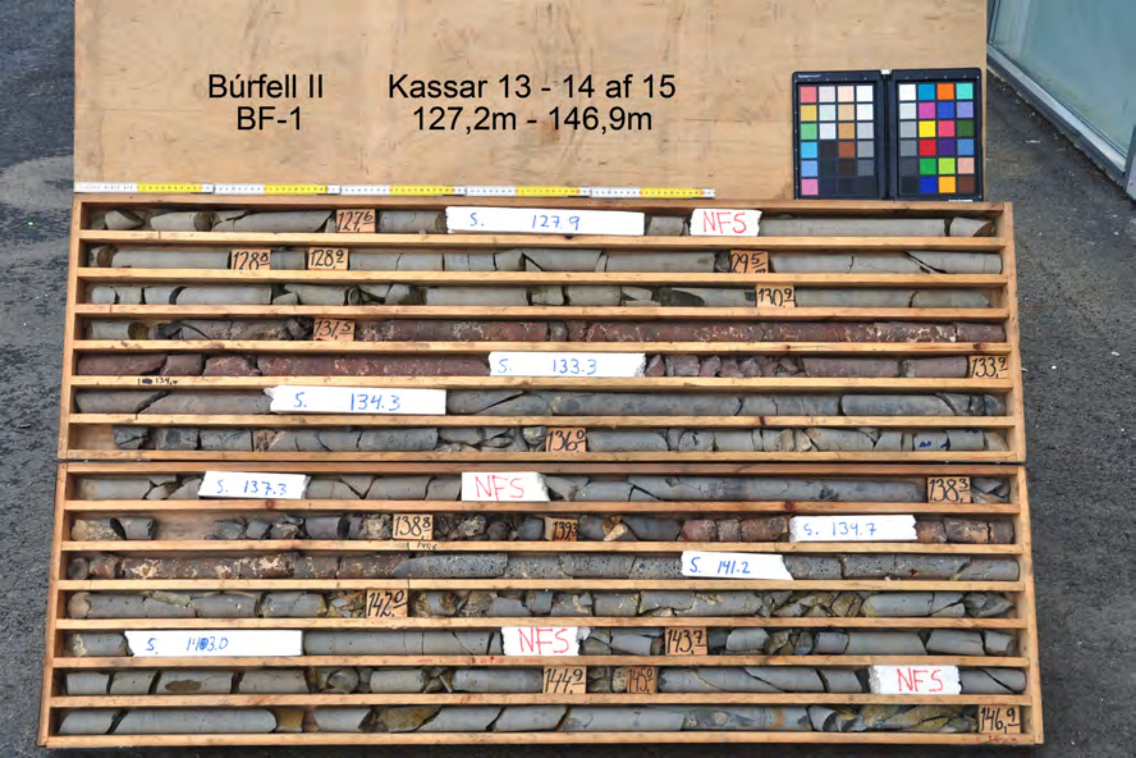

Búrfell II
BF - 1
Kassar 3 - 4 af 15
15,0m - 40,9m
17,2
19,1
21,2
22,4
23,1
BF-1
23,6
S. 23.70
25,1
26,0
26,5
27,4
28,0
S. 28.25
29,4
29,8
30,1
NFS
31,2
31,5
31,7
32,0
32,7
33,6
34,8
35,0
36,1
36,9
S. 39.10
39,3


Búrfell II
BF - 1
Kassar 5 - 6 af 15
40,9m - 62,1m
41,1
42,7
S. 43.0
43,6
44,1
44,7
45,6
46,3
47,1
48,2
49,1
50,4
50,6
50,7
51,0
51,2
51,5
52,8
S. 53.40
S. 55,55
55,9
NFS
59,0
60,2
S 60,90
S 61.30


Búrfell II
BF - 1
Kassar 7 - 8 af 15
62,1m - 86,5m
62,4
S 64.10
64,4
65,1
NFS
65.8
NFS
66.45
67,4
S. 67.6
69,3
70,7
73,8
74,1
74,6
S 75.4
77,7
S. 79.2
79,7
NFS
S. 82.35
82,6
82,9
83,4
84,5
85.75
86,1
86,5


Búrfell II
BF - 1
Kassar 9 - 10 af 15
86,5m - 107,4m
87.1
88.2
88.8
S. 89.2
90.9
91.2
91.6
NFS
92.9
S. 92.7
93.8
94.9
S. 96.1
NFS
97.9
99.4
101
S 102.4
102.5
NFS
S. 104.8
105.7
106.6

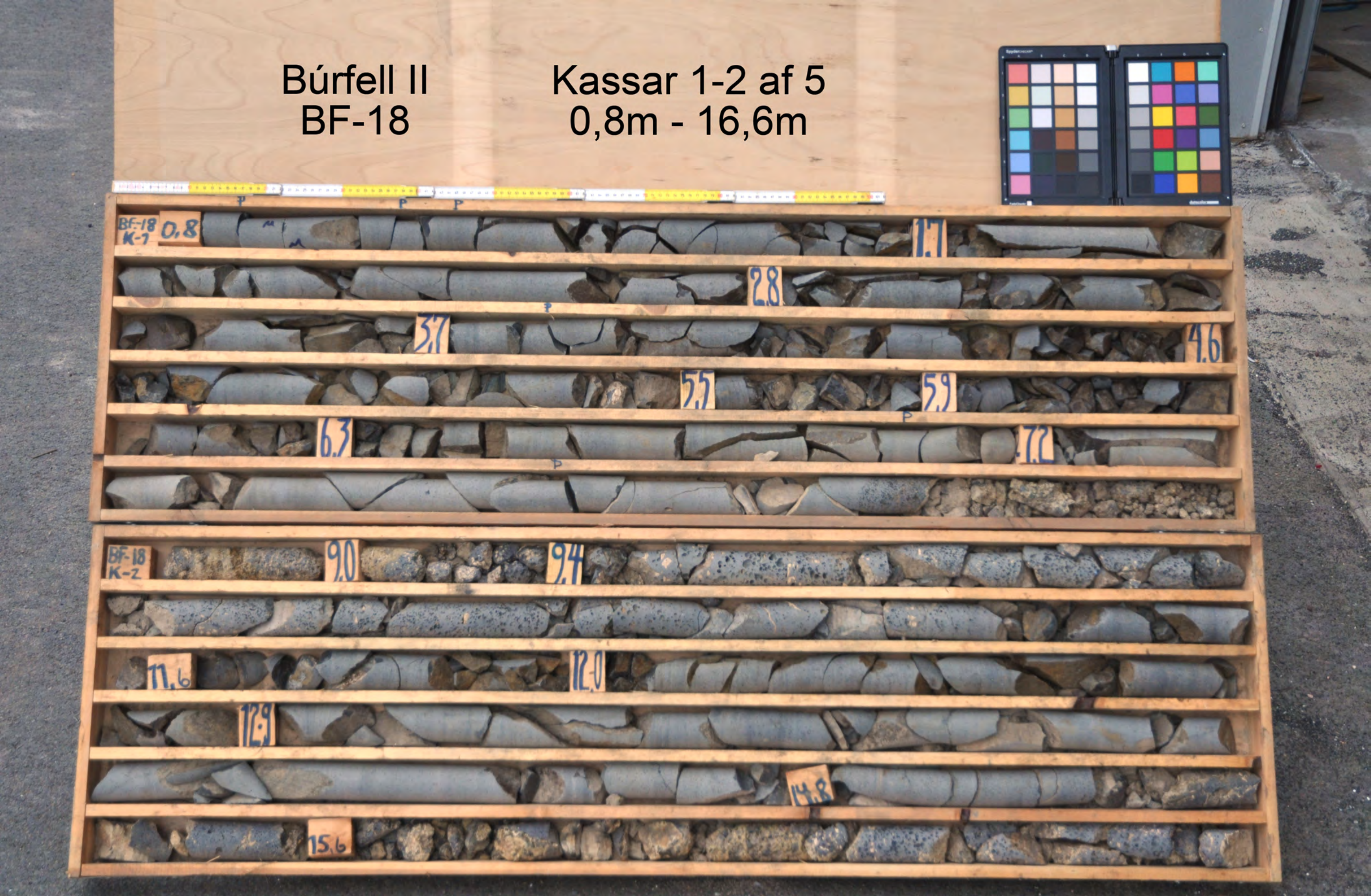

Búrfell II
BF - 1
Kassar 11 - 12 af 15
107,4m - 127,2m
S. 108.6
108,7
111,3
NFS
114,1
S. 115.1
S. 116.75
116,9
120,0
121,2
122,2
122,9
123,3
124,2
125,6
126,6

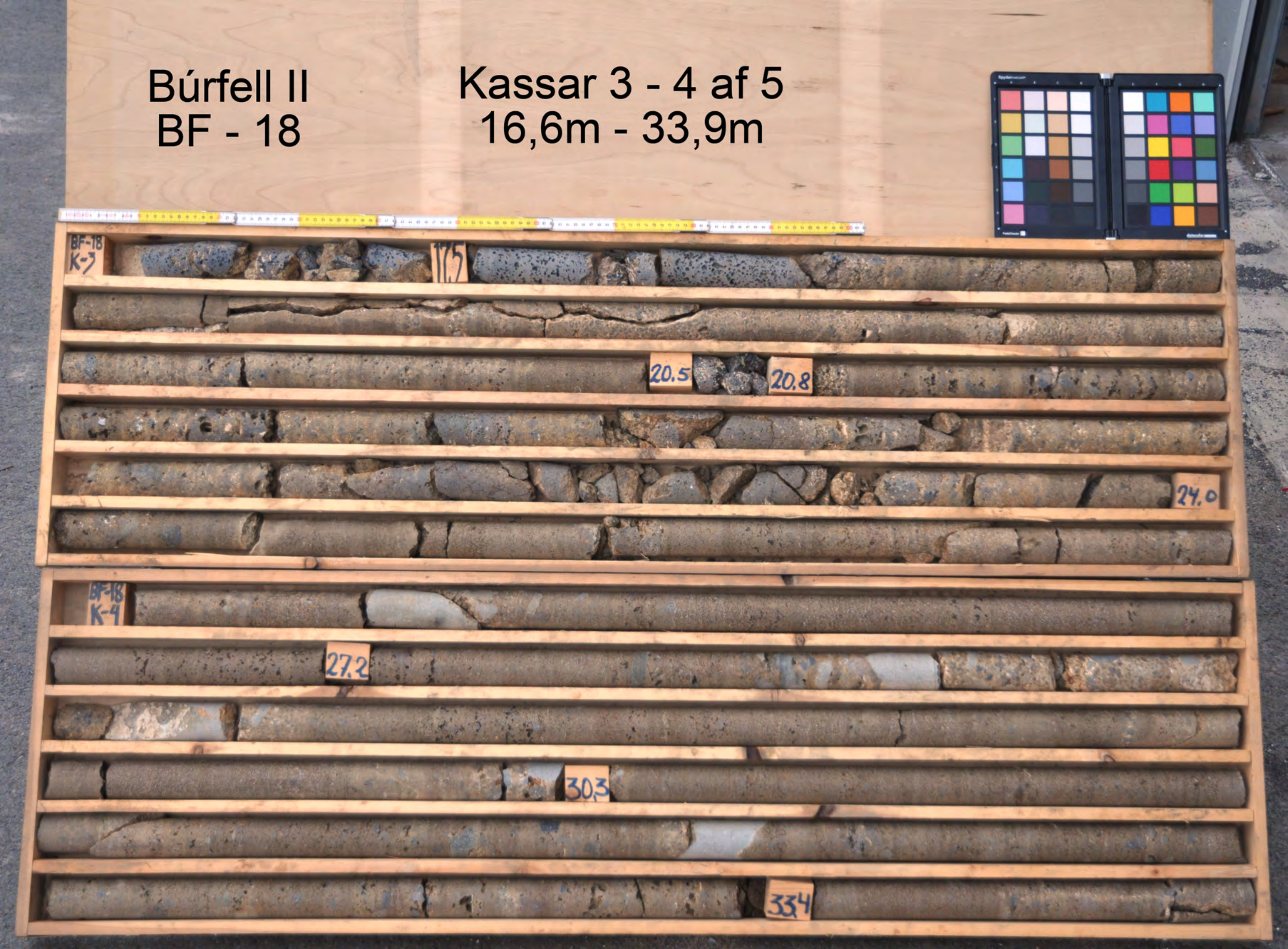

Búrfell II
BF-1
Kassar 13 - 14 af 15
127,2m - 146,9m
127,6
S. 127.9
NFS
128,0
128,9
129,5
130,9
131,5
S. 133.3
133,9
S. 134.3
136,0
S. 137.3
NFS
138,3
138,8
139,3
S. 139.7
S. 141.2
142,0
S. 1403.0
NFS
143,7
144,9
145,0
NFS
146,9

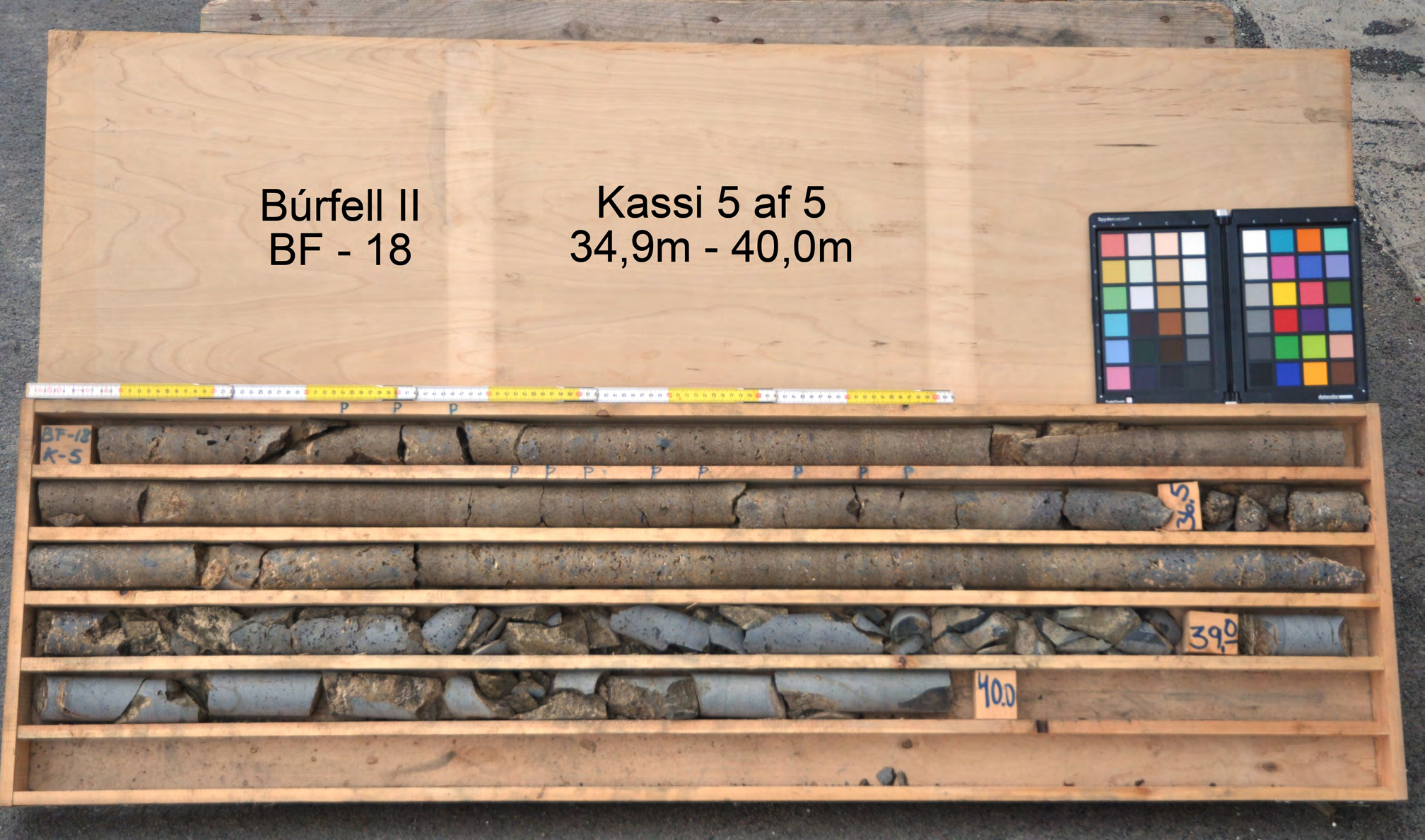

Búrfell II
BF - 1
Kassi 15 af 15
147,0m - 151,5m
147,0
147,6
Sýni 147,7
148,4
148,8
149,7
150,1
Sýni 150.7m
NFS
151,5
LOK
151,5m

Búrfell II
BF-18

Kassar 1-2 af 5
0,8m - 16,6m

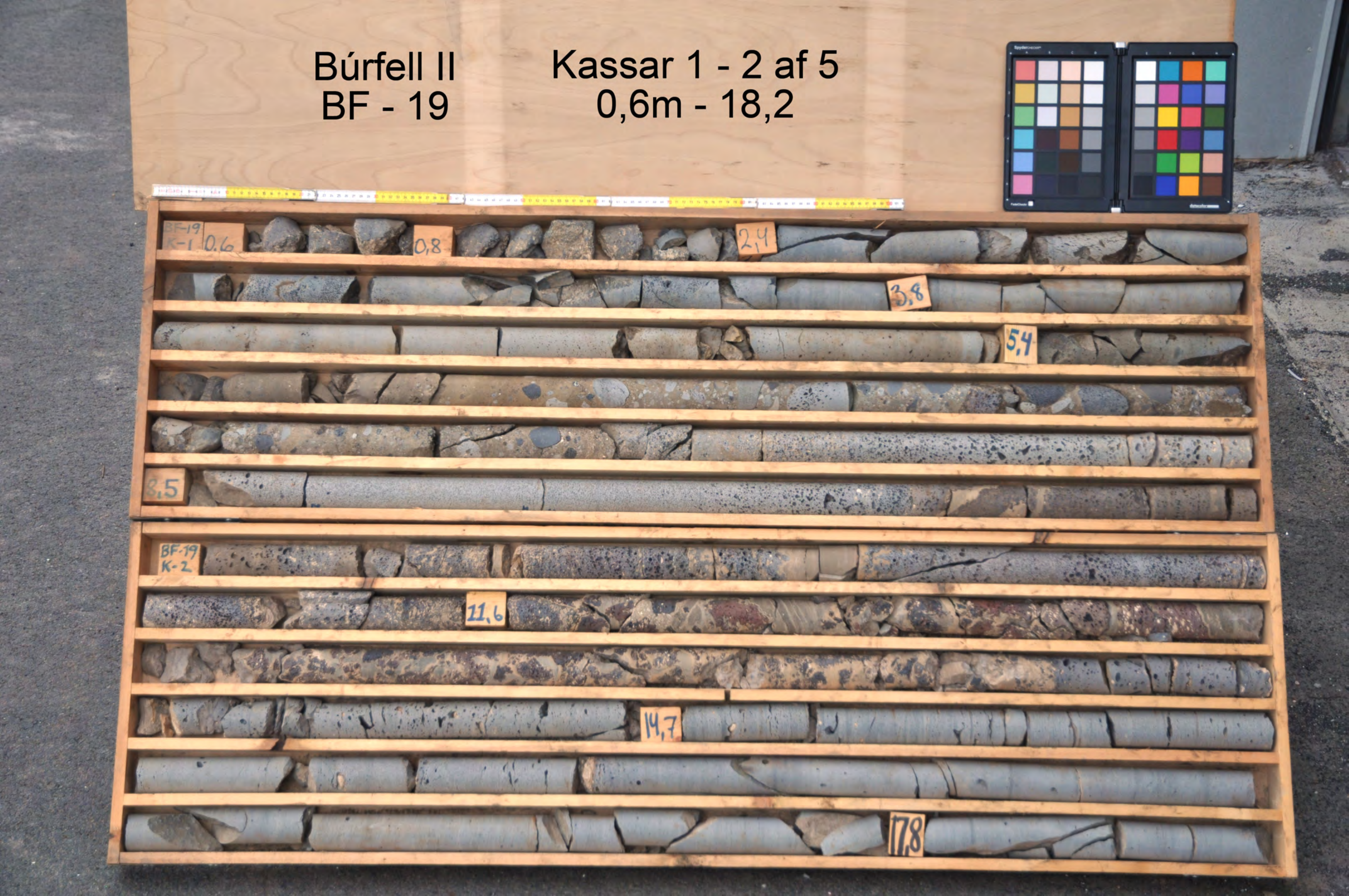



Búrfell II
BF - 18
Kassar 3 - 4 af 5
16,6m - 33,9m
BF-18 K-3
17,5
20.5
20.8
24.0
BF-18 K-4
27,2
30,3
33,4

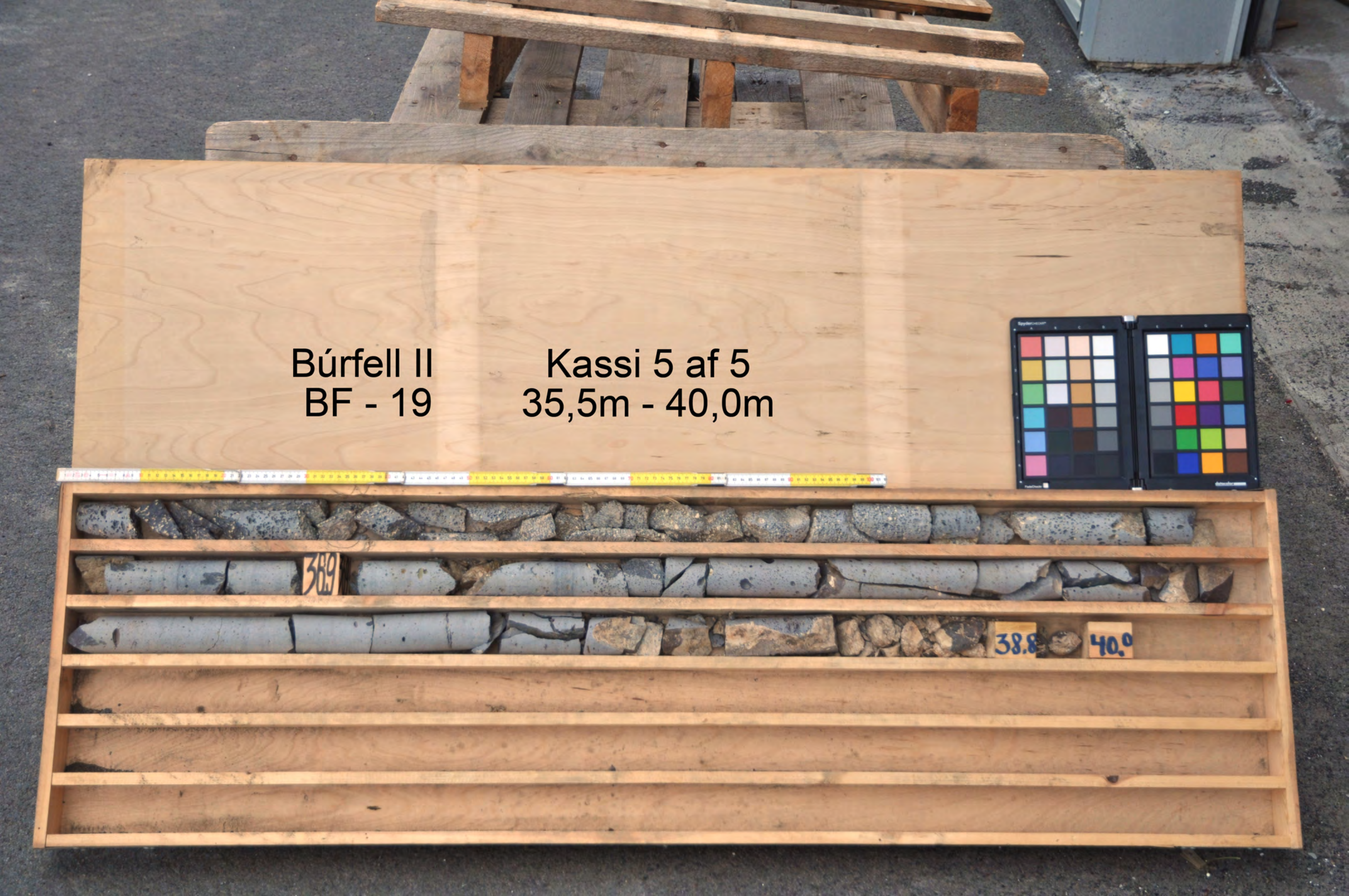


Búrfell II
BF - 18

Kassi 5 af 5
34,9m - 40,0m


Búrfell II
BF - 19
Kassar 1 - 2 af 5
0,6m - 18,2
BF-19
K-1
0,6
0,8
2,4
3,8
5,4
8,5
BF-19
K-2
11,6
14,7
17,8


Búrfell II
BF - 19
Kassar 3 - 4 af 5
18,2m - 35,5m
BF-19 K-3
20,9
24,0
BF-19 K-4
27,0
30,6
31,4
34,3



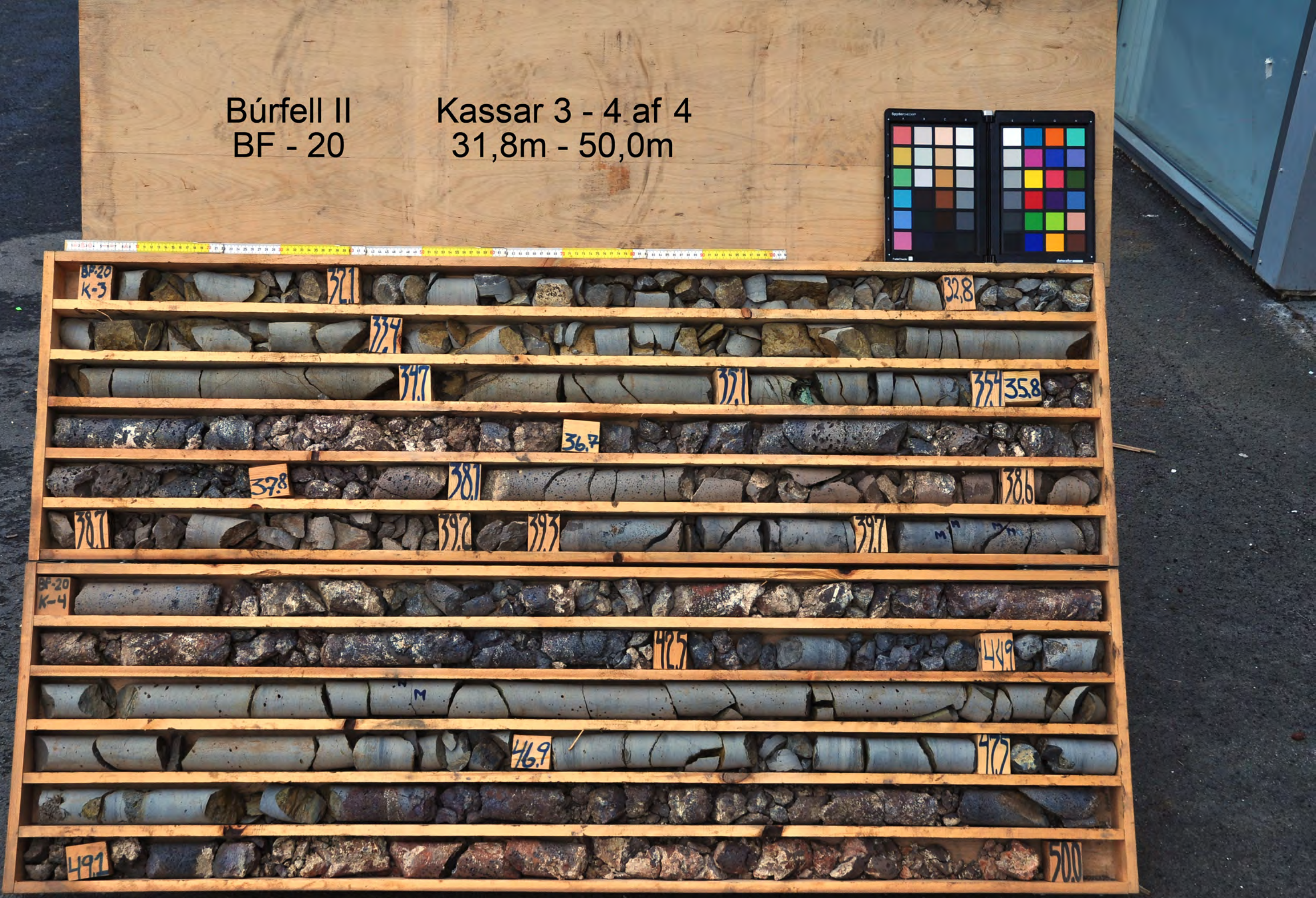
Búrfell II
BF - 19

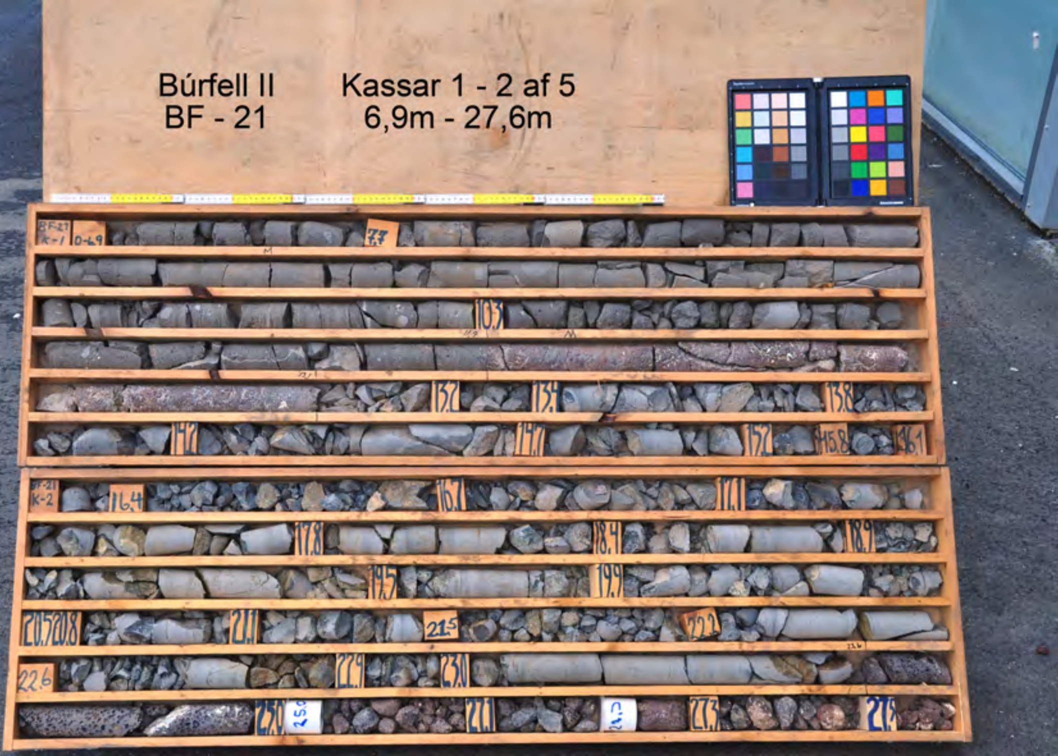
Kassi 5 af 5
35,5m - 40,0m

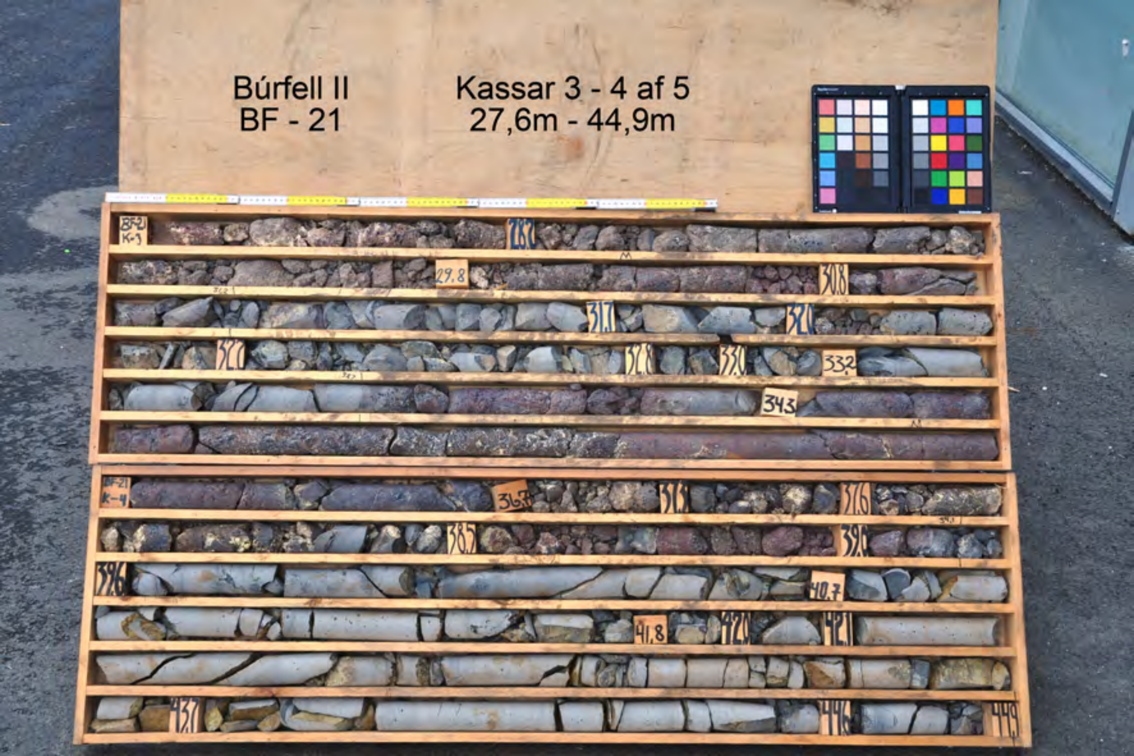

Búrfell II
BF - 20
Kassar 1 - 2 af 4
0,0 m - 31,8 m
BF-20
K-1
0,0-
13,0
15,7
18,1
21.0
21,9
BF 20
K-2
24,1
24,3
25,1
25,9
26,4
27.0
27,2
27,4
27,6
27,8
28,6
29,1
29,5
30,1
30,3
30,8
31,3

Búrfell II
BF - 20

Kassar 3 - 4 af 4
31,8m - 50,0m




Búrfell II
BF - 21
Kassar 1 - 2 af 5
6,9m - 27,6m
BF-21 K-1
0-6,9
7,7
10,3
13,2
13,4
13,8
14,2
14,7
15,2
15,8
16,1
BF-21 K-2
16,4
16,7
17,1
17,8
18,4
18,9
19,5
19,9
20,5
20,8
21,1
21,5
22,2
22,6
22,9
23,0
25,0
27,1
27,3
27,5


Búrfell II
BF - 21
Kassar 3 - 4 af 5
27,6m - 44,9m
BF-21
K-3
29.8
30.8
31.7
32.0
33.0
33.2
34.3
BF-21
K-4
36.7
37.6
38.5
39.0
39.6
40.7
41.8
42.0
42.1
43.7
44.9

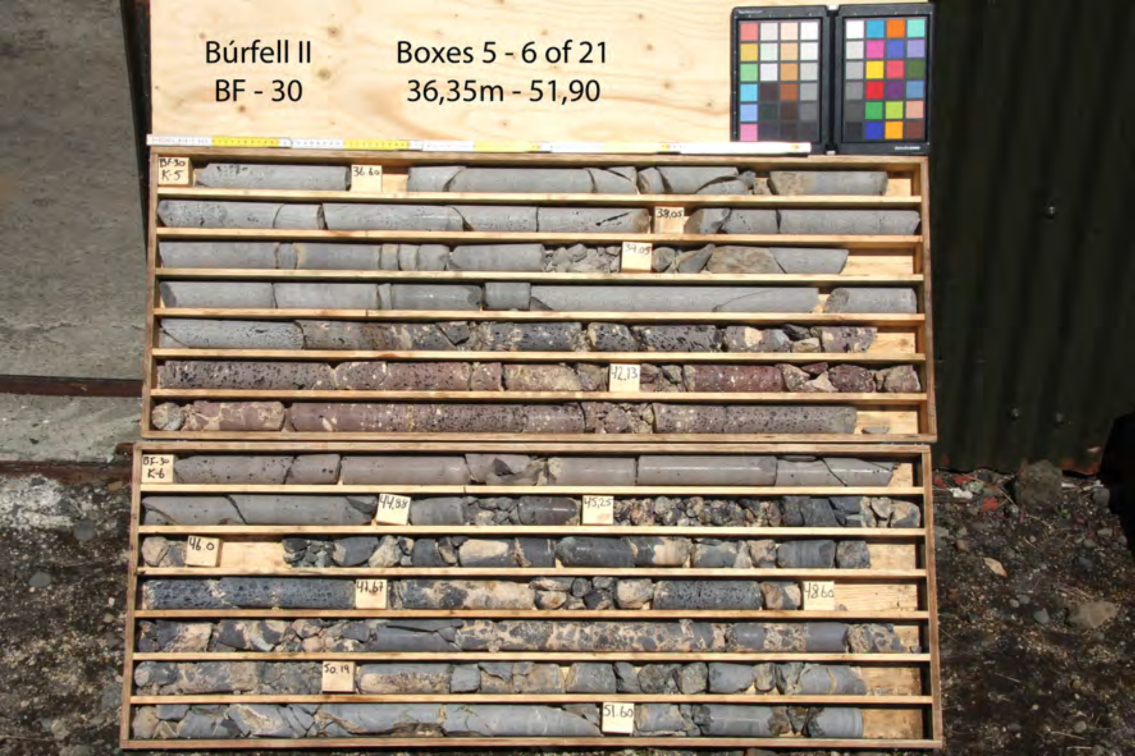
Búrfell II
BF - 21

Kassi 5 af 5
44,9m - 50,1m


Búrfell II
BF - 30
Boxes 1 - 2 of 21
2,30m - 21,50m
BF-30 K-1
2,30
2,94
3,43
3,54
4,16
6,33
9,59
11,67
12,25
BF-30 K-2
15,60
18,60

Búrfell II
BF - 30

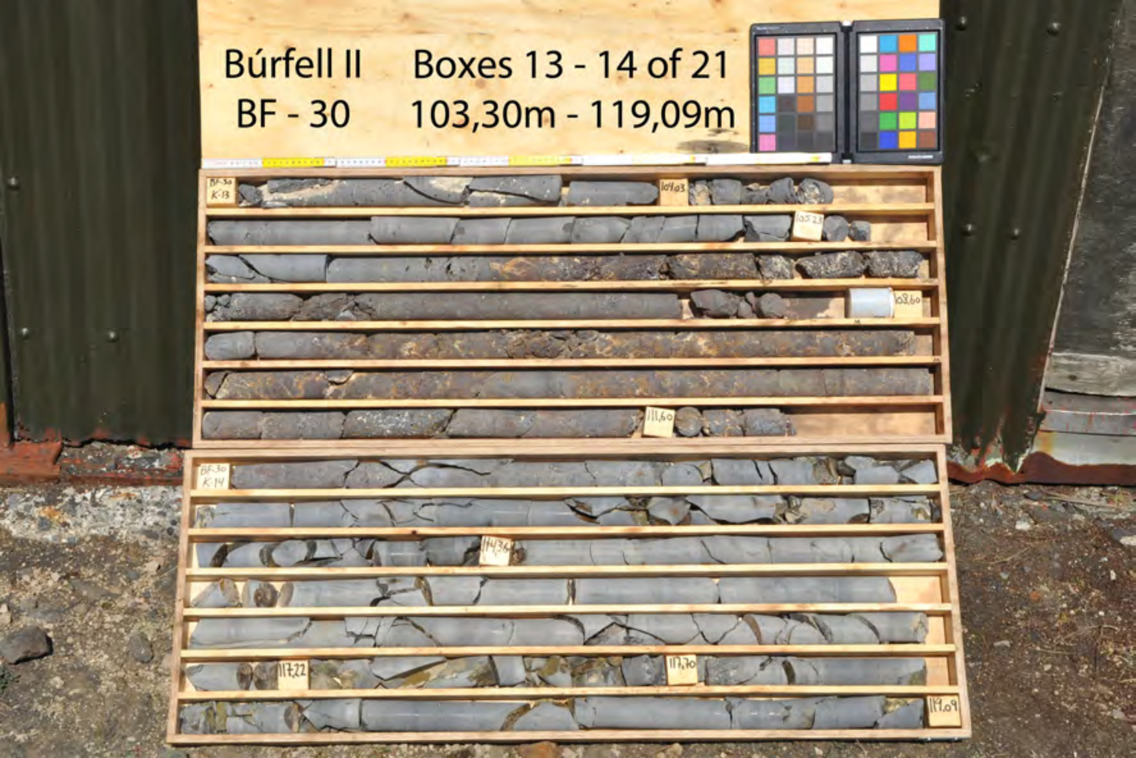
Boxes 3 - 4 of 21
21,50m - 36,35m

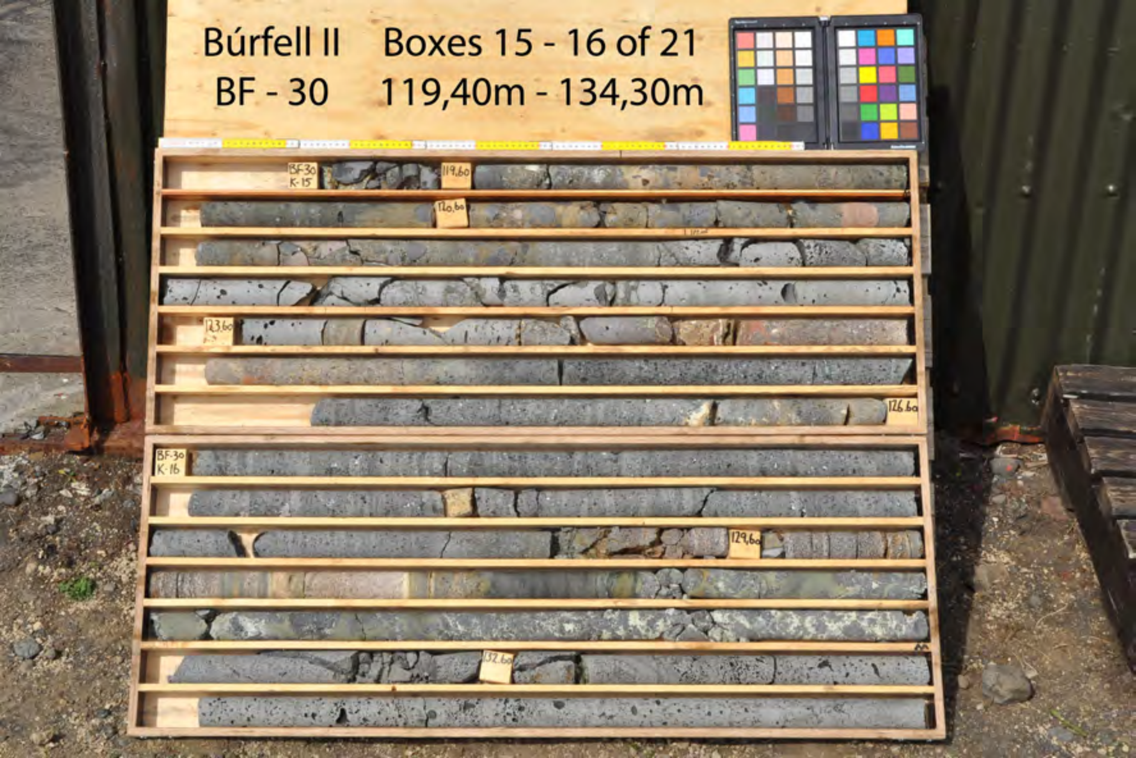

Búrfell II
BF - 30
Boxes 5 - 6 of 21
36,35m - 51,90
BF-30 K-5
36.60
38.05
39.05
42.13
BF-30 K-6
44.88
45.25
46.0
47.67
48.60
50.19
51.60

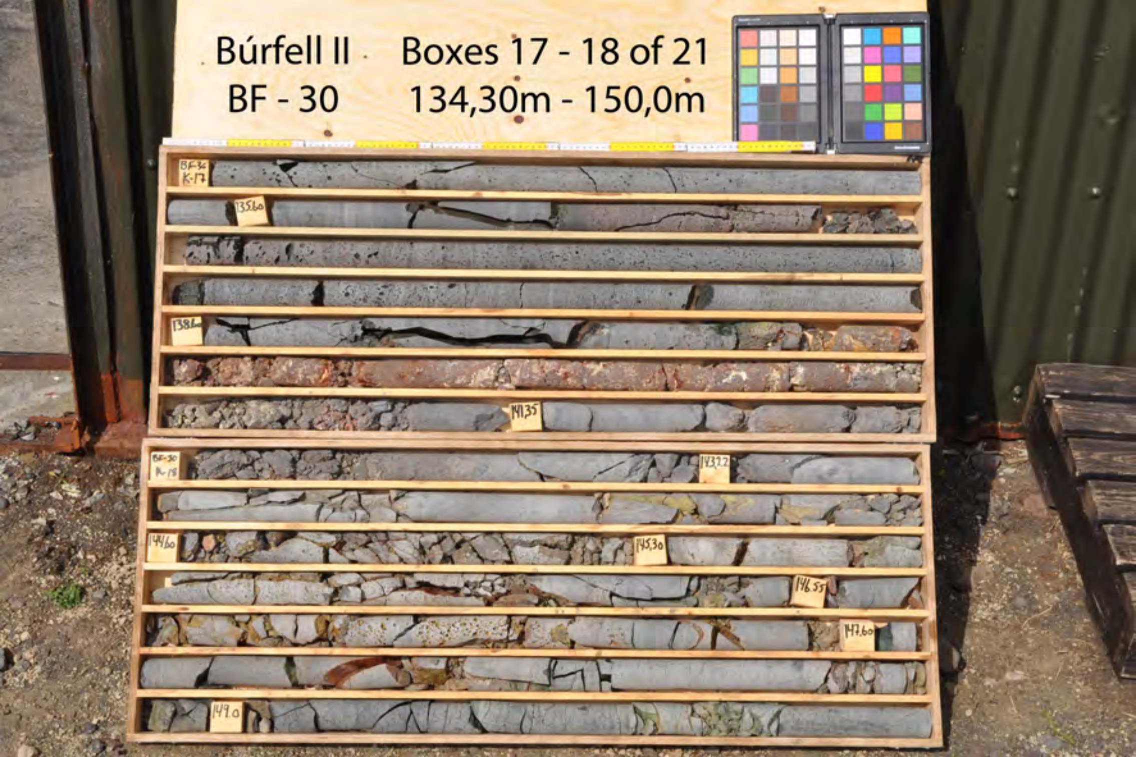

Búrfell II
BF - 30
Boxes 7 - 8 of 21
51,90m - 67,60m
BF30 K-7
53,06
54,60
55,65
56,39
57,14
58,70
BF-30 K-8
59,56
60,56
61.0
61.87
62,70
63,60
65,02
65,79
66,42
67,23

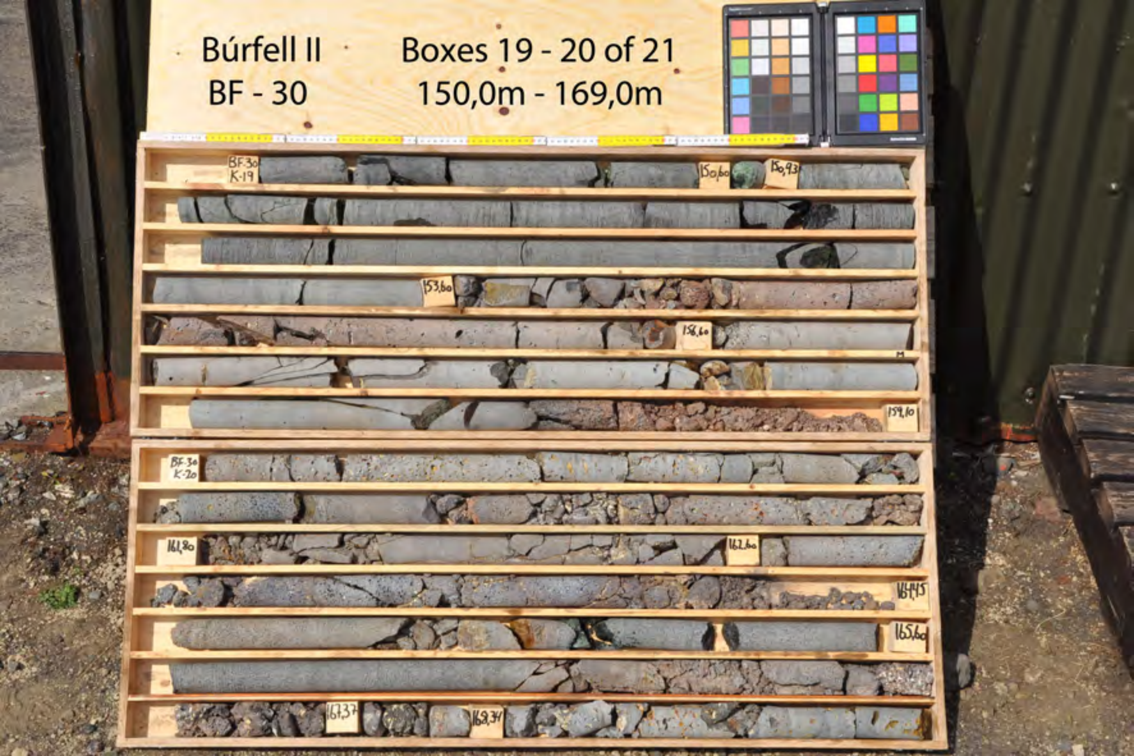

Búrfell II
BF - 30
Boxes 9 - 10 of 21
67,60m - 87,0m
BF30 K-9
68.93
72.03
72.60
73.74
74.60
75.42
75.49
78.60
79.33
BF-30 K-10
80.86
82.21
82.86
84.60
85.76
86.16
86.85


Búrfell II
Boxes 11 - 12 of 21
BF - 30
86,80m - 103,4
BF-30 K-11
90.58
92.57
92.88
93.60
94.91
BF-30 K-12
96.60
99.30
100.10
102.58


Búrfell II
BF - 30
Boxes 13 - 14 of 21
103,30m - 119,09m
BF-30 K-13
104,03
105,23
108,60
111,60
BF-30 K-14
114,36
117,22
117,70
119,09

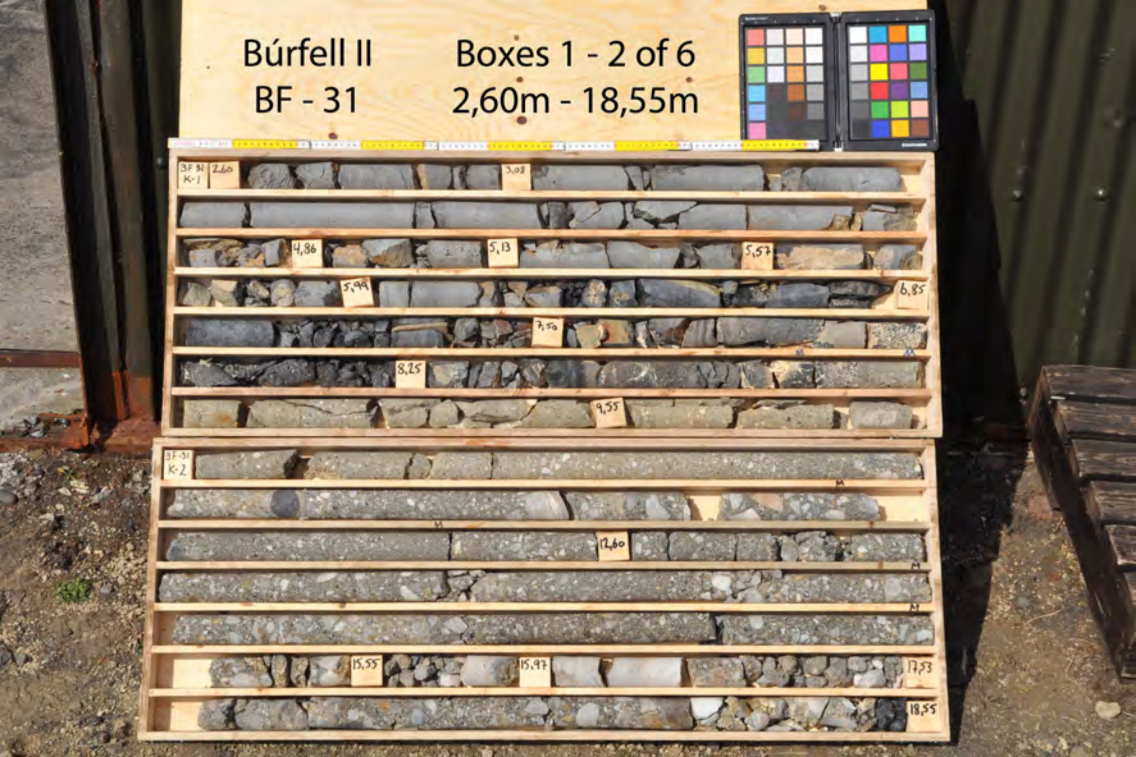

Búrfell II Boxes 15 - 16 of 21
BF - 30 119,40m - 134,30m
BF-30
K-15
119,60
120,60
123,60
126,60
BF-30
K-16
129,60
132,60

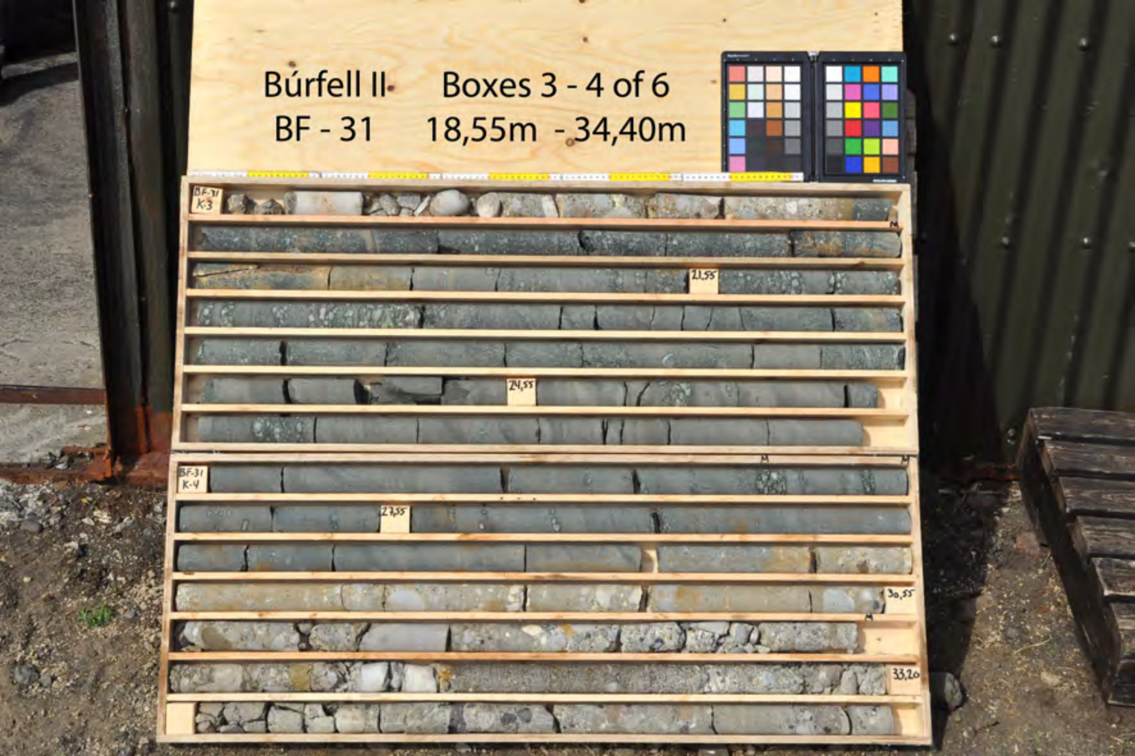

Búrfell II
Boxes 17 - 18 of 21
BF - 30
134,30m - 150,0m
BF-30 K-17
135,60
138,60
141,35
BF-30 K-18
143,22
144,60
145,30
146,55
147,60
149,0


Búrfell II
BF - 30
Boxes 19 - 20 of 21
150,0m - 169,0m
BF-30 K-19
150,60
150,93
153,60
156,60
159,10
BF-30 K-20
161,80
162,60
164,45
165,60
167,37
168,34

Búrfell II
BF - 30

Box 21 of 21
169,0m -174,10m


Búrfell II
BF - 31
Boxes 1 - 2 of 6
2,60m - 18,55m
BF 31 K-1
2,60
3,08
4,86
5,13
5,57
5,99
6,85
7,50
8,25
9,55
BF-31 K-2
12,60
15,55
15,97
17,53
18,55


Búrfell II
Boxes 3 - 4 of 6
BF - 31
18,55m - 34,40m
BF-31
K-3
21,55
24,55
BF-31
K-4
27,55
30,55
33,20


Búrfell II
BF - 31
Boxes 5 - 6 of 6
34,40m - 48,18m
BF-31 K-5
36,30
39,32
BF-31 K-6
42,38
43,68
45,01
46,80
48,18


Búrfell II
BF-32
Box 1 - 2 of 7
3,25m - 40,0m
BF-32 K-1
3,25
6,70
9,62
12,70
15,70
17,74
18,70
21,70
22,68
24,70
BF-32 K-2
27,70
28,94
30,47
31,15
34,17
34,65
35,67
36,70
39,55

Búrfell II Boxes 3 - 4 of 7
BF - 32 40,0m - 60,95m

Búrfell II BF - 32

Boxes 5 - 6 of 7

60,95m - 78,50m


Búrfell II
BF - 32
Box 7 of 7
78,5m - 84,32m
BF-32
K-7
78,70
79,60
M
81,70
83,74
84,32

Appendix F

Logs of rotary pneumatic percussion drilled boreholes.

Almenna verkfræðistofan
Landsvirkjun

Búrfell HEP Extension

Explanations
Corehole logging

Date: March 2013
Designed: AKS
Drawn by: AKS

🟫	Overburden	▨	Hyaloclastite
🟪	Basaltic Andesite	🟩	Peat
🟥	Scoria	🟧	Tuff
🟩	Olivine Basalt	▲	Moraine
🟨	Conglomerate	🟦	Tholeiite Basalt
🟩	Porphyritic Olivine Basalt	🟥	Sandstone

Explanations of symbols

Ⓝ / Ⓡ / Ⓐ	Rock magnetisation Normal / Reverse / Anomalous
―	Water level depth in meters (date)
15,5-24,7m >100 LU	Permeability Interval (in metres) and LU values
5,0 kN ⧗ 11,0 MPa	Point Load Test (PLT) kN = average readings from point load test MPa = point load strength index IS 50
I 3" ODEX I	Cuttings samples
▌	Casing

Explanations of formation

FG	Finiglacial
GT	Glacial till
SB	Sámsstaðarklif basalt
SM	Sámsstaðarmúli group
OB	Older Búrfell group

Q - system of rock mass quality

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

RQD (Rock Quality Designation)

Jn (joint set number)

Jr (joint roughness number)

Ja (joint alteration number)

Jw (joint water reduction factor)

SRF (Stress Reduction Factor)

$$Q_c = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

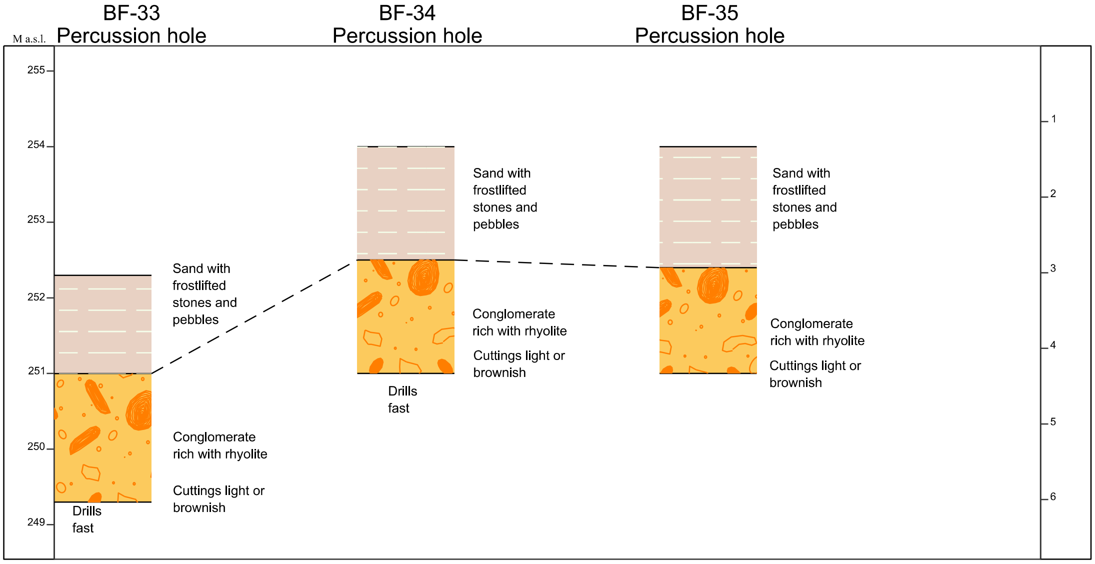
Jw and SRF are evaluated as 1/1 in the boreholes

Q_c = Q evaluated from core sample from borehole

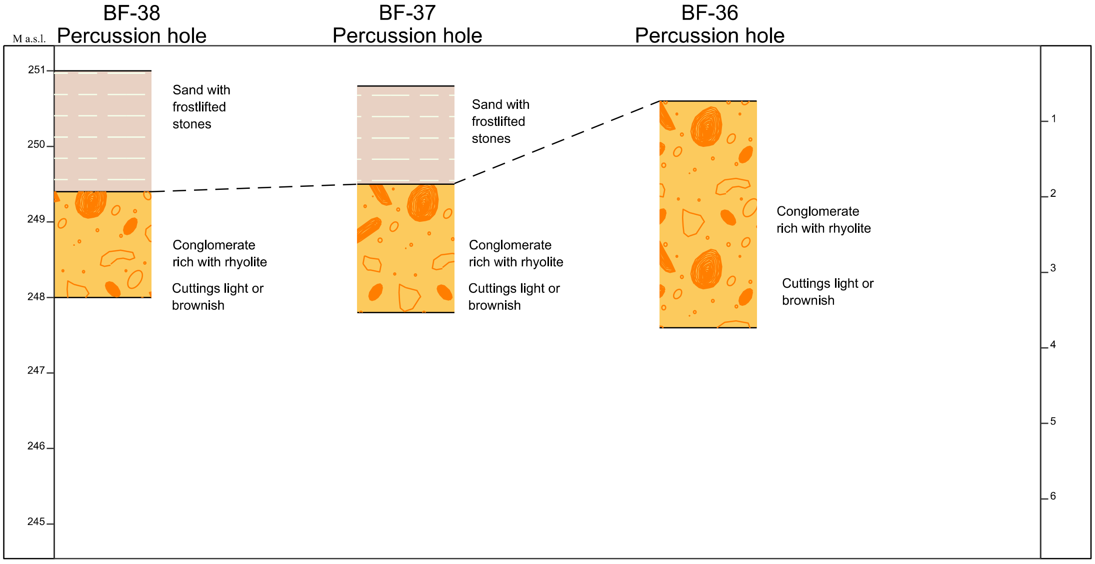
Búrfell HEP Extension

Drawing
Simplified Borelogs Owerview

Date: September 2012
Des.: SPS/ÁÓT
Drawn: ÁÓT



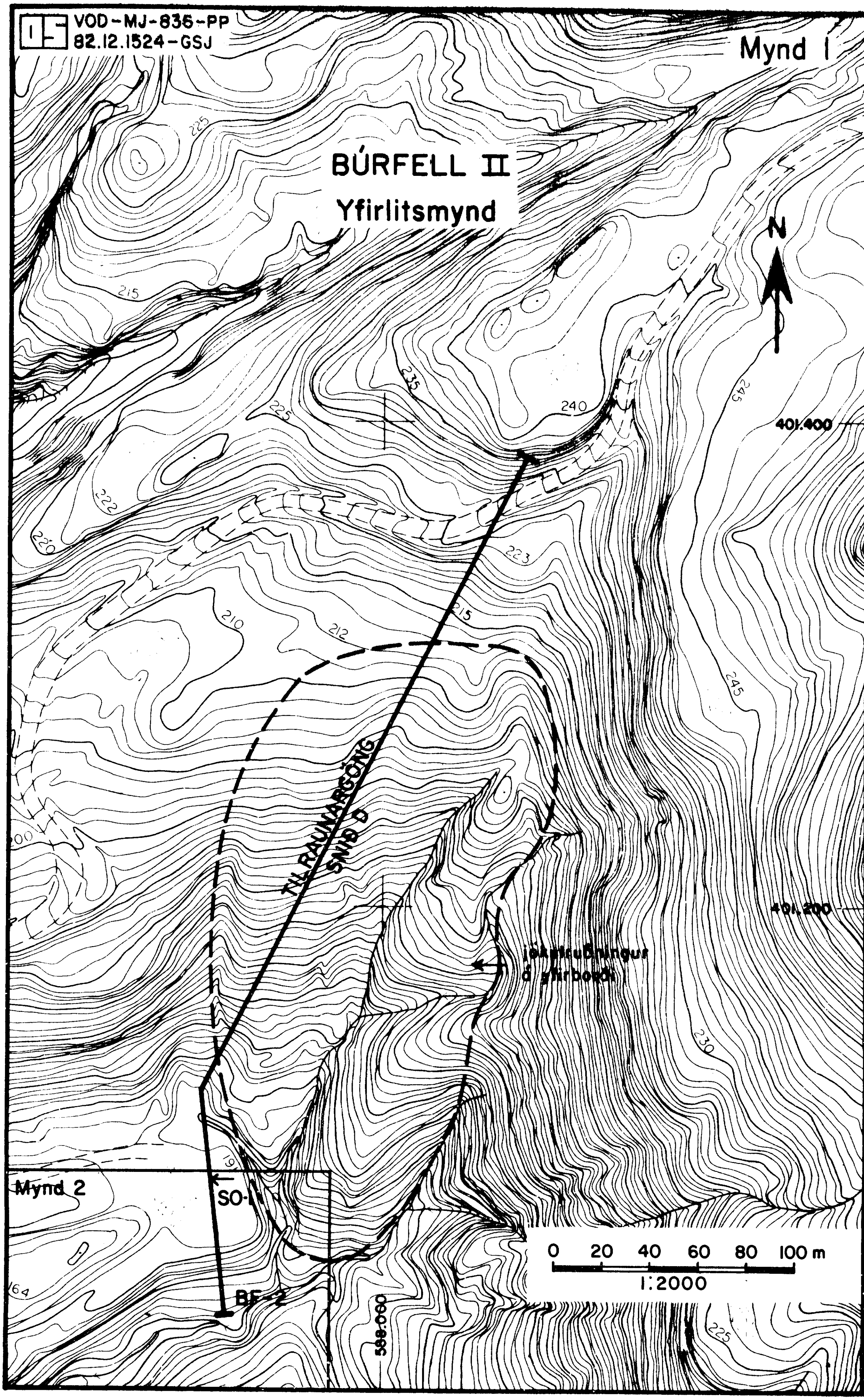
Elevation from topographic map

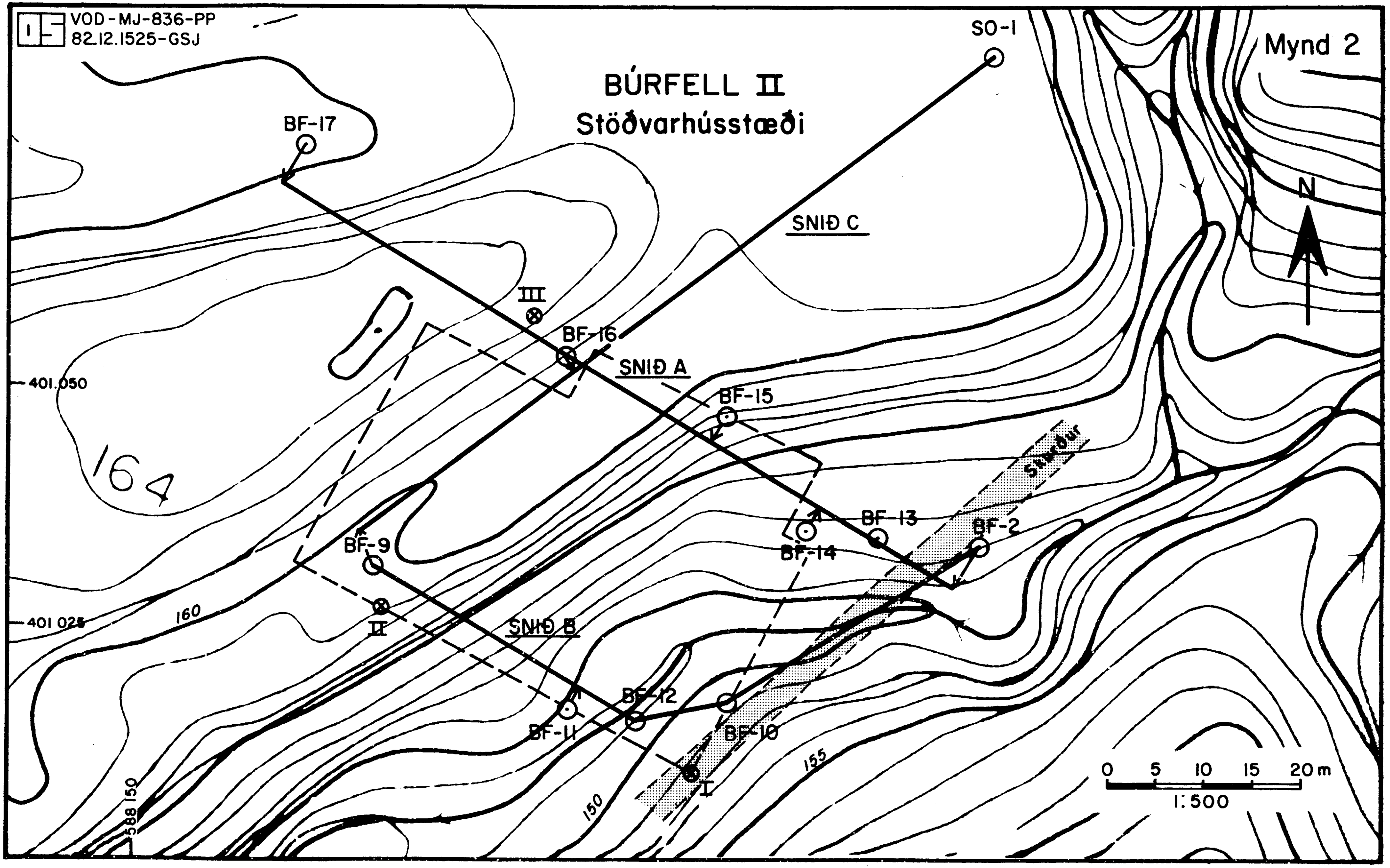


Elevation from topographic map

Appendix G

Mapping of glacial moraine according to (Pétur Pétursson (1982)).


VOD-MJ-836-PP
82.12.1524-GSJ
Mynd 1
BÚRFELL II
Yfirlitsmynd
N
225
215
235
240
245
225
222
220
223
210
212
215
245
200
401.400
401.200
TILRAUNARGÖNG
SNIÐ D
jökulruðningur
á yfirborði
230
Mynd 2
SO-1
BF-2
164
191
588.000
225
0 20 40 60 80 100 m
1:2000



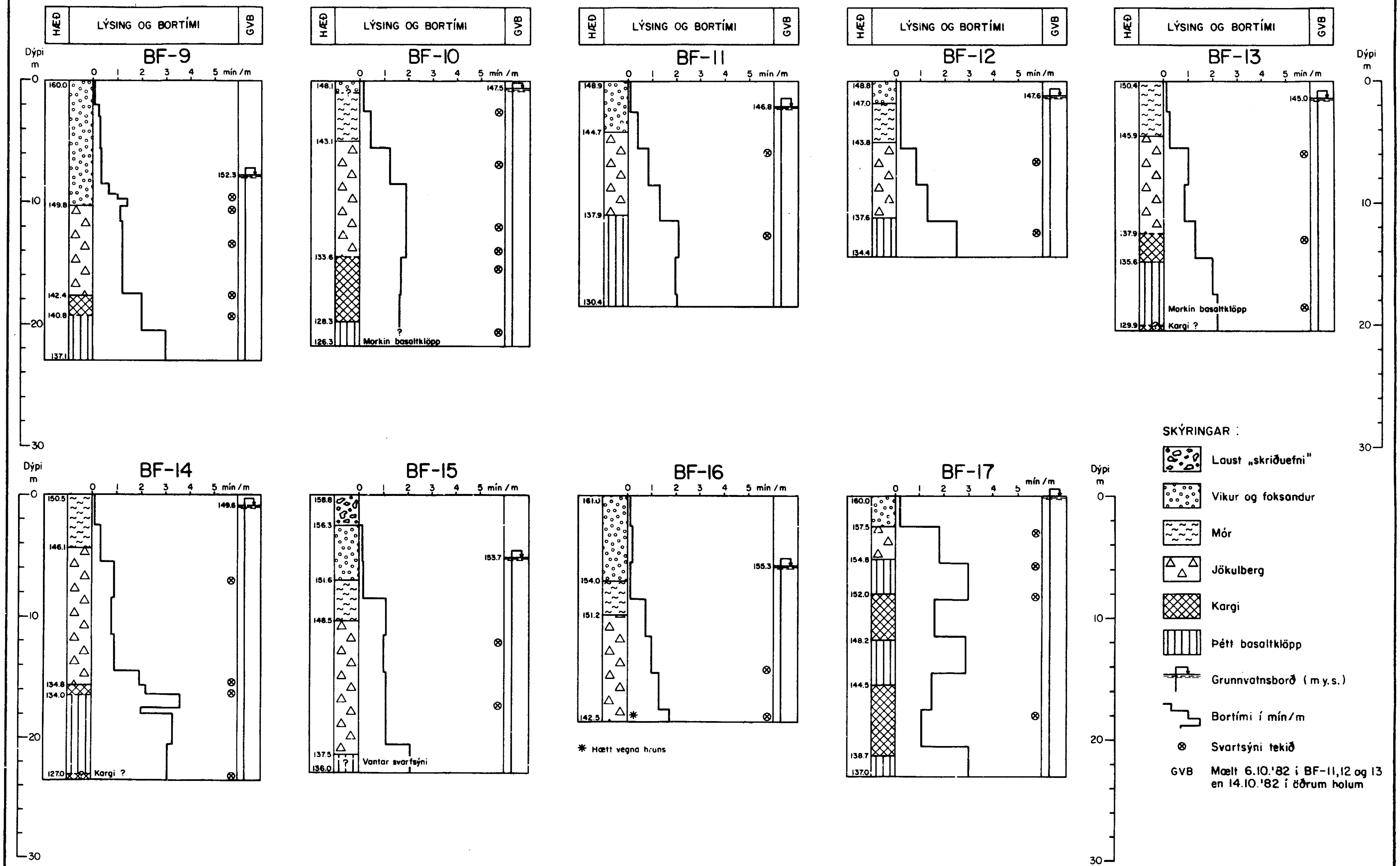
Mynd 2

BÚRFELL II
Stöðvarhússtæði

VOD-MJ-836-PP
82.12.1529-GSJ

Mynd 3

BÚRFELL II. Stöðvarhússtæði

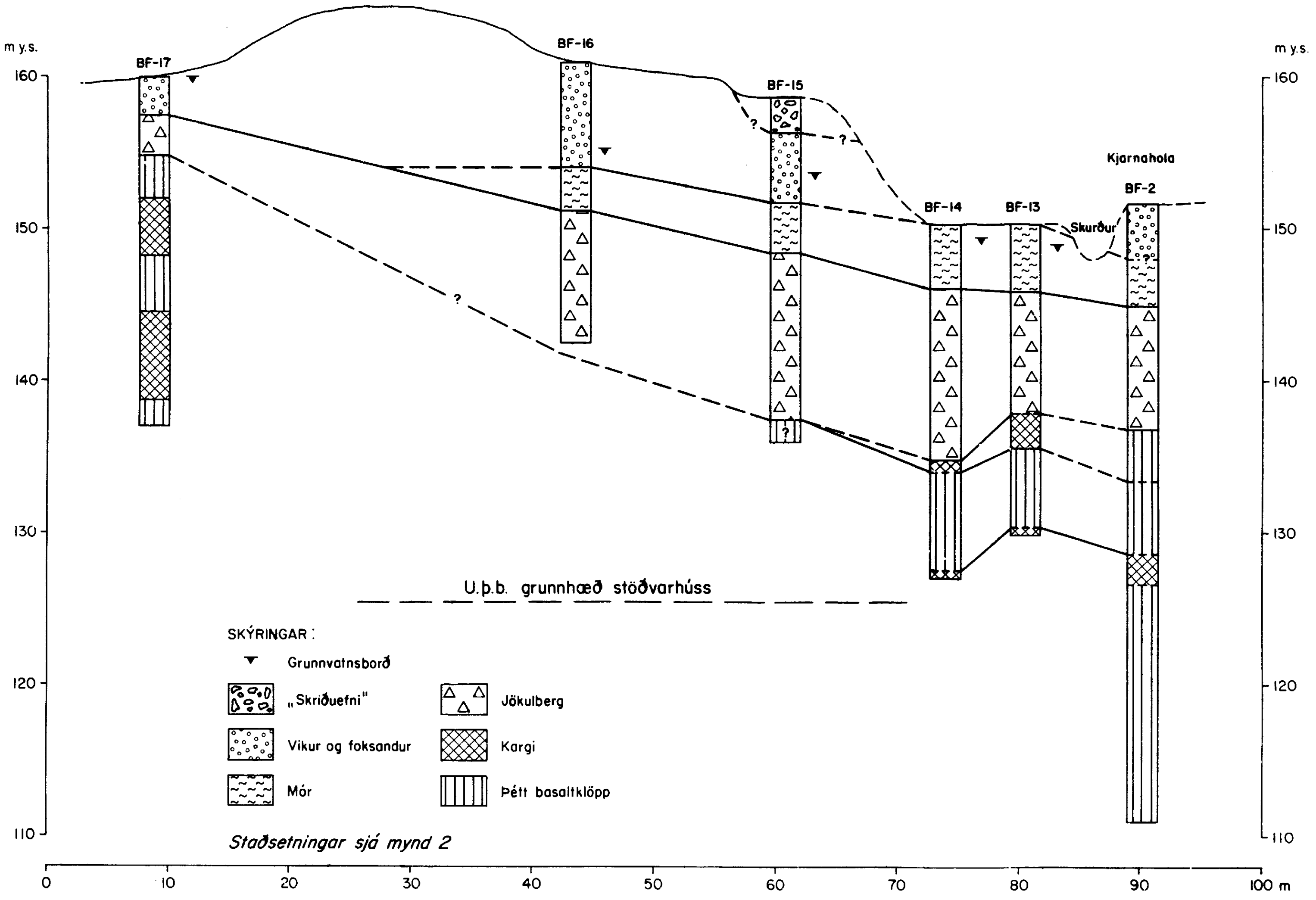


VOD-MJ-836-PP
82.12.1526-GSJ

BÚRFELL II

Mynd 4

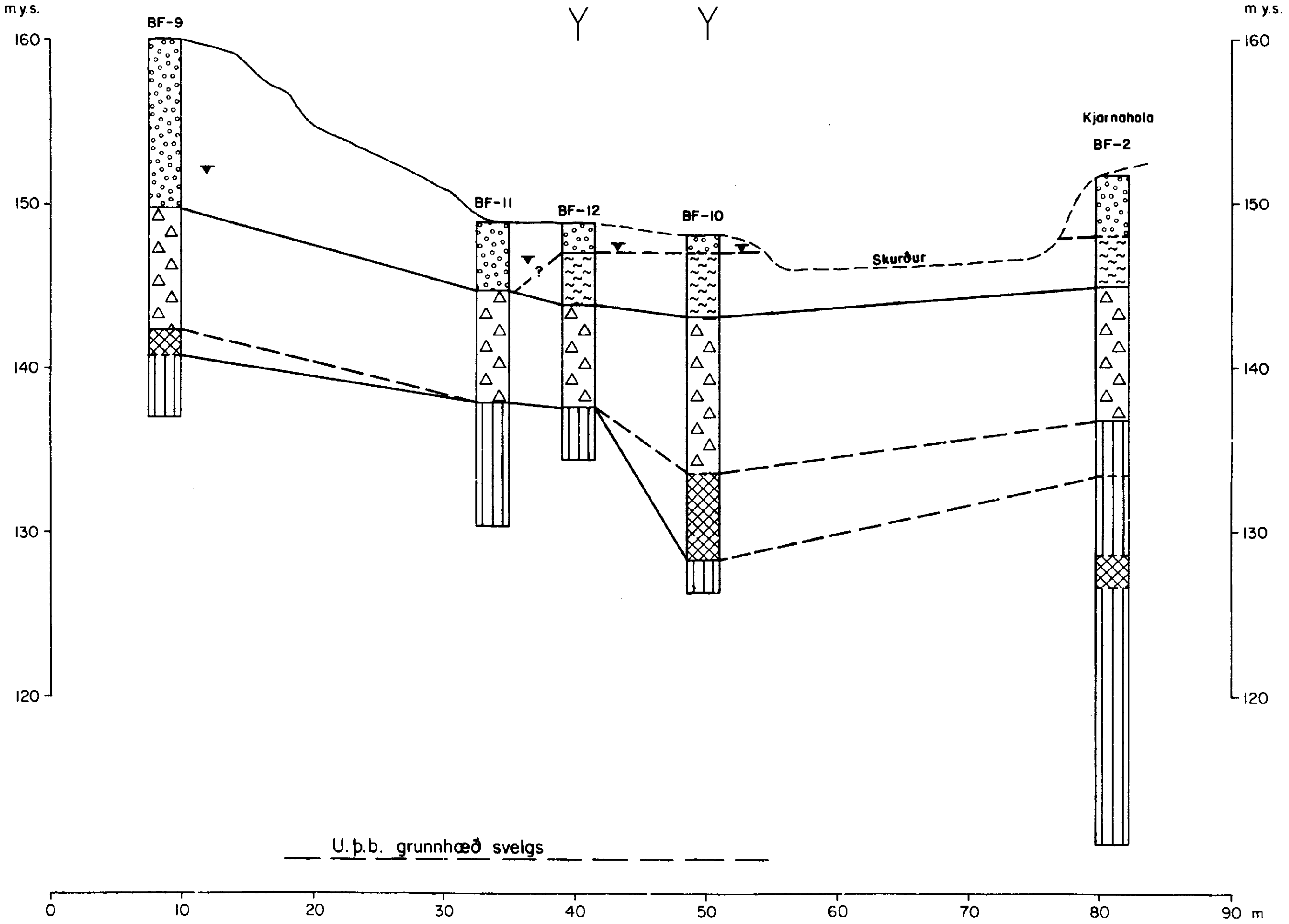
Stöðvarhússtæði. Snið A



VOD-MJ-836-PP
82.12.1527-GSJ

BÚRFELL II
Stöðvarhússtæði. Snið B

Mynd 5



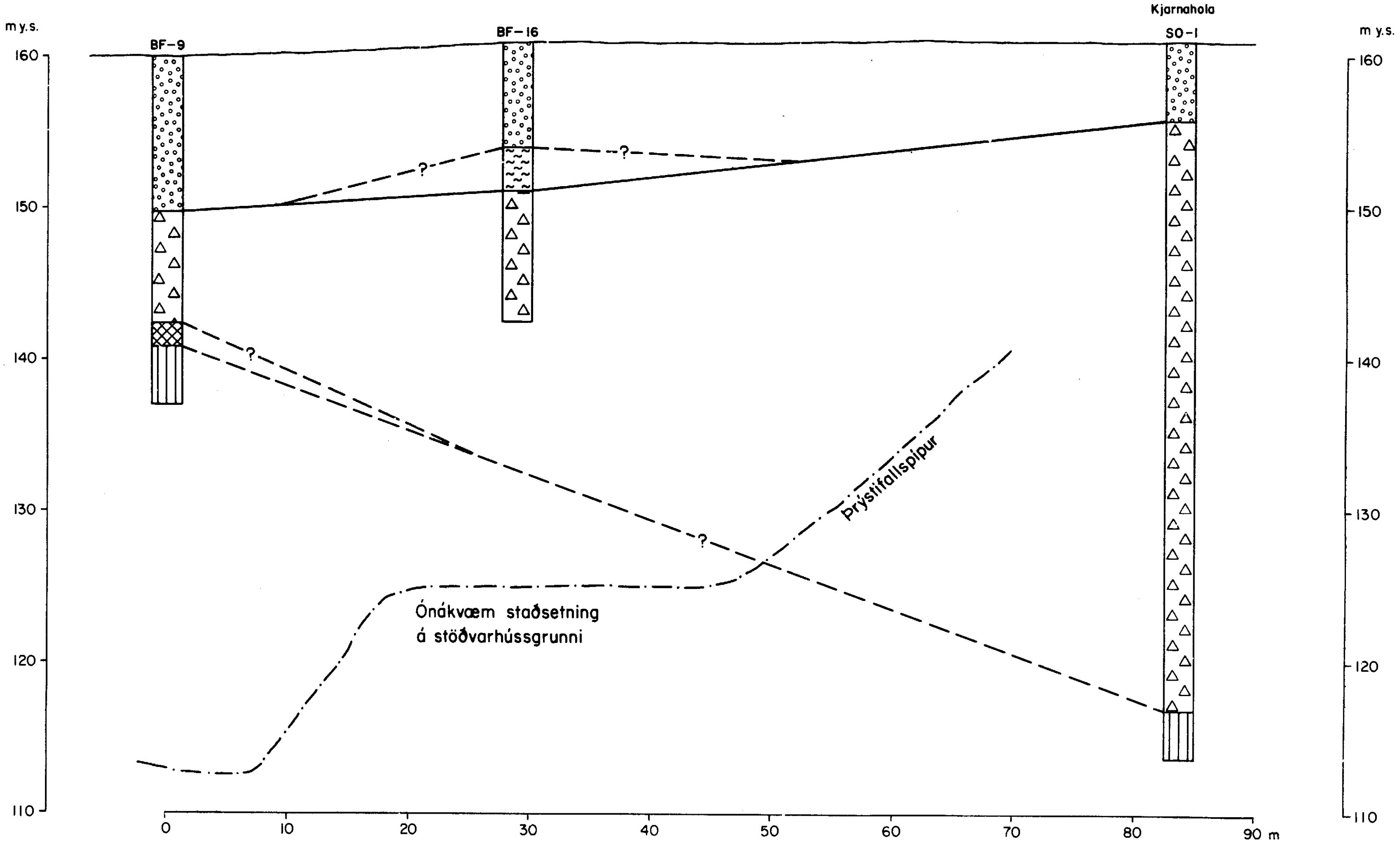
Skýringar sjá mynd 4
Staðsetningar sjá mynd 2

VOD-MJ-836-PP
82.12.1528-GSJ

BÚRFELL II

Stöðvarhússtæði. Snið C

Mynd 6

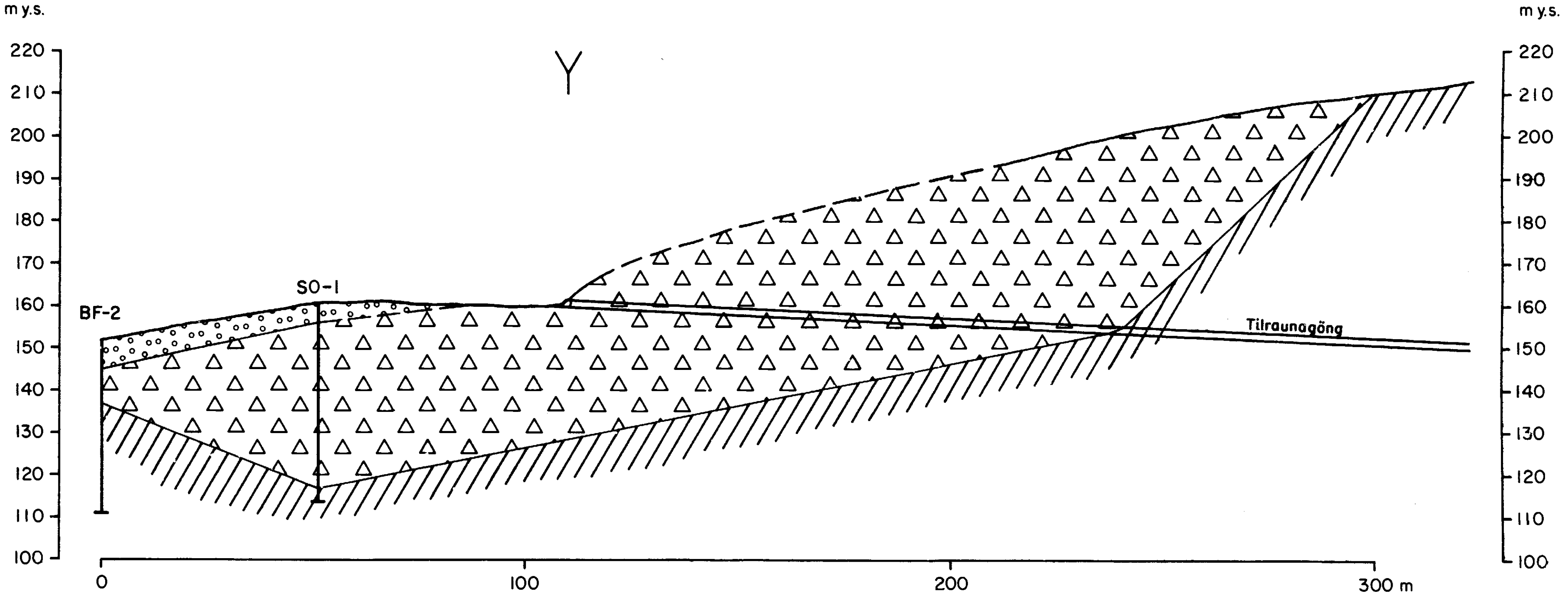


Skýringar sjá mynd 4
Staðsetningar sjá mynd 2

VOD-MJ-836-PP
82.12.1523-GSJ

Mynd 7

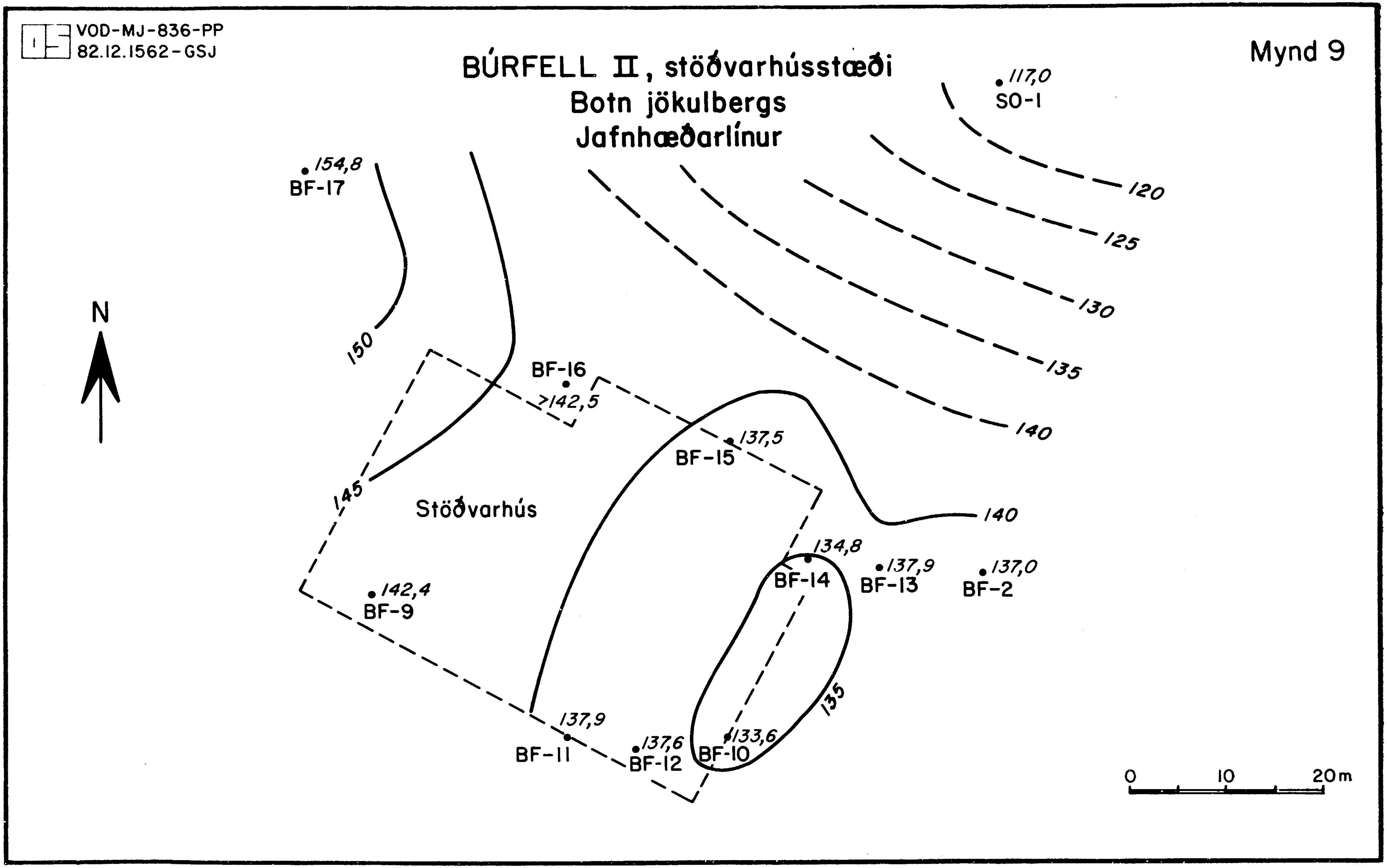
BÚRFELL II
Snið D gegnum BF-2, SO-I og tilraunagöng



Saðsetningar sjá mynd I
Skýringar sjá mynd 4

Mynd 9

BÚRFELL II, stöðvarhússtæði
Botn jökulbergs
Jafnhæðarlínur



Appendix H

Exploration tunnel in 1962. Location and geological section (Haukur Tómasson (1963)) and studies of progress (Haukur Tómasson (1967)).

stöðulónum, sem birtist í Verkfræðingatímaritinu, 4.–7. hefti 1964.

8.4 *Jarðsveiflumælingar.*

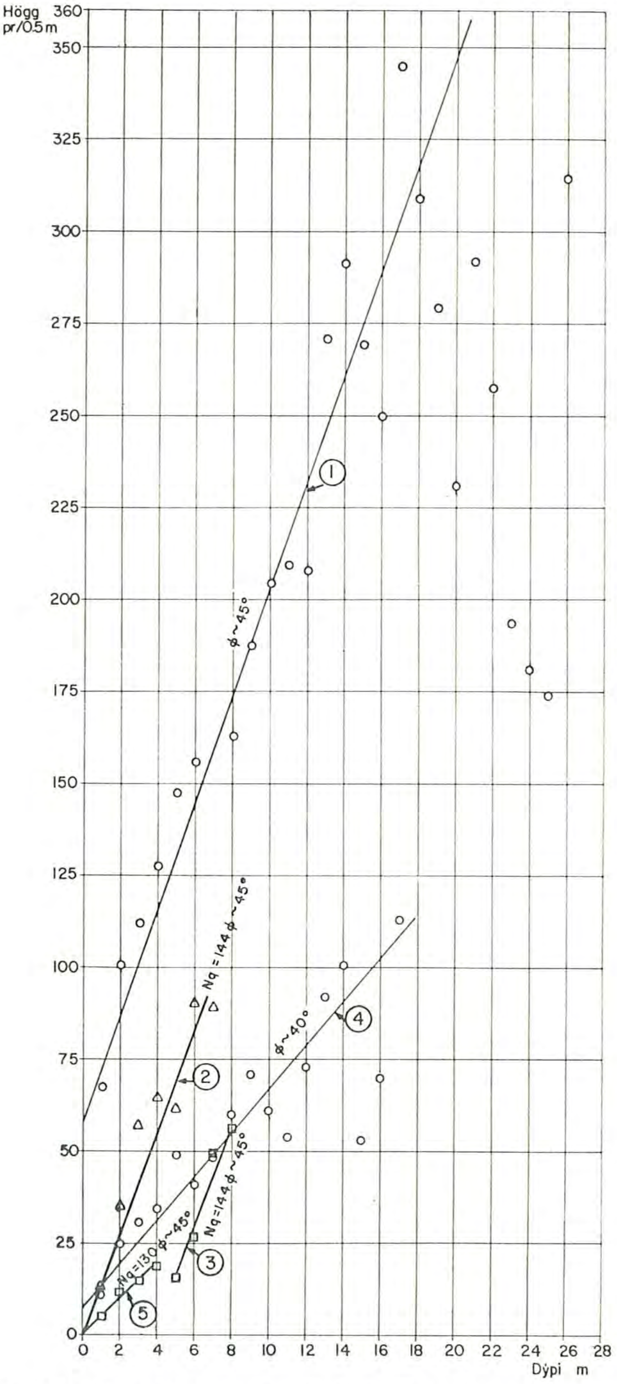
Til könnunar á þykkt lausra jarðlaga ofan á berggrunni er mest notaður Borro-bor, en einnig hafa verið notaðar jarðeðlisfræðilegar mælingar svo sem jarðsveiflu- og jarðviðnámsmælingar. Jarðsveiflumælingarnar byggja á mælingu hljóðhraða í jarðlögum, en hann er miklu meiri í bergi en lausum lögum. Jarðviðnámsmælingar byggja á því, að rafmagnsviðnám í jarðlögum er mjög mismunandi. Jarðsveiflumælingar henta betur til mælinga á þykkt lausra jarðlaga og hafa langmest verið notaðar. Yfirleitt er ekki hægt með jarðsveiflumælingum að finna þykkt lághraðalaga undir lögum með hærri hraða. Það var þó reynt við Búrfell að finna þykkt millilagsins undir fyrsta hraunlagi og var það gert með því að sprengja dínamit niðri í holum, sem náðu niður í millilag. Niðurstaða fékkst, sem nægði til að leiðbeina frekari borunum, sem var tilgangur þessarar mælingar.

8.5 *Borro-boranir.*

Borro-bor er lítill höggbor og eru stálstangir reknar með honum niður á fast berg. Fast berg er þá skilgreint á því dýpi, sem Borro-borinn kemst. Að sjálfsögðu hefur þetta sínar takmarkanir, því borinn getur stöðvast á stórum steini og einnig getur smáharðnað niður á fast þannig, að engin skörp skil séu milli fasts bergs og jarðvegs. Við borun með Borro er höggafjöldinn talinn þannig, að talin eru höggin, sem þarf til að slá borinn niður hverja ½ m færu. Höggtalningalínurit gefa verðmætar upplýsingar um jarðlög þau, sem borað er í gegnum. Bæði eru þau til hjálpar við greiningu þeirra og einnig má nota höggtalningalínurit til þess að reikna út skriðhorn og fá vissar hugmyndir um burðarþol og fleira. Á mynd 11 eru sýnd meðaltöl höggtalningarlínurita í nokkrum mismunandi jarðlögum við Búrfell.

8.6 *Könnunargryfjur.*

Til þess að bæta upp niðurstöður Borro-boranna og annarra mælinga á þykkt lausra jarðlaga henta könnunargryfjur mjög vel, því í þeim er unnt að gera athugun á berginu undir og einnig að fá örugga greiningu á lausu jarðlögunum. Þetta var töluvert gert við Búrfell, sérstaklega á stíflustæðunum. Voru sumar holurnar handgrafnar, en þó flestar grafnar með jarðýtu.



Mynd 11. Höggtalningarlínurit fyrir Borro-boranir. 1. er sandur frá ísaldarlokum; 2. er yfirborðslag hraunanna, sem er sand- og vikurblandið hraungjall og molar; 3. er sama, en liggur þar undir þykku vikurlagi; 4. skriður við Sámsstaðamúla, aðallega vikur; 5. vikur, mjög stórgerður, sem liggur ofan á 3.

Figure 11. Blow count in Borro soundings. 1. Finiglacial sand; 2. The surface layer on the postglacial lava flows, which is sand and pumice mixed with scoriaceous lava fragments; 3. is the same but is underlaying thick pumice layer; 4. Talus at Sámsstaðamúli, mainly pumice; 5. Very coarse pumice overlaying 3.

8.7 *Rannsóknarjarðgöng.*

Rannsóknarjarðgöngin, sem gerð voru við

Búrfell 1962 gáfu ýmsar fróðlegar niðurstöður og þar sem úrvinnsla á þeim hefur hvergi birzt, finnst mér rétt að birta þær hér. Ætlunin var, að jarðgöngin næðu inn í neðanjarðarstöðvarhús, sem þá var mest hugsað um. Staðsetning þeirra var einnig gerð með þau sjónarmið í huga, að vegalengdin inn í stöðvarhús yrði sem stytzt og halli ganganna sem minnstur. Engar rannsóknir voru gerðar áður en hafizt var handa nema séð var, að jarðgöngin mundu byrja í mórenu, sem menn þó bjuggust við að væri þunn yfirborðsskán. Talið var, að kostnaður við jarðgangagerðina mundi sparast upp í lægri tilboðum ef hægt væri að sýna tilbjóðendum bergið, sem vinna ætti frá jarðgöngunum. Einnig mundu þau spara tíma við bygginguna, því fljótlegt væri að stækka þau í aðkeyrslugöng fyrir stöðvarhússsprengingar og aðra vinnu þar.

Jarðgangagerðin var framkvæmd af vinnuflokki frá Almenna byggingafélaginu og var áætlað að ljúka 6 m á dag. Stærð ganganna var hin minnsta mögulega, eða 2 m á hæð og 2 m á breidd. Var því ekki hægt að koma að nema mjög smáum tækjum við gangagerðina. Göngunum hallaði 4.6% inn á við.

Mórenan, sem jarðgöngin byrjuðu í, reyndist vera miklu þykkri en búizt var við og voru göngin 130 m í mórenu. Þar fyrir innan tók við andesit, og hittu göngin á lagamót með andesit breksíu að ofan og heillegu andesiti í botni. Lögunum hallaði meir en göngunum, og gengu þau því smám saman upp í andesitbreksíu eingöngu, og síðan andesit í lofti og breksíu í gólfi, og innst voru þau eingöngu í andesiti. Í mórenunni var yfirleitt ekkert vatnsrennsli inn í göngin fyrr en komið var innst í hana nærri andesitinu. Þar var mórenan mun sandbornari og stóð verr. Fyrir innan mórenuna var alltaf töluvert innrennsli vatns, sem smájókst eftir því sem innar og neðar dró. Þetta innrennsli hafði töluverð truflandi áhrif á verkið, því vatnið rann að vinnustaðnum vegna halla ganganna. Vatnsrennslið var allan tímann í innstu 10–20 m ganganna en göngin þornuðu utar.

Helztu vinnslueinkenni hinna ýmsu jarðlaga voru: Leir- og mélurík mórena þótti sæmileg í borun en fremur erfið í útmokstri vegna þess, að hún vildi klessast við skóflur. Hægt var að ná mikilli inndrift í hverri umferð. Mórenan stóð vel en hélt áfram að veðrast allan tímann, sem verið var að vinna í göngunum. Opnuðust þá upp smásprungur og steinar losnuðu.

Sandkennda mórenan var erfið í allri vinnslu vegna vatnsaga. Inndrift var lítil, borun erfið og virtist mórenan standa illa meðan rennsli var í henni, en vel eftir að hún þornaði. Erfiðast var að moka henni, því vatn og mórena hrærðust saman í þunnan velling.

Andesitbreksían var mjög erfið í borun og sprakk illa. Inndrift var því lítil en vatn og salvi skildi sig vel að svo hún var auðveldari í mokstri en sandkennda mórenan. Göngin stóðu ágætlega í henni og var auðvelt að fá rétta lögun á þau.

Hið óreglulega stuðlaða andesit undir breksíunni var auðveldara í borun og hleðslu og formaði sig nokkuð vel. Það var alltaf unnið með breksíu og skil þess og breksíunnar óglögg.

Andesitið í lofti ganganna innst var grófstuðlað og mjög þétt. Það var seinborað vegna hörku en annars auðvelt í vinnslu. Það sprakk oft með stuðlum og voru því töluverðar yfirsprengingar í því. Ekki bar á láréttri kleifni í stuðlunum, sem er svo áberandi í veðruðu andesiti.

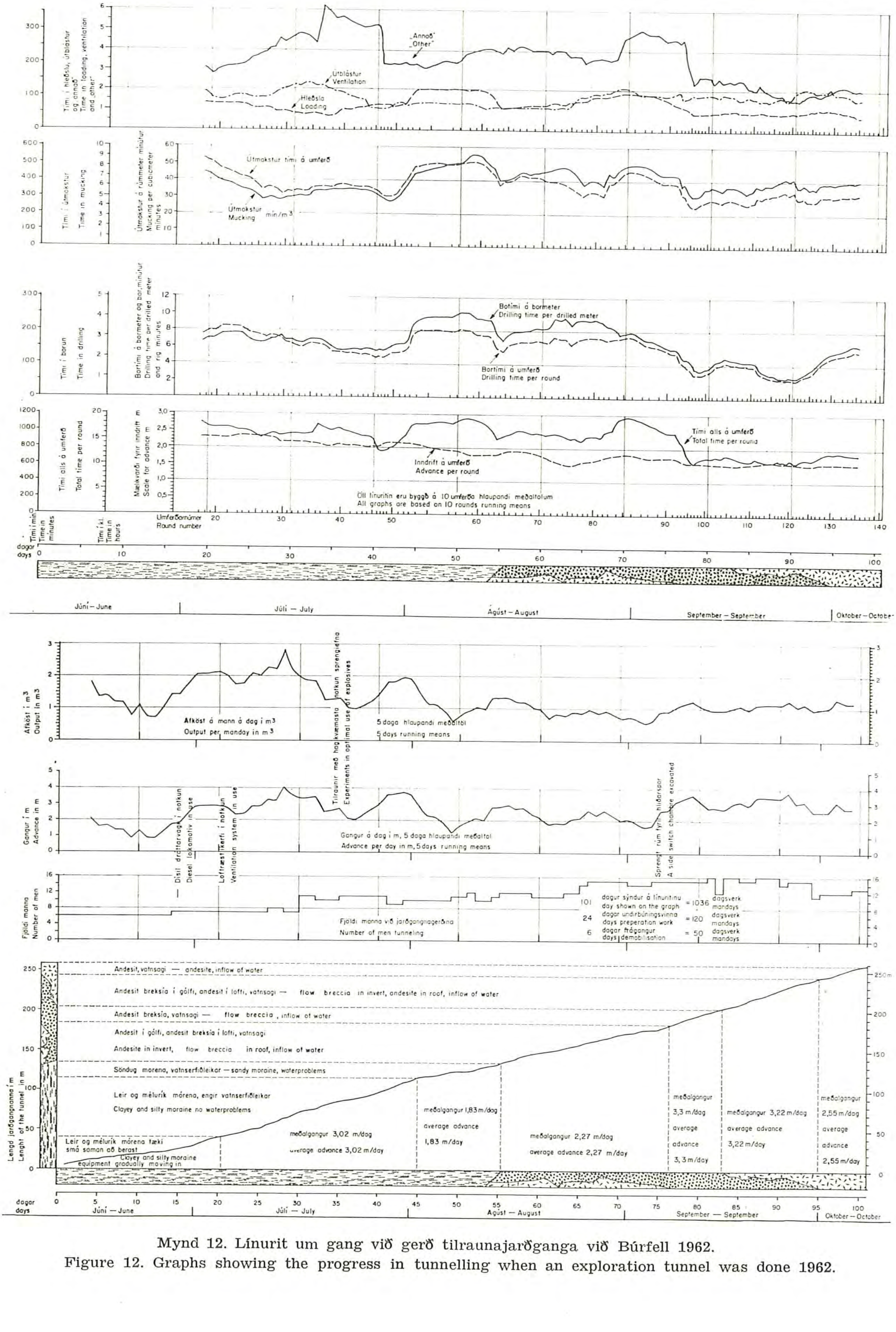
Á mynd 12 er í línuritsformi úrvinnsla á flestu því, sem í tölum var talið í sambandi við þessi göng. Neðsta línuritið sýnir gang verksins og jarðlög, sem farið var í gegnum. Upp á endann er einskonar jarðlagasnið af göngunum með gólfið til vinstri og loftið til hægri. Sama snið er sett á tímaásinn og sýnir í hvaða jarðlögum göngin eru á hverjum tíma.

Næsta línurit sýnir fjölda manna við jarðgangagerðina. Ekki tókst að ná hinum áætluðu 6 m á dag og var því stöðugt verið að bæta við mönnum til þess að reyna að flýta verkinu. Ekki virtist nást neinn árangur með því, eins og línuritin næst fyrir ofan bera með sér.

Þriðja línuritið sýnir lengd graftar á dag. Graftarhraðinn er mestur í mórenunni, áður en farið var að gera tilraunir með sprengiefnanotkun, sem dró nokkuð úr afköstum. Minnstur er hann innst í mórenunni. Í andesitinu var hann lítill lengi framan af en óx mjög verulega, þegar fengin var norskur verkstjóri, Olav Töndervold, til að reyna að flýta verkinu. Hafði koma hans veruleg áhrif, þótt honum tækist ekki að ná áætluðum afköstum.

Næsta línurit sýnir afköst í m^3 á mann á dag. Hefur það sömu sveiflur og næsta línurit fyrir neðan, en vegna þess hversu miklu færri menn voru fyrst eru afköstin langmest í mórenunni utan til. Fer það þar upp í 2 m^3 á mann á dag.

Næsta línurit sýnir inndrift á umferð og tíma alls á umferð. Inndriftin er mest í mórenunni frá 2.0–2.4 m en inni í andesitinu yfirleitt um 1.6 m. Tími á umferð var lengi vel milli 15 og 18 tímar en minnkaði niður í 12 tíma þegar Olav Töndervold kom.



Mynd 12. Línurit um gang við gerð tilraunajarðganga við Búrfell 1962.
Figure 12. Graphs showing the progress in tunnelling when an exploration tunnel was done 1962.

Bortími á umferð og boraðan metra er næsta línurit og þar næsta er útmokstur á umferð og rúmmetra. Þessi línurit eru mjög lík með topp frá sandkenndu mórenunni þangað til norski verkstjórinn kom. Honum tókst að auka borhraðann meira en útmokstürshraðann.

Efsta línuritið sýnir hleðslu, útblástur og annað, sem ekki fellur undir neitt þeirra atriða, sem þegar er upptalið. Hleðslulínuritið er mjög svipað og bor- og útmokstürslínuritin. Litlar sveiflur eru á útblástürslínuritinu. Útblásturstíminn er mestur snemma, nær svo lágmarki og vex svo jafnt og þétt eftir því sem innar dregur. „Annað“ hefur tvo toppa. Er annar þegar verið er að gera tilraunir með sprengiefni en hinn þegar reynt var að auka inndrift inni í andesitinu, en það gaf mjög slæma raun. Norska verkstjóranum, Olav Töndervold, tókst að minnka tímann, sem fór í „annað“ mjög verulega, eða niður í 2 tíma frá því að hafa verið yfirleitt 4 tímar.

Hætt var við tilraunagöngin þegar þau voru orðin 258 m löng, enda var þá útséð um, að þau mundu ekki verða búin fyrir þann tíma, sem ætlað var að skila áætlun um virkjunina. Ástæðuna til þess, að ekki tókst að ná tilskildum gangi, tel ég liggja í töfum vegna vatnsaga og því að bergið leyfði ekki nema mjög litla inndrift á hverja umferð. Gangurinn var beztur í mórenunni utantil eða allt upp í 4 m á dag. Hefði sú hagræðing, sem fylgdi komu Olavs Töndervolds verkstjóra verið komin, þá hefði þar mátt ná upp undir 6 m hraða á dag með 2.4 m inndrift. En með þeirri inndrift sem möguleg var í andesitinu hygg ég að 6 m áætlunin hafi alls ekki verið raunhæf.

9. Aðstæður á stöðum helztu mannvirkja.

Stíflustæðið er á hraununum, sem runnið hafa á eftirjökultíma. Aðstæður eru þannig, að Þjórsá rennur í þéttum stokk, sem aurburður árinnar hefur þétt. Langt út frá ánni á báða vegu hefur einnig borizt mikill leir úr ánni út í hraunið. Í efra borði hraunsins er, auk leirsins úr ánni, mikið um eldfjallaösku og vikur aðallega úr Heklu. Saman við þetta er blandað hraunmolum alveg upp á yfirborð. Hraunmolarnir eru sennilega frostlyftir. Þetta yfirborðslag er yfirleitt nokkrir metrar á þykkt og tekur þá við hið massiva hraun með mjög ójöfnu yfirborði. Jarðvatn er lítið í yfirborðslaginu, en niður við botn fyrsta hrauns kemur í jarðvatn. Er það venjulega 10–12 m fyrir neðan vatnsborð árinnar og hefur hún engin áhrif á það. Undir fyrsta hraunlagi, sem er venjulega um 18 m að þykkt, að meðtöldu lausa yfirborðslaginu, kemur millilag úr sandi og vikri eða þar sem annað hraun er undir, nákvæmlega eins lag og yfirborðslag efsta hraunsins.

Ekki er þess að vænta, að neinn verulegur leki verði í gegnum hraunið og sá leki, sem í fyrstu kann að verða, mun hverfa mjög fljótt vegna þéttingar af aurburði árinnar. Þar sem lekaleiðir eru stytztar var talin þörf að þétta millilag vegna hættu á grefti þess við aukinn jarðvatnsþrýsting. Verður þar gert þéttitjald niður í gegnum millilag, en að öðru leyti mun stíflan byggð á þéttu efsta hrauni.

9.2 *Jarðgöng.*

Aðrennslisgöng virkjunarinnar liggja í blágrýti og blágrýtisbreksíu myndaðri á lagamótum. Hvert blágrýtislag er venjulega um 10 m að þykkt með breksíunni og hallar lítið eitt til suðausturs. Þar eð göngunum hallar til suðvesturs skera þau nokkur lagamót. Einnig munu göngin liggja í gegnum 2 sprungur. Blágrýtið er með tvennskonar stuðlun, grófa og reglulega stuðlabergsstuðlun og óreglulega og miklu þéttari stuðlun, sem við köllum kubbabergsstuðlun. Bæði stuðlabergið og kubbabergið mundi samkvæmt Karl Terzaghi teljast mjög þéttsprungið berg og þurfa mikla styrkingu. Svo er nú samt ekki. Sprungufletir stuðlabergsins liggja þétt saman og eru svolítið bylgjaðir þannig, að hreyfing getur ekki orðið eftir þeim án þess að brjóta massivt berg. Stuðlarnir eru sem sagt mjög vel læstir saman. Kubbabergið hefur yfirleitt smærri og óreglulegri stuðla. Það er því einnig læst saman á svipaðan hátt auk þess sem það fær styrkleika á því, að stuðlarnir eru að heita má vafðir saman. Hvelfingar standa því ágætlega bæði í kubbabergi og stuðlabergi, en hægara er að forma hvelfingar í kubbabergi.

Breksían á lagamótum hefur allt aðra jarðtæknilega eiginleika eins og þegar fékkst reynsla af í tilraunagöngunum 1962. Breksían springur mjög illa og steinar eru oft hálflausir í millimassanum þannig, að hún borast og hleðst illa. Það sem samsvarar stuðlun blágrýtisins finnst varla og má næstum kalla bergið massivt með tilliti til þess. Það virðist standa vel í hvelfingum en þörf er á að verja það gegn vatnsgrefti.

9.3 *Stöðvarhús.*

Stöðvarhús virkjunarinnar er aðallega í móbergi, einkum þeirri gerð þess, sem nefnist tuff. Einnig reyndist vera kerfi af blágrýtisgöngum þar. Tuffið er mjög vel samlímt, enda er

Summary.

A geological investigation at the Búrfell Hydropower site on the Thjorsá River has been going on since approximately 1960, guided each time by the project under consideration. First it was proposed to build a large dam between Búrfell and Sauðafell but in 1961 it was abandoned because of difficult geological conditions on the damsite and a new project was proposed with a dam farther upstream near a site already chosen 1915 by a Norwegian engineer, Sætersmoen, in a study on the hydro-power potentials in the rivers Thjorsá and Hvítá. This new site was investigated thoroughly in 1962 and onward. To begin with a tailrace development was proposed but in 1964 a headrace development was planned and that project is now under construction.

The rocktypes in the project area are a variety of volcanic rocks with basaltic lava flows as the most common rock. Other types are tuff, breccias and pillowlavas mostly formed through subglacial and subaqueous eruptions, dolerite (gray basalt (diabase) lava flows, andesitic lava flows and rhyolitic lava flows and intrusions. Some sedimentary rock does also exist but has similar properties as tuffs or breccias.

The geological history of the Búrfell area starts some 4 million years ago and the oldest formation is a basalt formation at the south toe of Búrfell. Next in age is the older Burfell formation which was built up by an active volcanism at some distance west of the Búrfell area. The erupting products range in composition from basalt through andesite to rhyolite. In Sámsstaðamúli that formation is named Older Burfell Formation. In Sámsstaðamúli a valley was eroded in the Older Burfell Formation which afterwards was filled with móberg, a subaqueous formation. Sandstone also deposited in the water and then along the hillsides a talus breccia was formed and finally the valley was filled with basalt lava flows. These formations are all named Sámsstaðamúli Group SM. During that time the eruption fissure was just west of Sámsstaðamúli or even in the westernmost part of it.

The first unmistakable glacial occured after the time of the SM group and during that time a subglacial eruption occured in Burfell and the thick pillow lava top of Búrfell was formed. It was almost one million years ago. In this eruption a very thick intrusive layer which is underneath most of Sámsstaðamúli was formed.

After this there was a valley or a canyon erosion in Sámsstaðaklif which shortly afterwards was filled with basaltic lava flows. This formation is named Sámsstaðaklif Basalt Formation SB. When this was formed the volcanic zone was north or northeast of Búrfell.

Doleritic rock was formed extensively during the last interglacial in Iceland. The dolerite (gray basalt) at Skeljafell might be of that age. The layers are almost horizontal and there is every indication of low age. The formation is called Skeljafell Dolerite SD.

During the last glacial the land was sculptured almost to the present form. The móberg ridges east of Ytri Rangá were also formed in subglacial eruptions. In Postglacial time i.e. during the last 10.000 years a substantial addition has been through sedimentary deposits, deposited on the South Icelandic lowlands in Finiglacial time when the sealevel was much higher than at present time and through lava flows coming from the Veiðivötn area which have built up the valley bottom east of Búrfell about 100 m, which create the head utilized at Búrfell. These lava flows have changed the drainage pattern of southern Iceland substantially as shown on fig. 6. Another volcanism in postglacial time is in the Hekla region only 12 km. away from Búrfell. It has formed enormous layers of pumice and ash which forms thick overburden in the Búrfell area.

Dating of the formations has mainly been through measurements of paleomagnetic polarity of the rocks. In figure 7 is a scheme showing the polarity epochs and events as they are now dated and tentative correlations of own polarity measurements.

The usual dip is towards east to north and clearly increases with increasing age. The oldest basalt formation is dipping 4°–5° but the youngest formations have practically no dip. There are two types of faults in the area: normal faults with vertical movements and strike slip faults with horizontal movements. At some of the strike slip faults a horizontal movement of the order of magnitude 500–800 m can be suspected. This is indicated by the offset of the other set of faults crossing it. The fault lines are not seen on the postglacial lava flows nor in the youngest móberg.

The geological investigation was done with: drilling permeability testing, ground water level measurements, seismic sounding, Borro sounding, test pits, and exploration tunnelling.

The drilling is the most extensive investigation. On the whole 128 holes have been drilled with

total length of almost 6000 m. Figure 10 shows the result of an analysis of the frequency of the different permeability in the layers which make up a lava field. It shows clearly that the lower contact of lava flow is by far the most permeable but the interbed has the lowest permeability. This was tested in the postglacial lava fields but there is every indication that this is a common rule independent of the over all permeability of the lava field which decreases rapidly with increasing age. In the uppermost line of figure 10 the permeability test is shown in rock which is mostly between one and two million years old.

Figure 11 shows results from blow count with the Borro sound which is really nothing but a small percussion drill designed for overburden drilling only. The friction angle and indications of bearing capacity can be obtained from these diagrams.

The exploration tunnel made 1962 was 258 m long and was in moraine, massive andesite and andesitic flow breccia. The diagrams on figure 12 show the progress and time studies connected with this tunnel.

The damsite is situated on postglacial lava flows highly permeable and with ground water level more than 10 m below river level. The tightening effect of the silt in the river water will take care of most of the water loss but where leakage path is shortest a slurry trench is made for the safety of structures and to decrease the loss of water.

The tunnel will be in basalt lava flows usually densly jointed. It stands though very well because the columns are so tight together that movement cannot occur without breaking the massive rock. The flow breccia at the contacts is much softer a rock than the basalt but it is sparsely jointed and stands well in tunnels. It is though difficult in blasting and needs much more explosives than the hard basalt.

The power house is founded on tuff and tuff-rich breccia. Also a set of basaltic dikes is crossing the power house area. The joint pattern has strong tendency to be parallel to the dikes and faultzones and the jointfaces are often a little altered to clayish material which makes it more problematic than the joints of the basalt even if it is much closer spaced.

Heimildir.

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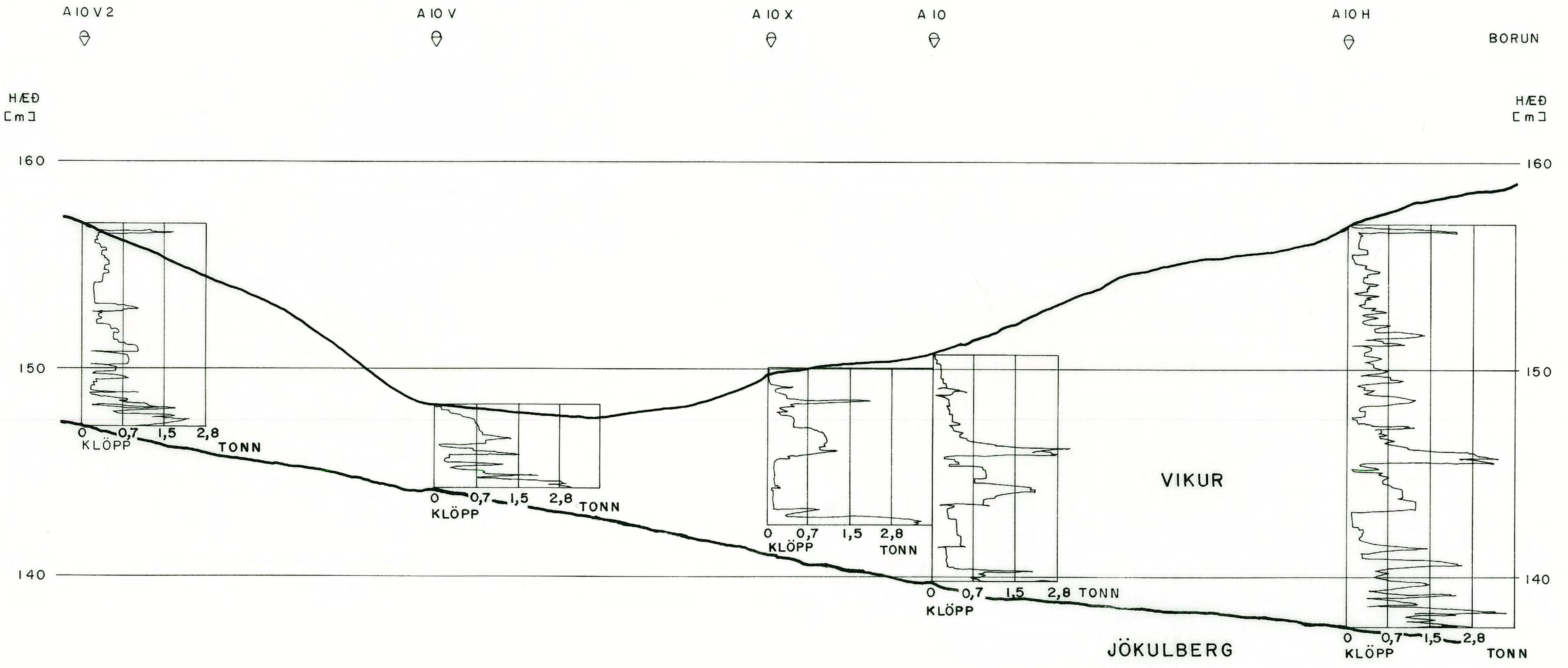
Appendix I

Surface powerhouse. Cross sections from thrust rotary soundings (Almenna verkfræðistofan hf. (1982)).



SKÝRINGAR :

⊖ GEONOR - BORVAGN

ALMENNA VERKFRÆÐISTOFAN H.F.

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SNIÐ 10-10

Hannað J.S. Teiknað H.S. Samþ

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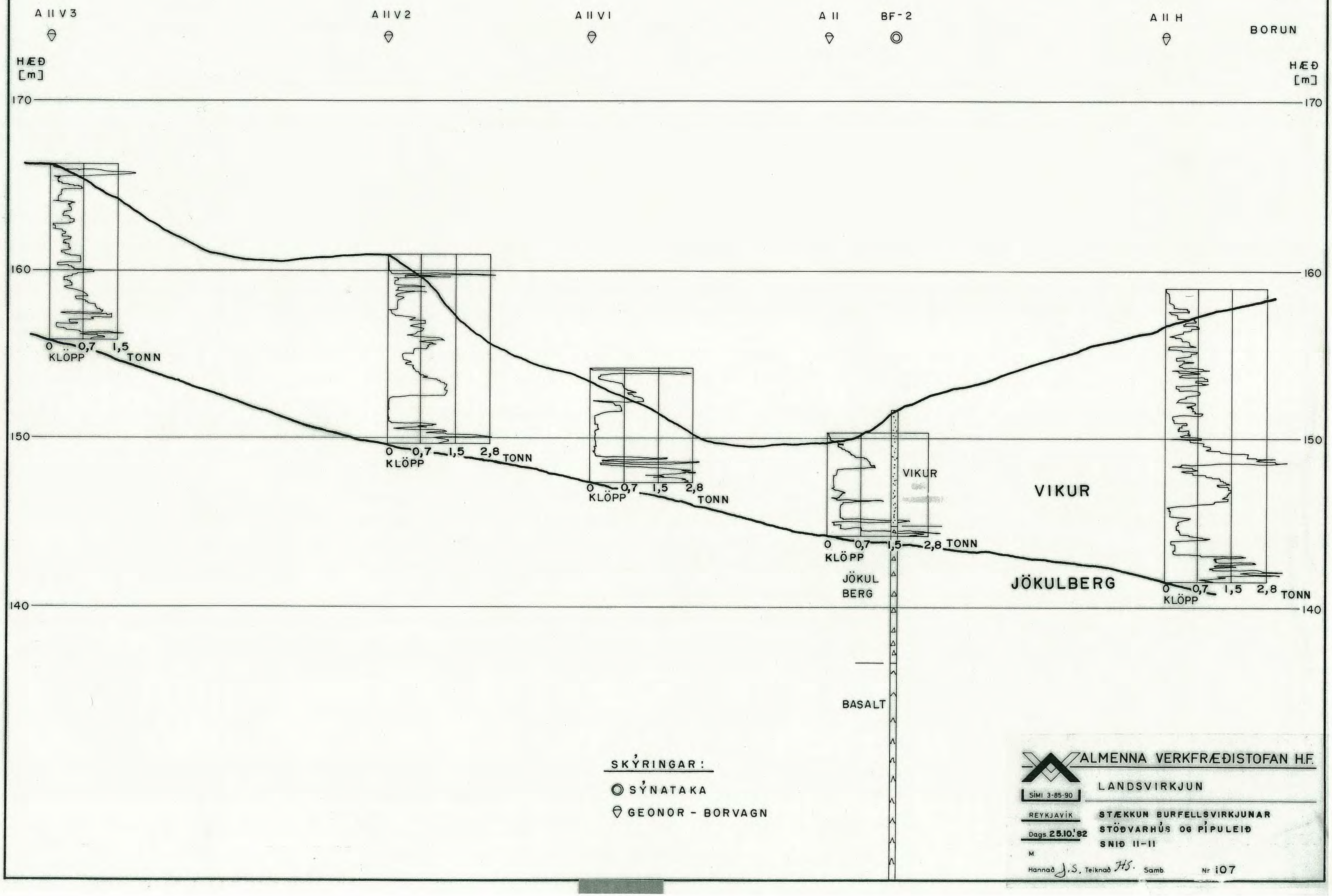

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SNIÐ 12-12

Hannað J.S. Teiknað H.S. Samþ. Nr. 108

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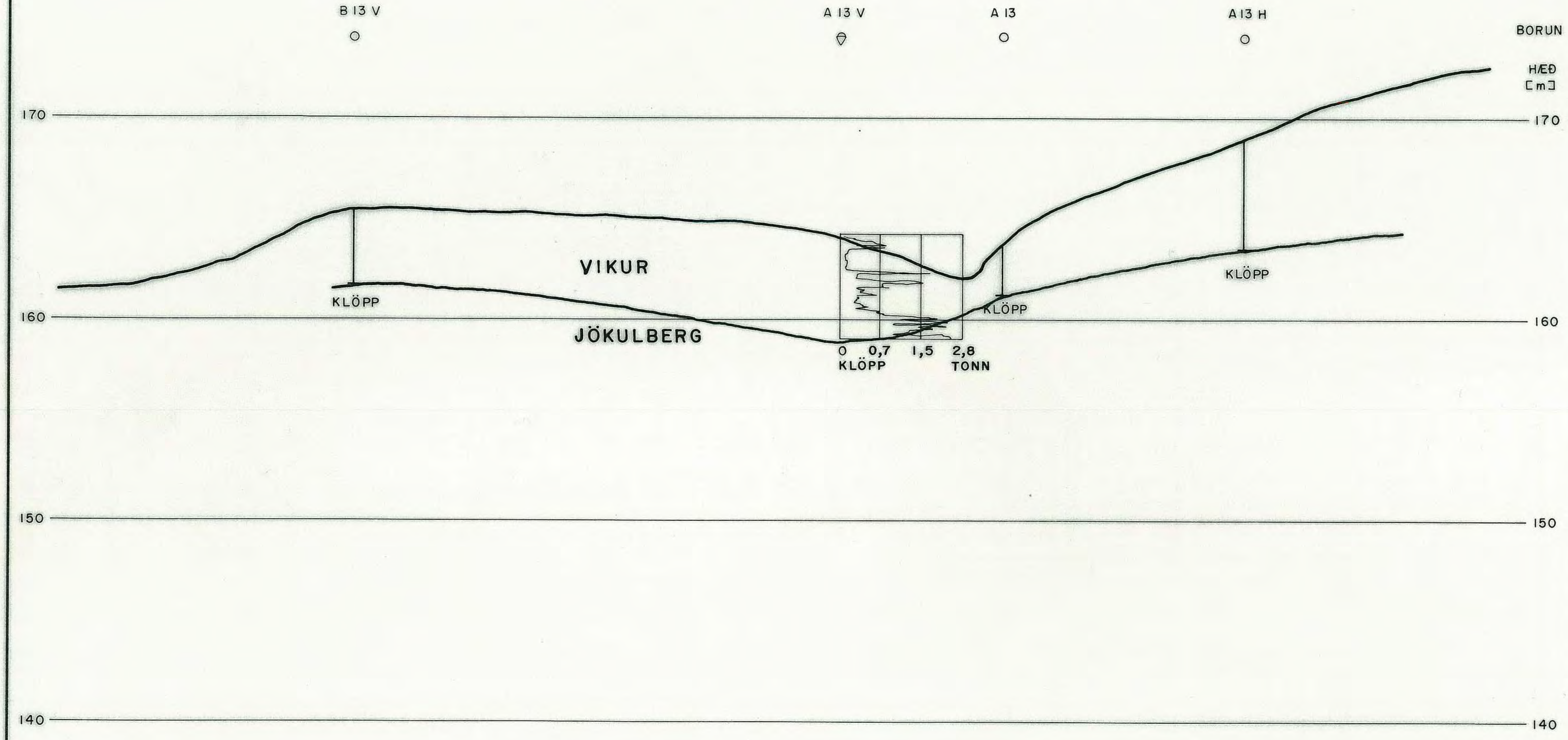

SKÝRINGAR :

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○ COBRABORUN

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