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Geological Investigations 2001-2006

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Abstract:

The report contains information and findings regarding geological investigation carried out in 2001-2006 for the Hydroelectric project of Holtavirkjun. The information consist of borehole logs, geological sections, temperature- and water level readings and informations of tests in holes and on core (Lugeon and Point load tests). Maps of surface deposits, general geology and basic geographic featurs are included.

Keywords: Geology, Holtavirkjun, Corelogs, Lugeon tests, Point load tests, pump test, seismic refraction survey, active fissures, temperature measurments, Þjórsá Lava.

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Landsvirkjun's project manager's signature

Guðlaugur Þórarinsson

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Summary

The bedrock in the area is comprised by a series of basalts and conglomerates from the extinct Stóra Laxá central volcano. The series are comparatively impermeable and reasonably competent rocks. They are overlain by series of competent interglacial lava flows of varying thickness. They are little or un-altered. On top of the interglacial lavas there are series of Holocene silt and sand. The silt is sandy and considerably cemented even if the apparent UCS strength is low but the thin layer of sand and gravel on top of the silt is poorly or un-cemented. The youngest formation is the Þjórsá lava which covers a good portion of the intake pond and forms the foundation for part of the project components. The lava is competent in most places but is very thin near the dam area

Several active fissures have been mapped in the area, some of which were mapped after the earthquake of 17. June 2000. The quake had an epicenter just south of the project are. Several active fissures have been found near most of the project components.

The main sources of permeability can be traced to the scoria of the Þjórá lava and to secondary permeability due to faults and especially active fissures.

The diversion structure and the weir will be founded on the Þjórsá lava. The lava is rather thin near the dam site and leakage paths to the gorge at Hamarinn are very short. The powerhouse and intake structure appears to be partly founded on old hydrothermally altered basalts and partly on younger interglacial basalts. Its present location appears to be near a fissure zone near the west flank of the Hamarinn. More fissure zones were found at the east flank. The mid section of Hamarinn appears to be least faulted site near the powerhouse. The tailrace canal will mostly be excavated in sand and gravel deposits near the Þjórsá river.

1 General geology

Introduction

The underlying part of the bedrock in the project area (Drawing 1) belongs to the Stóra-Laxá central volcano series. The Stóra-Laxá (SL) volcano was first identified and partly mapped by Ingvar B. Friðleifsson 1970 [20]. The centre of the volcano lies to the north and west of the project area. Orkustofnun updated the mapping 1976-1980 [11] as a part of a geothermal survey in the area. The report provided the first geological data used in the early studies of the present project area. A more detailed study of the area is found in a report published by Orkustofnun [5], see also geological map in drawing 3. The geological investigation was continued in 2000-2002 [1]. Geological observations in the area were intensified still in the present study, which started with a drilling campaign, which lasted from October 2006 to December 2006. Almenna Consulting Engineers performed the present investigation. The geologists Snorri P Snorrason, Gunnlaugur Þorbergsson, Melkorka Matthíasdóttir, Sigmundur Einarsson and geographer Áki Thoroddesen prepared this report. Ágúst Guðmundsson, from JFS Geological services, assisted and evaluated some details of the geological observation and performed magnetic and VLF surveys. Active fissures were mapped by The University of Iceland in 2000 and 2001 [15].

The present drilling campaign was mostly done in October and November 2006. The first holes were drilled on the Árnes Island but it was not fully completed as ice in the Þjórsá river made crossing untenable for the drillers crew. The diversion structure at Búði Waterfall and the canal from the intake and down to the intake lake was not investigated as planned. The investigation of the easternmost part of weir was not completed either.

Figure 1-1. Þjórsá river (Árneskvísl) iced over 16. November 2006.

Regional geology, a brief outline

The bedrock in the southern lowlands of Iceland was formed some 2-2.5 million years ago during a cold climatic period extending from 3.1 million years ago to the end of the Pleistocene ten thousand years ago. This era in Icelandic geology is often referred to as Plio-Pleistocene as it covers the Pleistocene and a part of the Pliocene eras of the Tertiary period. The climate in Iceland during the era is consistent with the Ice age of the Pleistocene.

The bedrock is characterized by series of basaltic lavas interbeded with relatively thin layers of conglomerate and sometimes irregular thick layers or heaps of hyaloclastite. The Stóra-Laxá central volcano dominates the volcanic pile to the north of the area. Activity in The Stóra-Laxá central volcano ceased in the Pleistocene era and after that erosion became the dominant geological process forming silt deposits in both marine and lacustrine environment [11]. The erosion process was interrupted by several Interglacial lava flows and a Holocene lava flow, all of which have their origins far outside the studied area.

Plio-Pleistocene rocks

Skarðsfjall tholeiite group (STG)

The oldest rocks in the project area are series of tholeiite and olivine tholeiite basalt layers and hyaloclastite, found at the base of Akbrautarholt where they are exposed and on the bank of Þjórsá River just downstream from the Búði waterfall. They are of the same age as the Stóra-Laxá central volcano and belong to its rock suite. These layers are not found at surface elsewhere in the project site, although basalt layers belonging to this group are found at the powerhouse site of Holtavirkjun. These rocks are hydrothermally altered and often intersected with dykes. They are generally highly jointed in the area.

Interglacial formations

Interglacial silt deposits (LTS)

After the volcanic activity of Stóra-Laxá central volcano ceased a period began of alternating erosion of valleys and their filling of silt deposits and lava flows which had their origins outside the study area.

During this period the glaciers eroded a valley in SW direction from Búrfell down to the moraines at Búði waterfall. This valley is now covered by the Þjórsá-lava. Evidence of this buried valley is found to a certain degree in most of the boreholes that penetrate the Þjórsá-lava. The age of the valley is not entirely certain. The presence of interglacial lava in the area of Hvammsvirkjun overlying a sequence of silt layers shows that the valley has existed for a long time and its minimum age dates as far back as to the Eem Interglacial Period. The silt deposits observed in boreholes display a lower silt series of Pleistocene age (LTS) and it must be assumed that this older silt series is to be found in the general area near the present Þjórsá river. The possibility of encountering silt formations belonging to these series during construction phase of the project are however remote.

Akbraut Interglacial Basalt (HIB)

The main river course in the area has probably been very close to the present location of the Þjórsá river for a long time. The cube jointed interglacial basalt in boreholes near Skarðsfjall indicates its presence between Skarðsfjall and Núpur. The cubic joint pattern shows the presence of water (probably in the form of a river flowing forth on top of hot lava). The interglacial lava found in this area is either almost fresh or slightly altered cube jointed olivine basalt. It is very similar to the Akbraut interglacial basalt found in the area of Holtavirkjun.

The simplest relation between the interglacial lavas in the aforementioned holes and in Holt district is that they represent the same formation or lava flows that have descended through the pass between Skarðsfjall and Núpur across the silt-covered valley to south towards Holt district were it is found today. The river would have kept on flowing down on top of the lava, cooling it at first but later eroding it with time. The glaciers of the Pleistocene period have later contributed to the process. The Akbraut Interglacial lava is found in Akbrautarholt, at the powerhouse site and also below the dam site in cored hole NK-38. It is not found in NK-36, but it is almost 40 m thick in NK-40. These observation shows that the layer is discontinuous and its thickness varies greatly.

Hreppar Interglacial Tholeiite

These layers are found in the hills of Flagbjarnarholt just east of the intake construction. They consist mainly of fresh or little altered tholeiite lavas sometimes columnar jointed or cube jointed. The low weir at the diversion structure might rest against these rocks.

Holocene formations

Silt and tillite series (UTS)

The valley described in previous chapters could have reached from the sea at Eyrarbakki and possibly as far up-land as Búrfell. Kristján Sæmundsson, 2001 (pers com) has pointed out thick layers of silt under the Þjórsá-lava in the area east of Hestfjall. The moraine at Búði is mostly reasonably cemented siltstone and the un- or poorly consolidated silt in area of Hvammsvirkun indicates that the glacier has retreated from the Búði moraine at the end of the last glaciation [8], forming a laccustrine lake (similar to the present Breiðamerkurlón) between the moraine and the glacier in the process. The UTS serie is found below the Þjórsá lava at the weir site and it is found in the river bed of Þjórsá River at the main dam site. The silt layer is about 10-16 m thick in cored holes NK-36, NK-37, NK-38 and NK-40, but only some 3 m in NK-39. Silt and siltstone of same age is also found under loose gravel at the tailrace site, as can be seen in cored holes NK-43 and NK-44.

Tephra sand (TS)

After the glacier retreated from the area, leaving a lake mostly filled with silt, Þjórsá eroded a river course through the area most probably into the old riverbed from the last interglacial near its present location. Soon after that a thick layer of sand was deposited all over the area. The sand appears to be water-born black tephra with occasional clear plagioclase crystals. Such a thick layer (15-30 m) of tephra-rich sand suggests a big subglacial eruption, followed by a glacial outburst ("Jökulhlaup") in the upper reaches of Þjórsá/Tungná. The tephra sand has spread evenly over the area upwards of the Búði moraine possibly reaching all the way to Rangá in the east and further down the riverbed of Þjórsá. See further reading on the origins of the layer in Hvammsvirkjun Geological Report 2007. The sand was found in most boreholes that penetrate the Þjórsá lava, drilled near Hvammsvirkjun but is mixed with gravel near the former riverbed of Þjórsá river. A thin layer of the sand (2-5 m) was found directly under the Þjórsá lava at the dam site in holes NK-37, NK-38, NK-39 and NK-40 (For location of boreholes see Drawing 4).

Sand with the same description and chemical composition has been found under the lava in Sultartangi reservoir and in the area between Búðarháls and Ósöldur, near Þórisvatn in upper reaches of Tungnaá. The chemical composition of the sand found at Núpur and Búðarháls area [10] is very similar to the composition of the tephra found in Lake Saksunarvatn in Faeroe Islands [12], see Fig 1.2. This event has levelled out all minor irregularities in the area and it has left a flat plain of sand, only disturbed by local river erosion in the area best visible in the former riverbed of Þjórsá where the river has carved a passage in the loose sand east of Þjórsárholt from NK-2 down to NK-14 and down to the present passage at the Búði waterfall. This event has laid a foundation for the great extension of the Þjórsá-lava, erupted one or two thousand years later. Similar sand has been discovered elsewhere under the lava. The area of Selfoss and Eyrarbakki (Johnny Símorarson 2000, pers com) could be mentioned and similar sand has been discovered in the Urriðafoss area in boreholes at the dam site (the hole ULO-16 at 34 m depth) [2]. Chemical analysis has not been carried out but the visual appearance of the sand is similar. The conclusion is that the sand can be expected anywhere under the lava but its thickness could vary greatly. Near the old river course the sand would be mixed with gravel of various grain sizes.

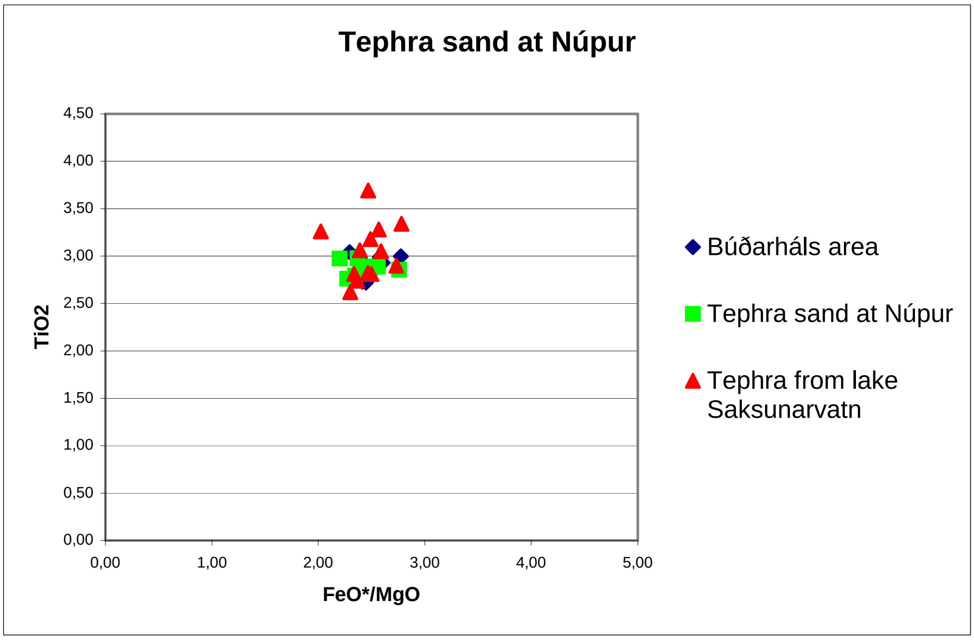

Figure 1-2. Comparison of chemical components of tephra sand at Búðarháls, Núpur and Lake Saksunarvatn.

Þjórsá lava (ÞL)

The latest event in the geological history of the area is the Þjórsá lava flow. Originating in an eruption in the Veiðivötn area some 8700 years ago, it is the largest postglacial lava known in Iceland. It flowed down from the Veiðivötn area to the coast at Eyrarbakki, a distance of 130 km. [9]. The lava covers the flat land west of the Búði moraine to Kálfá in the north and almost to Ytri Rangá in the east. A large portion of the Þjórsá lava flowed through the Búði passage along the old rivercourse of Þjórsá River. The Þjórsá lava is rather thin at the site of the weir of Holtavirkjun especially near the intake. It seems likely that the main lava flow has descended down the old riverbed and the thickness of the lava in the cored holes indicate that the old river course has been north of the weir and also north of the cube jointed tholeiite in Þinghólar. (see Drawing 8). The lava is rather thin near the main dam at the gorge of Þjórsá River (down to 4 m in NK-40) and in NK-37 it was not found. After the eruption the river found a new path down at Hestafoss and it flowed partly over the lava and eroded away the top scoria of the lava (see drawing 8 and fig 1-3). The gorge at Hamarinn was eroded later.

Figure 1-3. The Þjórsá lava a the dam and weir site. The scoria of the lava has been eroded away by the river.

Figure 1-4. The Þjórsá river gorge at Hamarinn and the weir site in background

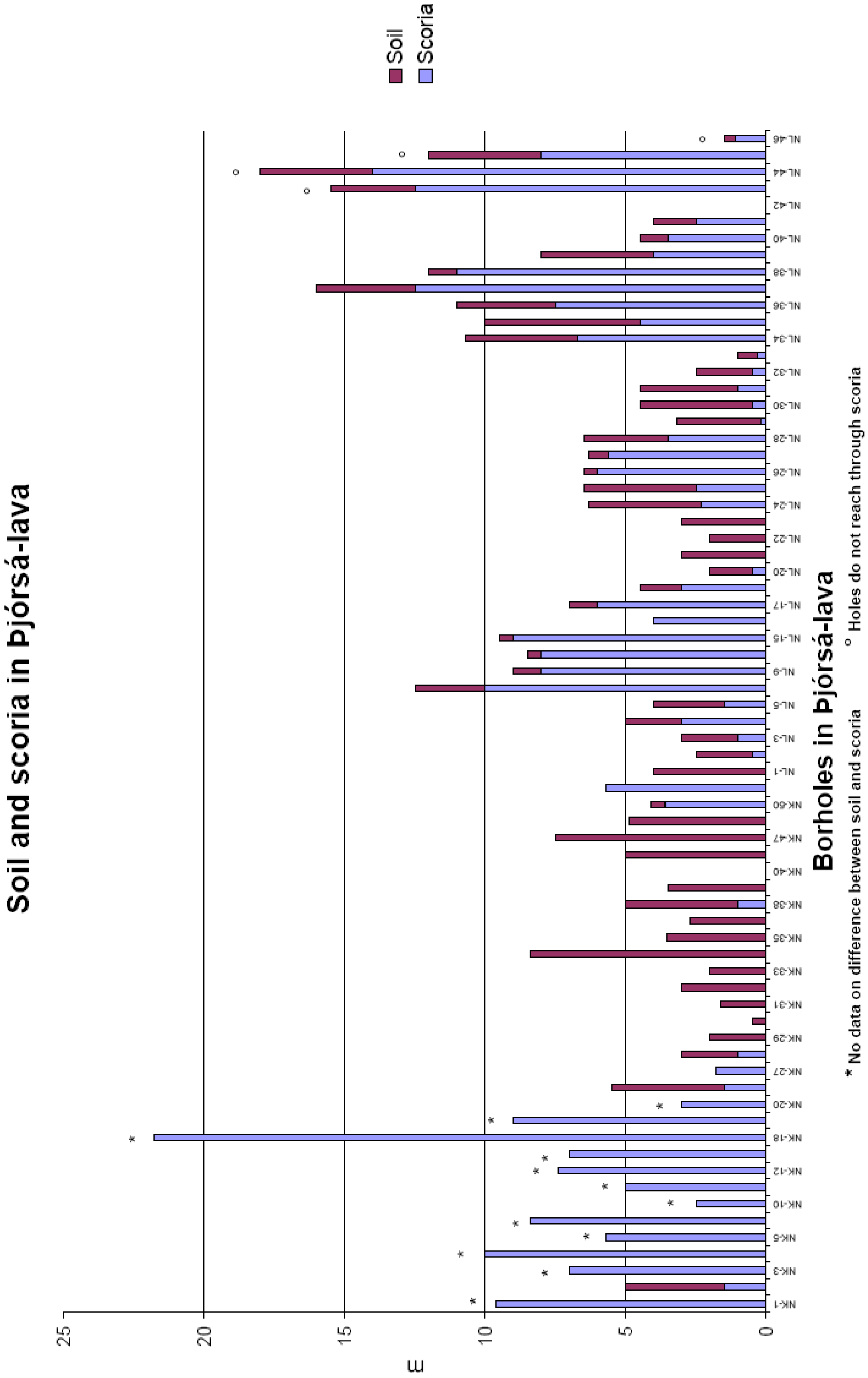

Figure 1-5. Thickness of scoria and soil in Þjórsá Lava

2 Tectonics

Tectonic setting

The project area is situated in an active tectonic area in southern Iceland. The area has been known for its earthquakes and fissures for centuries. Earthquakes have occurred in several places in the area with a frequency of up to one hundred years between episodes. The magnitude of the earthquakes can reach 7 on Richter scale or possibly higher [18].

Many faults have been observed in the area and also several fault orientations. Three set of faults are most frequent: Old north-easterly-directed faults that are associated with the period of active volcanism in the area and younger active faults oriented in a northerly direction, are associated with the South Icelandic seismic zone. The third set which has a variable direction of N70°A to N105°A is probably also related to South Icelandic seismic zone. Faults of various types have been found, both strike–slip and normal [5].

Active faults and fissures

In the years 2000-2001, the Science Institute of the University of Iceland mapped active fissures related to the South Iceland seismic zone [15].

The location of the fissures is shown on drawing 9

The appearance of the fissures can be highly variable. They are easily identified in some areas for example at Minnivellir, but the fissure sets to the east from Minnivellir tend to be obscure. Active fissures in the project are reasonably mapable.

Several sets of active fissures were found in the project area and they all have the common north-south direction: The easternmost set (1) strikes at the farm Vindás just east of Búðafoss (Drawing 9). These fissures will not affect the construction site.

Fissure set (2) strikes at Búðafoss near the fish farm. The geothermal field at Laugar is almost certainly connected to the fissure set. A few fissure features near this set were mapped by AV. They show north-easterly direction.

A fissure set (3) strikes near Hestafoss and the farm Lækur. These fissures are part of the fissures related to the earthquake of June 17th 2000 just south of the project area. The fissures at Hestafoss are quite obvious and signs of movements were visible in the area just after the quake on both sides of the river, but they have not been included in previous mappings. They are quite narrow and display irregular openings of ~5 cm and sometimes up to ~10 cm. A fissure was found near the river just north of the Lækur farm and another one between the farm houses (Andrés Eyjólfsson 2007 pers.com). Fissures of this set can be traced some distance to the north from Hestafoss in the island Árnes. According to the current plan the weir will cross these fissures. Springs related to the fissures can be seen just below Hestafoss.

Fissure set (4) is found south of the farm Akbraut and is not clearly defined and it can be divided into three subsets of fissures. One is just east of Akbrautaholt and runs near Þinghólar in Árnes.

The second subset can be traced to the south from the Akbraut farm just west of the road to Akbraut. The northernmost fissures of this recently active set, were mapped some 1200 m to the south of Akbraut. It is likely that their continuation can be found at the eastern cliff edge of Akbrautarholt close to the proposed powerhouse site and possibly crossing the gate section of the main dam in the gorge of Þjórsá, just north of Akbraut farm.

The third subset is located just west of the Akbraut farm and it appears to cross the tailrace canal. Weak signs were found in a fissure survey at the Akbraut farm in fissure trench AK-1, indicating the presence of a fault there. Signs of recent movement were not found.

The fissure sets (3) and (4) were active in the earthquake of June 17th 2000.

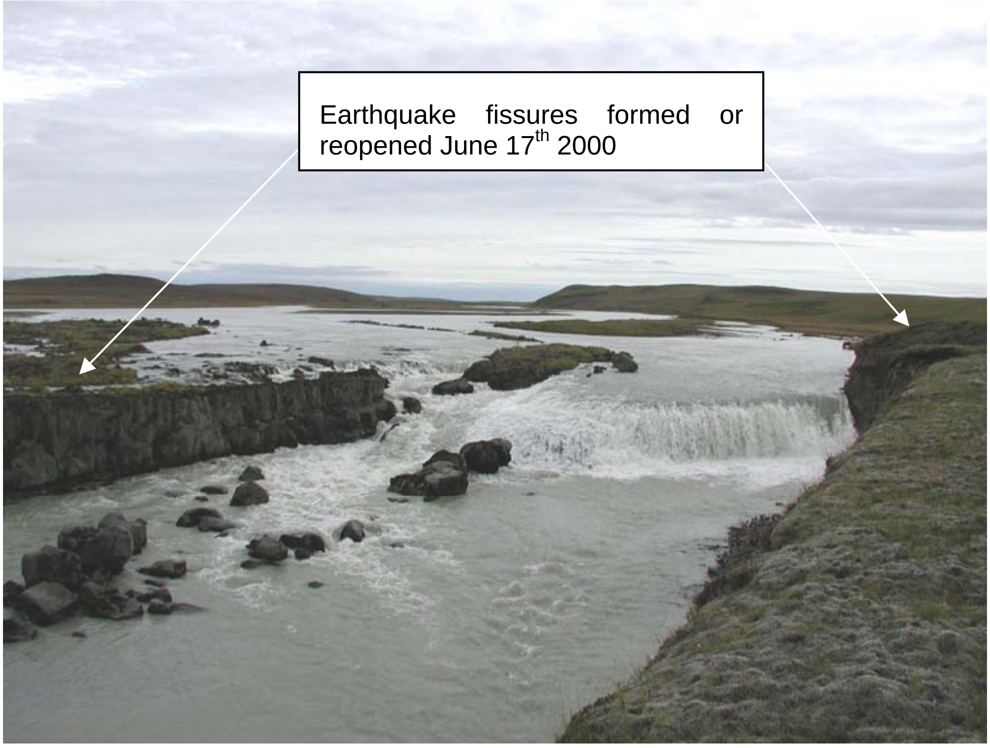

Figure 2-1. Earthquake fissures at Hestafoss. Fissures have also shaped the riverbed.

Fissure survey

Active fissures were mapped by the University of Iceland in 2000-2001 in the project area [15]. The mapping is the main source of information regarding the fissures. Some additional investigations were carried out as a part of the geological investigation of this report. The result is shown on drawing 9. The fissures present at Hestafoss were traced in gravel deposits by the river soon after the earthquake (of June17th 2000) and in open bedrock fissures by the farmhouse of the farm Lækur (Andrés Eyjólfsson 2007 pers.com). A spring wells out of such fissure (~10-20 l/s) at Hestafoss, see drawing 12. The leak path is however very short.

Figure 2-2. Fissure trench AK-1 at Akbraut farm.

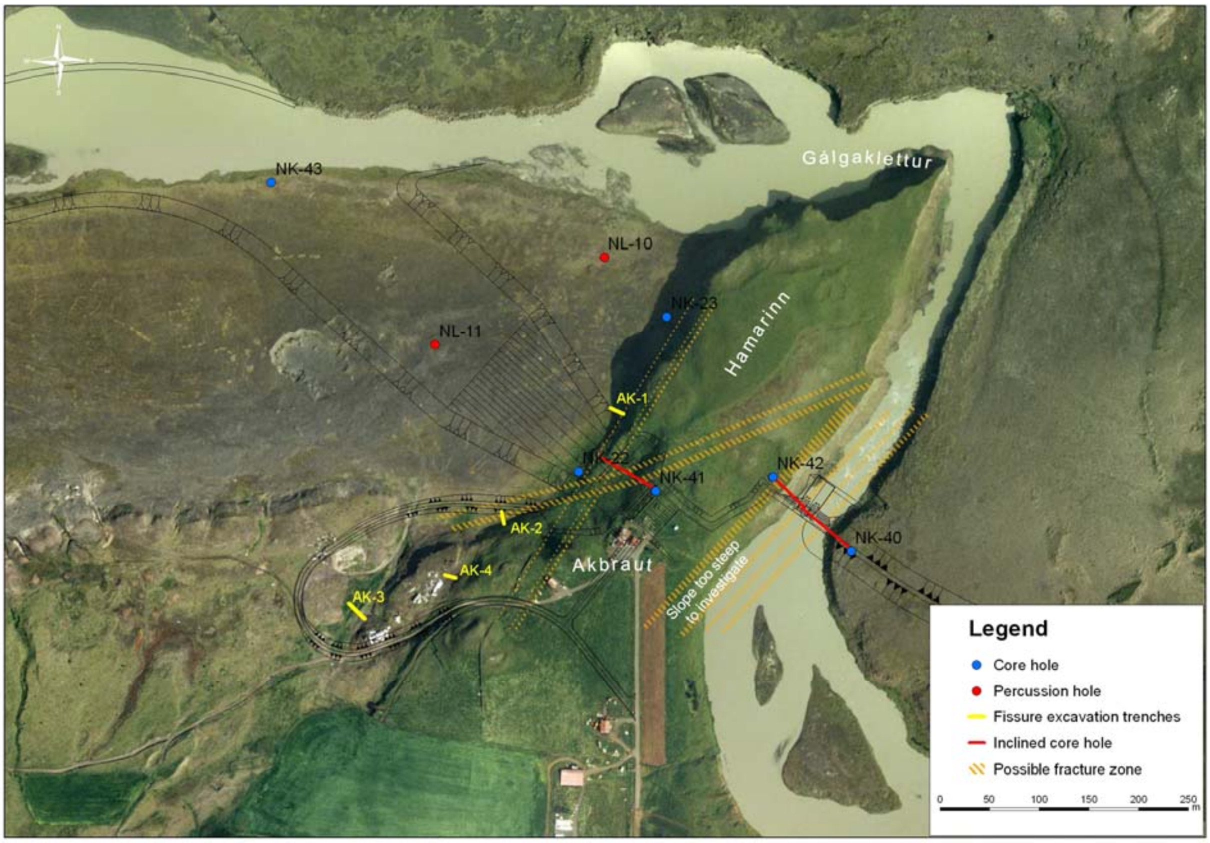

Figure 2-3. Location of fissure trenches at the farm Akbraut.

Several fissure trenches were excavated in the western slope of Hamarinn. The overburden was mostly eolian sand and fine grained gravel from the river. Neither of those leave any indication of fissure movement in the past. The groundwater is high and it was not possible to dig the trenches to full length because of inflow of groundwater. No direct evidence of fissures was found in any of the trenches. Steep face in conglomerate was found in the fissure trench AK-1 just where it meets the slope uphill. The sign was rather steep rockface, probably a fault face. No signs of recent movement were found in any of the trenches. The overburden was not suitable to preserve signs of fissures. In AK-1 and AK-2 the soil was mostly sand and gravel and in AK-3 and AK-4 sand and stony peat with frostlifted stones of the bedrock and till.

The possibility of digging fissure trenches in the eastern slopes, south of Hamarinn was considered but the slope is too steep and the excavator would have to stand in the river with a limited reach. The survey was abandoned on the east side and decided to investigate the fissures by drilling an inclined hole at the west end of the damsite (NK-42).

Figure 2-4. Fissure trench AK-1 just after excavation. Unsure signs of a fissure or fault are in the shadow at the light spot just above the inflowing water.

Figure 2-5. Fissure trench AK 3 in process of excavation. The inflow of groundwater made the study difficult

3 Lithology

The classification of the bedrock in the Holtavirkjun area is based of field observation and inspection of hand specimens and cores from the holes.

Basalt

Plio-Pleistocene basalts

Each basalt lava flow has typically a three way subdivision, top scoria (often some 10-25% of the layer), dense or semi vesicular middle part (frequently 70-80% of the lava) and a layer of bottom scoria 3-8%. The top scoria is often well consolidated. It consists of scoriaceous and vesicular basaltic fragments. It often contains sedimentary infiltration of silt or sandstone from overlying layers. The top scoria is often hydrothermally altered and in most cases the alteration increases the degree of cementation. The crystalline middle segment of the lava consists in many cases of hard dense rock with irregular joint system derived from cooling of the lava. In addition to the cooling joints there is flow cleavage related joints and tectonic joints. Bottom scoria is usually free from sedimentary fillings and is most often fairly well consolidated.

The basalts are classified into three main types, tholeiite lava, olivine basalt (olivine tholeiite) and porphyritic basalt (G.P.L. Walker 1959). The olivine basalt is in most cases olivine tholeiite. It should be pointed out that these three types of basalts form a complete transition between them. The secondary minerals serve best as indicators in recognizing each type. The basalt layers at Holtavirkjun are mostly olivine basalt.

Olivine basalt occurs both as single flows and as a sequence of belted flows with scoriaceous or vesicular belts between the layers. Porphyritic basalts are basically tholeiite or olivine basalt with a various content of plagioclase phenocrysts and sometimes a small amount of olivine phenocrysts. Plagioclase phenochryst content higher than 5% is a common reference but if plagioclase crystals are rare in the area this number has a tendency to drop. Low contents of plagioclase content (ca 1-3%) is not significant in terms of engineering properties of the rocks but as phenocrysts content is increased, the number of primary joints often drop.

All rocks from the active period of Stóra-Laxá central volcano have been hydrothermally altered. Hydrothermal alteration as observed in the field and in the cores has most often reduced the strength of the crystalline rocks and increased the strength of the scoria parts. The powerhouse will most probably be founded in layers of this series and the tailrace canal will be excavated into these layers a short distance closest to the powerhouse.

The Olivine basalts display a medium or high strength with typical apparent UCS value in the range of 50-160 MPa. Permeability values are 8-13 LU.

The porphyritic basalts display a medium strength with typical apparent UCS value in the range of 50-80 MPa. Permeability values are 10-14 LU.

Interglacial lavas

Olivine basalt of Akbraut interglacial basalt are series found below the Þjórsá-lava in drillholes NK-38, NK-40 and at the surface at Akbrautarholt and in a large area south of the project area.

This basalt is slightly or unaltered with dark fillings in joints. It is generally massive and with little scoria. Cube jointing is most prominent in the boreholes, but the rocks in outcrops at Akbrautarholt are highly jointed and the joints appear to be of tectonic origin. The thickness of this lava or series of lavas varies very much over a short distance, indicating river channels or similar landscape in the area at the time of formation. The intake channel, penstock and the powerhouse will be excavated and partly founded in this formation. The main dam will also be partly founded on it in the riverbed of Þjórsá.

Similar Interglacial lavas are found east of Árnes Island, in Flagbjarnarholt and to the south of these places. They appear to be older than the Akbraut intergalcial basalt. These layers are found in several places to the north of the project area in Þjórsárholt and Skaftholt and both Núpur and Miðhúsafjall. The lavas seem to have filled up shallow valleys in these places. Cube and columnar joints are prominent features of this series but no boreholes have so far been drilled into it. They appear to be competent rocks and have obviously withstood glacial erosion better than most layers in the area.

The Interglacial lavas display a medium or high strength with typical apparent UCS value in the range of 160-200 MPa, UCS 186 MPa. Permeability is in the range of 10-20 LU.

Holocene lava

The Þjórsá-lava is the only Holocene lava in the area. It has a very typical cross section of tholeiite lava described in the Plio-Pleistocene section. It is usually 20-30 m thick and has often a 5-10 m thick top-scoria. The top-scoria can be (in some cases) difficult to excavate with backhoe but a percussion drill penetrates the scoria fast or very fast. The crystalline part is of porphyritic olivine lava, with 5-10% plagioclase phenocrysts and occasional olivine crystals. It is usually 10 to 25 m thick and is normally solid and most often returns core well. But the lava is considerably thinner near Akbrautarholt were it can be as thin as 4 m in NK-40 and at the damsite it has flowed up to a silt bank and it is not found in cored hole NK-37. The scoria part is largely absent in the area next to Hamarinn (thickest 1 m in NK-38). The most plausible reason for this is that the scoria has been eroded away when the Þjórsá river flowed over the area, see Drawing 8. The scoria has not yet been investigated in Árnes, east of hole NK-39, at the inner part of the weir or at the diversion at Búðafoss, but according to observation in the field the scoria appears to be thicker. The thickness of scoria in the Þjórsá lava is shown in fig 1-5.

The Þjórsá lava displays a rather mixed results with apparent UCS values of 50 and 60 MPa. UCS test yielded 138 MPa. Permeability is in the range of 10-50 LU for the solid part of the lava but the permeability of the bottom scoria varies. (Over 200 LU in NK-38 but only 14 in NK-40). It is not possible to measure the scoria separately. Part of the lava and the sand directly under the lava are always included the test.

Dykes

Basaltic dykes

Several basaltic dykes have been found in the cored boreholes. They appear to be some variation of thin and inclined cone sheets and/or inclined dykes. The inclination of the dykes varies. They tend to intrude the more soft layers as the scoria segments of the basalt layers, or conglomerates. The breaking strength of the dykes is high as the average point load varies from 60-100 MPa. The joint pattern is mostly inclined with rough and undulating joint surfaces. The most common dykes are made of grained dark olivine basalt somewhat finer grained towards the margins. The dykes are typically dense and slightly jointed or even joint free. Joints are rough and undulating. Hydrothermal alteration of the dyke is usually slight but joints are often coated with various secondary minerals. Zeolites, calcite (often Iceland spar) and pyrite are prominent. Clay minerals are less common in the dykes than in the surrounding rocks. The margins of the dykes are often fused or welded to the surrounding rock and the contact is displayed intact in the core.

The dykes display a medium or high strength with typical apparent UCS value in the range of 60-100 MPa, Permeability is not conclusive for the dykes.

Sedimentary rocks

Plio-Pleistocene siltstone and conglomerates

The few sedimentary layers found in the project area are generally fairly well cemented, fine grained conglomerate, competent rock. The fine-grained conglomerate is the most common type but sandstone, siltstone and coarser types of conglomerates are also known to be present in the general area. The breaking strength of the conglomerate varies from low strength to high (25-75 MPa). Permeability is rather low. Indicated permeability (tested with other formations) is 16 LU but that appears to be too high, 5 LU seems to be a more likely figure.

Interglacial tillite and silt

The interglacial silt layers are found in several boreholes under the Þjórsá-lava. They consist of a blend of silt and fine sandstone often layered with thin layers of fine sand. Their apparent UCS value is low (1-8 MPa in Hvammsvirkjun, measured parallel to layering) with weaker layers of sand in between. These layers are known to be present in the general area of the project but they have not been found in direct contact with the project components.

Holocene silt

The Holocene layer of silt and fine sand is found in several boreholes under the Þjórsá-lava (NK-36, NK-37, NK-38, NK-39 and NK-40). It is 10-15 thick in most holes and it is exposed in the Búði moraine and in banks along Þjórsá River below the Hamarinn and in cored holes NK-44 and NK-45. This layer or layers are often poorly cemented. They are generally layered with alternating layers of silt and fine sand.

The core tends to break along the sand layers. The layering and the joints are planar and smooth. In some cases the silt tends to become coarse near the base of the formation, resembling silty tillite. This coarser part is far more competent than the alternating silt and sand layers. The silt layer is found under the Þjórsá lava at the damsite and the main dam will probably be partly founded on this layer in the Þjórsá gorge east of Hamarinn.

The Holocene silt displays a low strength with typical apparent UCS value in the range of 6-13 MPa (measured parallel to layering). Permeability is in the range of 10-15 LU, under the Þjórsá lava at the dam and weir site. Higher values, 70 LU were encountered in NK-40 (22-27,2m). These values indicate the presence of a fissure or unknown weakness near the hole.

Holocene tephra sand (TS)

In several places under the Þjórsá-lava a thick layer of tephra rich sand has been found. No core has been recovered from the sand and its properties must mostly be deduced from recovered cuttings and general drilling operation during ODEX drilling.

The sand layer can be divided into three parts, each of varying thickness. One or more parts may not be present in any given section. At the bottom and top there is often a layer of loose sand and gravel displaying rounded material with high content of tephra. The middle section is of pure black tephra with grains of clear plagioclase crystals. The grain size is medium to coarse sand in most cases. The cuttings and drilling operation in general indicate a loose or poorly cemented layer. Drilling operation (ODEX) in NK-4 and 5 were particularly fast and fine-grained gravel (with high content of tephra) was observed in the top section of the sand. A thick layer of coarse tephra sand is exposed along the banks of Rangá underlying the Þjórsá-lava. Similar tephra rich deposits (poorly cemented sandstone and packed sand) are exposed along the bank of Þjórsá down from Búrfell [7], towards the project area but it disappears under the lava and alluvium from the river above the projected intake pond. The mineralogy and chemical composition of these layers has not been studied in detail but they suggest that the tephra sand below the Þjórsá lava in the present study area could be the similar or same. Similar deposits have also been observed along the banks of Rangá a considerable distance to the east.

The permeability of Holocene tephra sand and gravel was evaluated 10-20 LU (lowest test results of combined scoria and sand), as no direct test could be made. The core recovery of the sand was often very little and grain size of the recovered material varied. The evaluation is therefore uncertain.

4 Engineering geology

Logging of boreholes

Detailed graphic logs of holes in the area are shown in Annex 1. The standard RQD values are given as well as the values for 30, 50 and 100 cm criteria, both for drilling intervals and rock units as detailed as possible. In addition to that location and results of point load tests are given along with results of UCS tests, permeability tests and rock mass quality Q-values. Photographs of the cored sector in boreholes are presented in Annex 2.

				Elevation			ODEX casing		Core
Hole	Depth	Coordinates ISN93		Casing	Ground	Date		depth	NQ
	m	x	y	m.a.s.l.	m.a.s.l.	Hole finished		m	m
NK-3	108,65	437705,9	393129,2	82,60	82,4	9.12.2000	5/3"	0-54	54-108
NK-9	84,65	439769,1	392143,4	86,40	86,2	16.3.2001	5/3"	0-29	29-84
NK-14	81,65	438138,0	391689,0	-	79,0	22.5.2001	3"	0-12	12-81
NK-22	21,65	433400,2	391071,4	60,59	-	4.12.2001	3"	0-3	3-21
NK-23	21,65	433489,3	391228,2	58,69	-	5.12.2001	3"	0-3	3-21
NK-36	39,53	434151,0	390844,7	68,7	-	21.10.2006	3"	0-4	4-39,53
NK-37	21,53	434071,8	390858,8	65,7	-	22.10.2006	3"	0-15	15-21,53
NK-38	34,38	434433,2	390702,2	70,9	-	23.10.2006	3"	0-6	6-34.38
NK-39	32,22	434843	390360	-	-	25.10.2006	3"	0-4,5	4,5-32,22
NK-40	99,55	433675,5	390996,1	65,4	-	9.11.2006	3"	0-1,6	1,6-99,55
NK-41	83,63	433478,6	391057,5	79,2	-	27.11.2006	3"	0-6,6	6,6-83,63
NK-42	66,53	433596,6	391071,8	79,8	-	2.12.2006	3"	0-3,55	3,55-66,53
NK-43	18,53	433091,4	391368,2	56,8	-	3.12.2006	3"	0-9,15	9,15-18,53
NK-44	15,13	432615,3	391335,1	55,8	-	4.12.2006	3"	0-12	12-15,13
NK-45	15,53	432305,5	391238,0	55,5	-	5.12.2006	3"	0-7,82	7,82-15,53

Table 1 Cored holes at Holtavirkjun

Field tests on core

The drilling campaigns were carried out during winter, often in frost and snow. The core was transferred to a nearby house or directly to Reykjavík in a closed vehicle. Special care was made to protect the silt and other sediments from freezing. The RQD measurements were therefore sometimes carried out off site and Q value estimated simultaneously. Samples for UCS test and partly for point load test were selected on site and covered in plastic to maintain original moisture content as possible.

The results of the RQD measurements (summarized 10-, 30-, 50-, and 100 cm lengths) are given in each log in Annex 1 with Q values.

Point load tests

Point load tests were carried out as soon after drilling as possible. The core is 45 mm in diameter and conversion factors were used to calculate IS50 and the "apparent" UCS calculated accordingly. The results from the point load tests and calculated apparent UCS are shown in Annex 6.2. The overview of apparent UCS is summarized in the following histogram, see figure 4-1.

The conversion feature of 18 was used to calculate the apparent USC value. The conversion factor chosen is in good concordance with the individual basalt types but is maybe too high for the softer rocks, for instance the siltstone. It was however used in the case of the softer rocks as no other values were available.

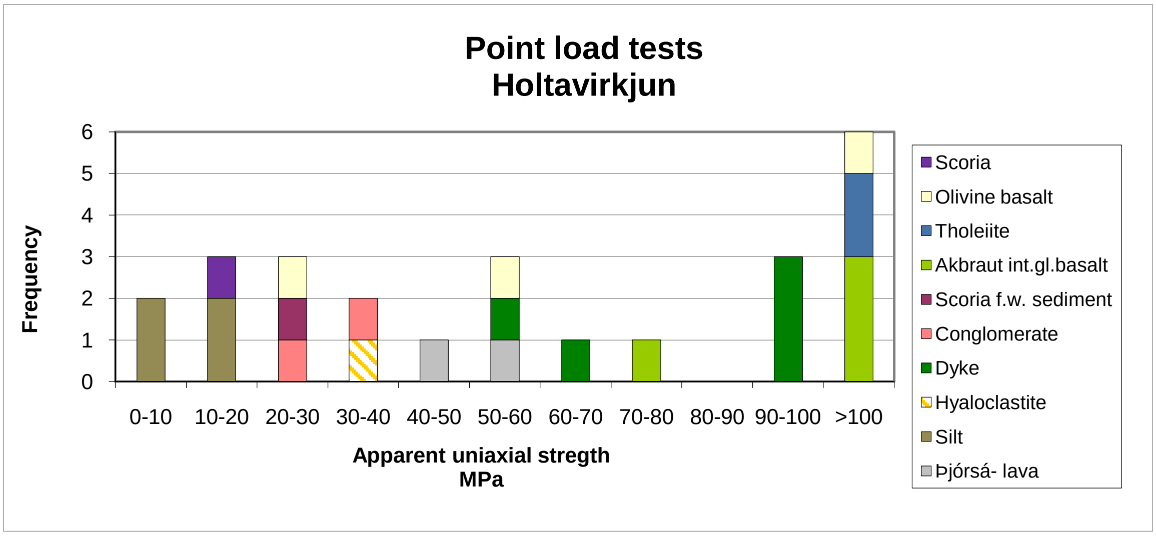

Figure 4-1. Apparent uniaxial strength of different rock types, estimated from point load tests.

Permeability tests in boreholes

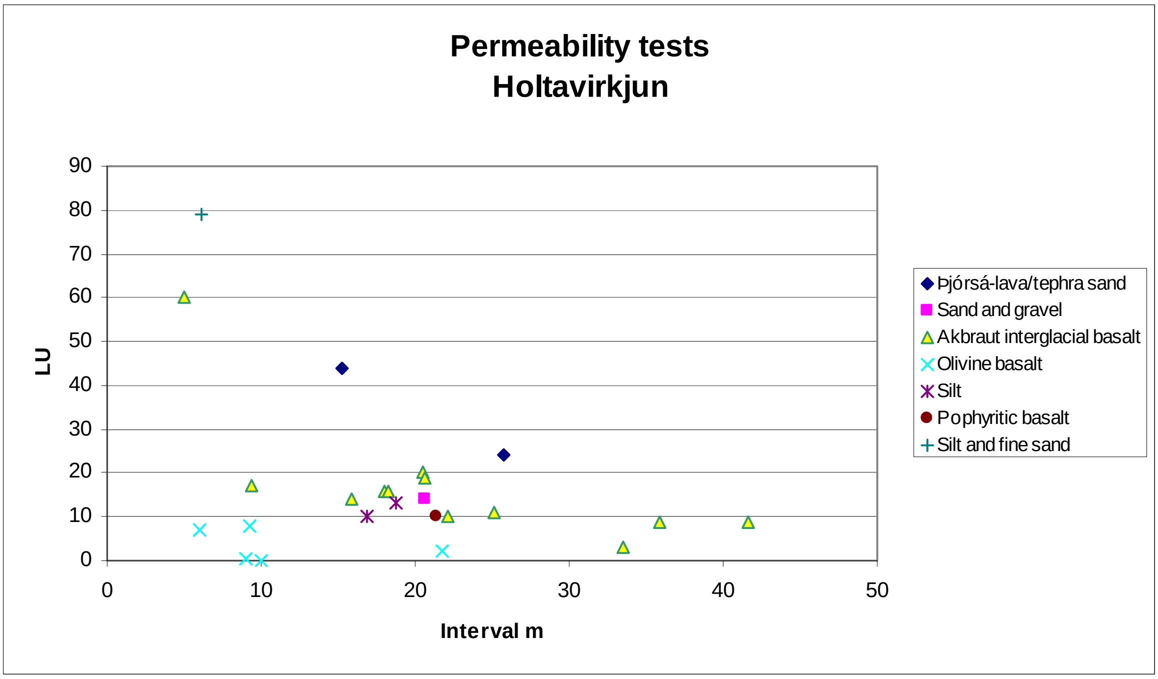

Figure 4-2. Length of tested intervals vs. permeability in Lugeon values.

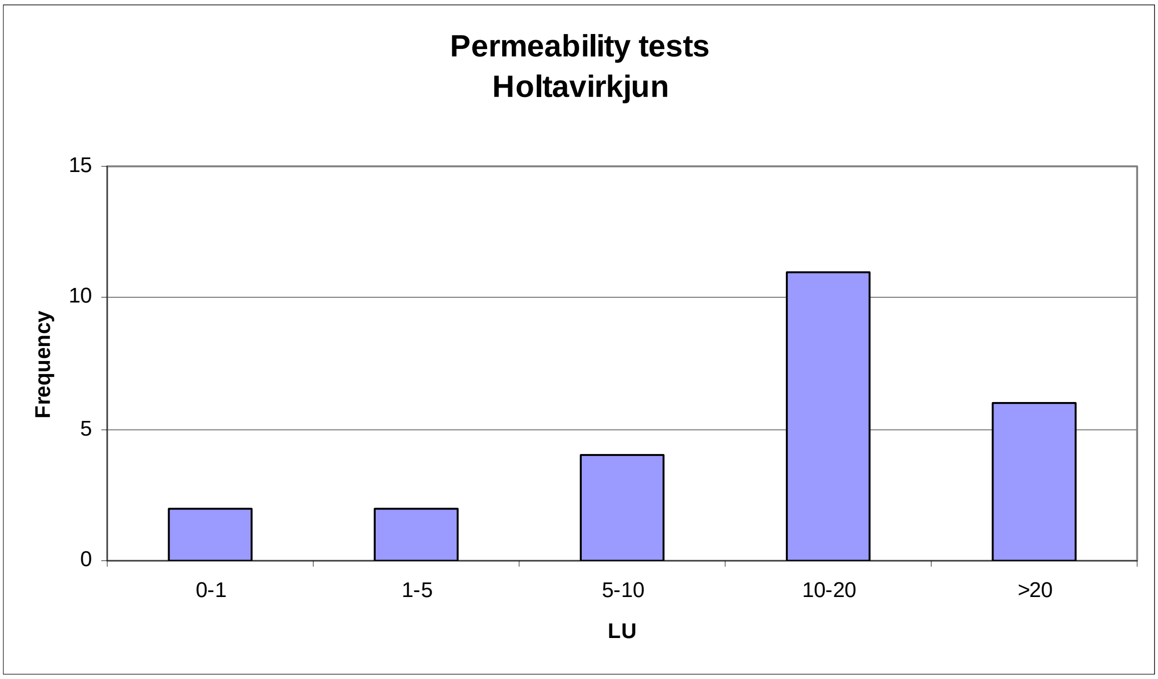

Figure 4-3. Distribution of permeability values.

Figure 4-.: Lekage from top section of the Þjórsá lava into salmon waterway at Budi waterfall.

Laboratory tests on cores

Uniaxial compressive strength (UCS)												Stress-Strain meas.			
Sample	Bore hole	Depth	Rock type	Length (mm)	Diam. (mm)	Ax.load (kg)	L/D	UCS (MPa)	Sample moist. (%)	Weights Water (g)	Ssd (kg/m3)	UCS (MPa)	Youngs E-ax (Gpa)	E-dia (Gpa)	Pois. ratio
1	NK41	60	Conglomerate.	-	45.0	3830	2.0	23.6	-	163.9	2248.0				
1-2	NK42	8.5	Akbr.Int.gl.bas	-	45.0	30170	2.0	185.9	-	269.1	2945.5				
NBS-08	NK20	33.8	Conglomerate.	94.01	44.71	12100	2.10	75.61	6.98	202.4	2374.1	110	64.62	124.2	0.52

Table 2 Uniaxial compressive strength.

Groundwater observation

Temperature readings

After completion the temperature of the groundwater was measured in most of the holes (see Annex 5-1). Some of the holes were drilled using hot water (~60°C) as drill fluid. Some of the holes had not recovered after drilling when they were measured so relevant temperature measurements were not achieved but the temperature logs show variation related to permeability.

The inclined holes are difficult to measure because the thermometer tends to get stuck on the way down, increasing the possibility of loosing the instrument during the measurement.

The temperature readings in the holes show a low and even temperature of 4°C to 5°C in the Þjórsá lava, with little variation. One hole is different, NK-39. It shows very steep thermal gradient below ~25 m depth (below the Þjórsá lava). The gradient appears to be over 60°C/100 m. The total depth of the hole is only 32m so this thermal gradient can not be regarded certain. It nevertheless indicates a high gradient in the area. NK-39 is located near a fissure mapped as active in 2001, see drawing 9. NK-39 is also near a potential geothermal site in Árnes, see drawing 6. No temperature measurements exist for this site but a shallow hole was drilled there several years ago for investigation and lukewarm water was found there (enough to feed a small bathing pond).

The first temperature measurements at the powerhouse site were made right after drilling in NK-41 and NK-42. They show the effect of the hot water used in the drilling process. The temperature curves are irregular and show probably outflow (places of higher permeability) where the curves show reversed gradient. NK 42 was measured several days after completion. The measurement shows even and low temperature (Annex 5-1).

The temperature of NK-43 to NK-NK is normal for the site. The measurements were carried out during a cold spell and they reflect the weather directly.

High temperatures found in NK-14 (up in the Þjórsá-lava) suggest an intrusion of warm water into the groundwater in the vicinity of the hole as a lens of 14°C hot water is found at the groundwater surface and lower temperature and increasing with depth is found immediately below. The nearest known geothermal field is at the fish farm at Laugar close to the diversion structure at Búði. Active fissures are very close to the fish farm and the simplest explanation of the temperature anomaly in NK-14 is that the fissure zone extends to the vicinity of NK-14 and significant inflow of hot water flows up and intermixes with groundwater.

Temperature anomalies as described above are positive indication of open fissures filled with warm upflowing water, most likely connected to active faulting. Most of geothermal fields in the Southern Lowlands in Iceland are connected to a set of earthquake fissures similar to those found in the project area.

Electrical conductivity

Electrical conductivity was measured in the holes. Substantial difference was found. The water in the Þjórsá lava has low conductivity but the water below has substantially higher values. The high values are probably from the silt formation as it was deposited in seawater. The difference in conductivity shows that the groundwater in the Þjórsá lava is a separate groundwater system.

Groundwater level

Groundwater observations date from the drilling campaign. Variations in groundwater level have not been monitored. The groundwater system consists of four main parts.

1 The Þjórsá lava

2 Sand and gravel formation on top of the lava in Árnes

3 The bedrock in Hamarinn at the Akbraut farm

4 The sand and gravel formation west of the Hamarinn.

Considerable groundwater flows past the project area within the Þjórsá lava at Árnes. The temperature profiles in the holes show consistent low groundwater temperature (4-5°C) and conductivity of the water supports this. The water level within the lava has higher elevation than the river below Hestafoss. Little water flows into the gorge of Þjórsá below the damsite. Only few springs have been observed amounting to a few tens of l/s of water. No water has been observed flowing into the Þjórsá river north of Árnes island or below Hestafoss but the conditions were not favourable as the water level of the river was usually too high to allow any observation likely to succeed. The main flow of the Þjórsá lava was along the Árnes Island to the west (see drawing 8) and it is likely that the main flow of groundwater in the lava follows the old rivercourse as it did provide wet areas to allow formation of scoria at the bottom of the lava during the flow of the lava. The groundwater in the lava seems to have two feeders besides precipitation. Firstly, groundwater flow in the lava through the Búði pass and secondly, infiltration into the sand and gravel formation on top of the lava from the Árneskvísl branch of Þjórsá river just south of Búðafoss. The Búði pass is narrow and carries limited amount of groundwater as can be seen just above the waterfall at Vindás where substantial groundwater flow (~0,5-1 m^3/s) is forced to the surface because of flow restriction in the lava at Búði pass.

The Árneskvísl Branch of Þjórsá river has higher elevation than the groundwater in the sand and gravel formations overlying the lava at the east section of Árnes island a distance of 1,5 km. The groundwater is high near the river (very near the surface) but lowers with a gentle gradient towards the west (see drawing 7), indicating infiltration of water from the river to the groundwater. Water can be seen in old channels of the river in the area seeping towards the river just above Hestafoss. Part of the water could infiltrate the top scoria of the lava along the scoria margin, see drawing 7. The Árneskvísl branch will be diverted during the construction. The groundwater table in Árnes is expected to lower as a result of the diversion.

Permeability in Hamarinn and at the powerhouse site is rather low and the groundwater system in the area is somewhat isolated. It is not in contact with groundwater in the Þjórsá lava or the sand and gravel deposits west of the Hamarinn. Little inflow of groundwater is therefore expected in the powerhouse pit except from the sand and gravel deposits in the tailrace canal site.

Extensive sand and gravel deposits are west of the Hamarinn hill. The main branch of Þjórsá River flowed here until few centuries ago and deposited the sand and gravel below the gorge. Close to the Hamarinn the deposits are thicker than 15 m but further downstream they are only few meters. The sand and gravel is rather uniform. Layer of silt was found under the sand at holes NK-43 to NK-45. The groundwater in the gravel seems to be governed by the water level of Árneskvísl. The Árneskvísl will be diverted during construction and therefore flow of water in the tailrace canal should dwindle with time. The inflow is expected to be substantial at first.

5 Geological conditions of the project components

Diversion structures at Búðafoss

The diversion structure will be constructed in Árneskvísl near Búðafoss. It will mostly be founded on the Þjórsá lava, but the easternmost section of the structure, just below the fish farm at Laugar, will probably rest on interglacial lavas.

The depression in the glacial formations at Búði is the main pass through which the Þjórsá lava has flowed to the sea at Eyrarbakki. It is therefore likely that the lava is reasonably solid at this place, but the thickness of the lava is still unknown and the lava near the fish farm is likely to be thin. The underlying strata, which could be encountered at/or near the lava margin, are most likely combination of glacial silt/tillite or some gravel and sand. The cube jointed basalt layers in Flagbjarnarholt could be found near the eastern part of the diversion structure.

Intake pond and lateral embankments

The weir along the northern side of the intake pond will mostly be founded on the Þjórsá-lava, near the margin of the lava. The thickness of the lava varies (3 m in NK-40 and 8 m in NK-38, 16 m in NK-36, 21 m in NK-39 and it was not found in NK-37). The scoria on the lava is very thin and it seems that it has been eroded away by the river especially on the westernmost part near the damsite. A thin layer of silt was found on top of the lava in holes NK-36 and NK-37. A layer of gravel and sand (2-4 m thick) was found directly under the lava in most of the holes (not in NK-36). Under the gravel there is a layer of silt 10-15 m thick in most of the holes but only 3 m in NK-39. Apparent USC values are 4-10 MPa and permeability 10-15 LU. Below the silt is competent interglacial lava or reasonably sound bedrock which consists of basalt, conglomerate or dykes with low permeability (0,1-7 LU) and reasonably uniaxial strength even if it varies a lot (basalt and dykes~50-150 MPa and scoria and conglomerate 20-40 MPa) Several fissure zones strike the weir. Active fissures strike close to NK-39 and just west of NK-37 (found after the earthquake of June 17th 2000). Active fissures are most likely in the gorge just west of NK-40. Several small fissures at each site are more likely than just one larger fissure at each site.

The dam

The main dam and gate section will be constructed in the gorge east of Hamarinn. The west section of the dam will be founded on the highly jointed Akbraut Interglacial basalt and the east part on a layer of Holosen silt. The silt layer is found in the inclined hole NK-40 on the east bank of the gorge where it is 10 m thick. The silt has good core recovery in the upper part of the hole (~100%). The upper part of the layer is sandy and has high pebble content and could be classified as silty tillite but the lower part is horizontally layered and the core breaks along the layering. The apparent permeability of the silt is 10-15 LU except in NK-40 (test 22-27,5 m, possibly up to 70 LU) but the short leakage path to the gorge and nearby fissures just west of the test site could interfere with the results. The apparent USC value for the silt is 4-10 MPa A 4 m thick layer of sand was found in NK-40 and in other cored holes to the east but it is not found in the gorge or in NK-36. The sand layer is permeable and the leakage path is very short near the gorge. The highest permeability of the sand (and the bottom scoria of the lava) was detected in NK-38 (~200 LU). Below the silt and the sand, the Akbraut Interglacial basalt was found. It is sound basalt except where intersected by tectonic fissures. Typical point load figures are in the range of 160 to 200 MPa. The permeability was in the range of 5-20 LU. The basalt from the Skarðsfjall Tholeiite Group (STG) was found in NK-36, NK-39 and NK-40. It is mostly of sound basalt and conglomerates intersected with dykes. The permeability of the older basalt is near 10 LU but the tests are few. Fissures which opened in the earthquake of June 17th 2000 were found south of the damsite. They seem to strike in the gorge at the foundation of the main dam, see drawing 9 and 14. The fissures and faults at the damsite must therefore be classified as active.

Approach channel, penstock and powerhouse

The excavations for approach channel, concrete penstocks and powerhouse will be performed mostly in Akbraut interglacial basalt (AIB). The AIB layer forms Hamarinn itself. It is sound olivine basalt and little altered. Joints and fissures are covered with dark glossy clay minerals. It is highly jointed in at the east flank of Hamarinn and also just west of NK-41. The joints indicate probably fissure zones, one at the proposed powerhouse site and another (possibly several others) on the east flank of Hamarinn and in the gorge of Þjórsá (see drawings 10-12). The powerhouse will be founded on the scoracious lower part of the AIB formation and/or in the olivine basalts and conglomerate of the STG formation. The scoraceous part of AIB was only found in one hole NK-41, thus it is quite conceivable that the scoria thins out to the east and the area just east of the present powerhouse site seems to be considerably less fractured than the present site. The apparent uniaxial strength of the older rocks varies considerably. The basalt layers from 50-150 MPa and the scoria and conglomerate appear to have strength of 20-40 MPa. The AIB has high apparent USC strength of 180-220 MPa and the scoria is competent with apparent USC of 20-40 MPa. Despite the fissure zones the permeability is in the range of 10-60 LU where the most common values are 15-20 LU. Magnetic and VFL survey were carried out at the powerhouse site and they indicated an anomaly at the present powerhouse site. The anomaly was interpreted as a fault zone and the presence of it was confirmed by drilling NK-41. The most likely location of the fault zone is shown in drawings 10-12 and 14.

Figure 5-1. Highly jointed basalt in Hamarinn

Active fissures were found to the south of the Akbraut farm (see drawing 9) and they seem to strike along the east flank of Hamarinn and/or in the Þjórsá gorge at the damsite. The highest section of Hamarinn seems to be the least faulted site for the powerhouse.

Tailrace canal and riverbed downstream of Akbraut

The upper part of the tailrace canal will be excavated in similar formations as the powerhouse site but the lower part of the canal and the riverbed below the end of the canal will be excavated in the sand and gravel deposits at the river. A layer of fine sand and silt was found in NK-44 and NK-45, near the bottom of the proposed tailrace canal. The elevation of the silt is near 45 and 48 m a.s.l. respectively or just above the elevation of the proposed tailrace canal at NK-45. The canal site was not investigated farther downstream Nátthagahólar by drilling. According to study of areal photos the lava margin of Þjórsá lava lies to the north of the Árneskvísl branch of Þjórsá river from Hamarinn and down below the junction of Árneskvísl branch and the main branch of Þjórsá river. This interpretation is supported by Cobra soundings on the west bank of the river.

Conclusion: The tailrace will mostly be excavated in loose gravel and sand in the river and on the south bank of the Þjórsá river.

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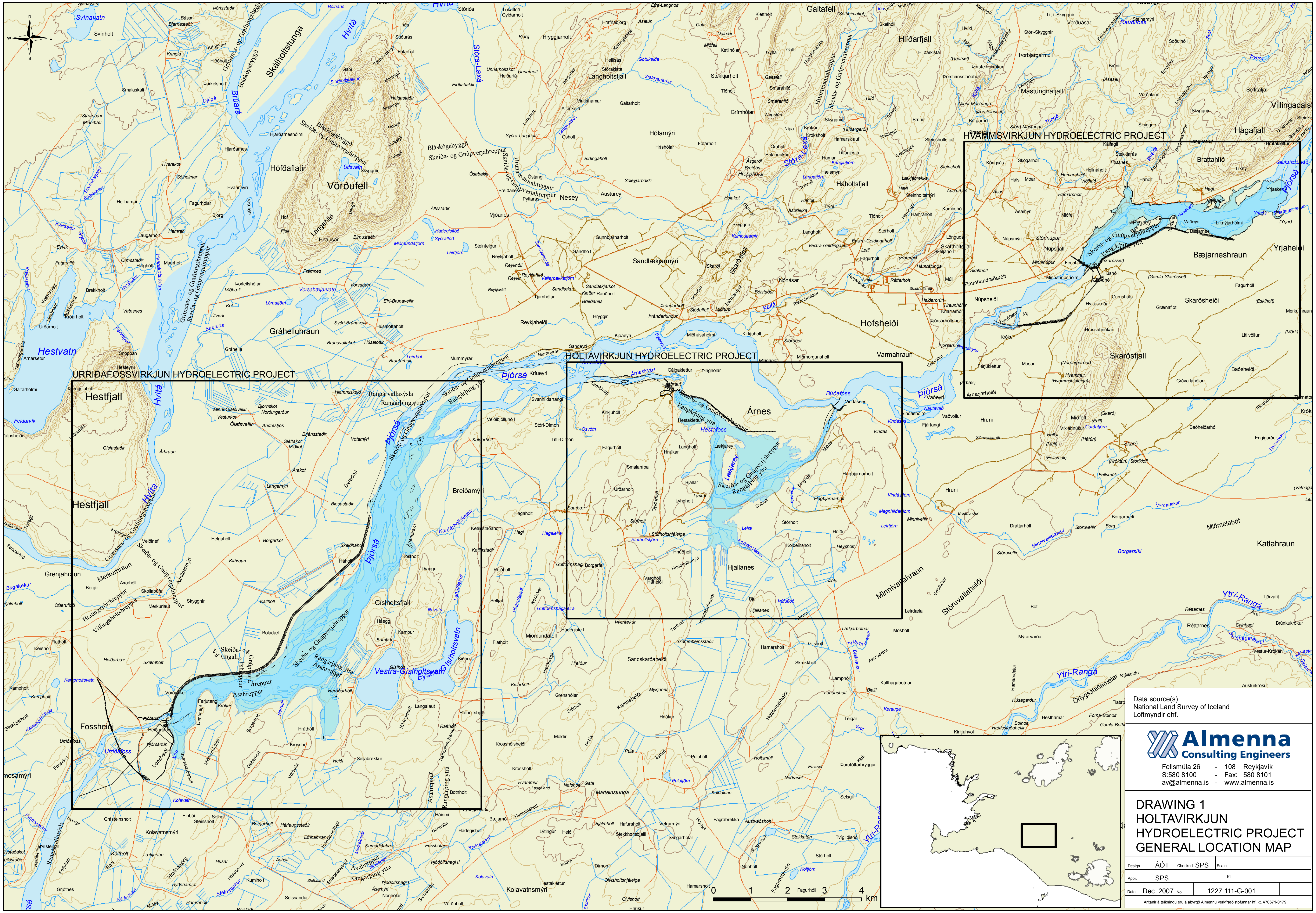
Drawings:



Data source(s):
National Land Survey of Iceland
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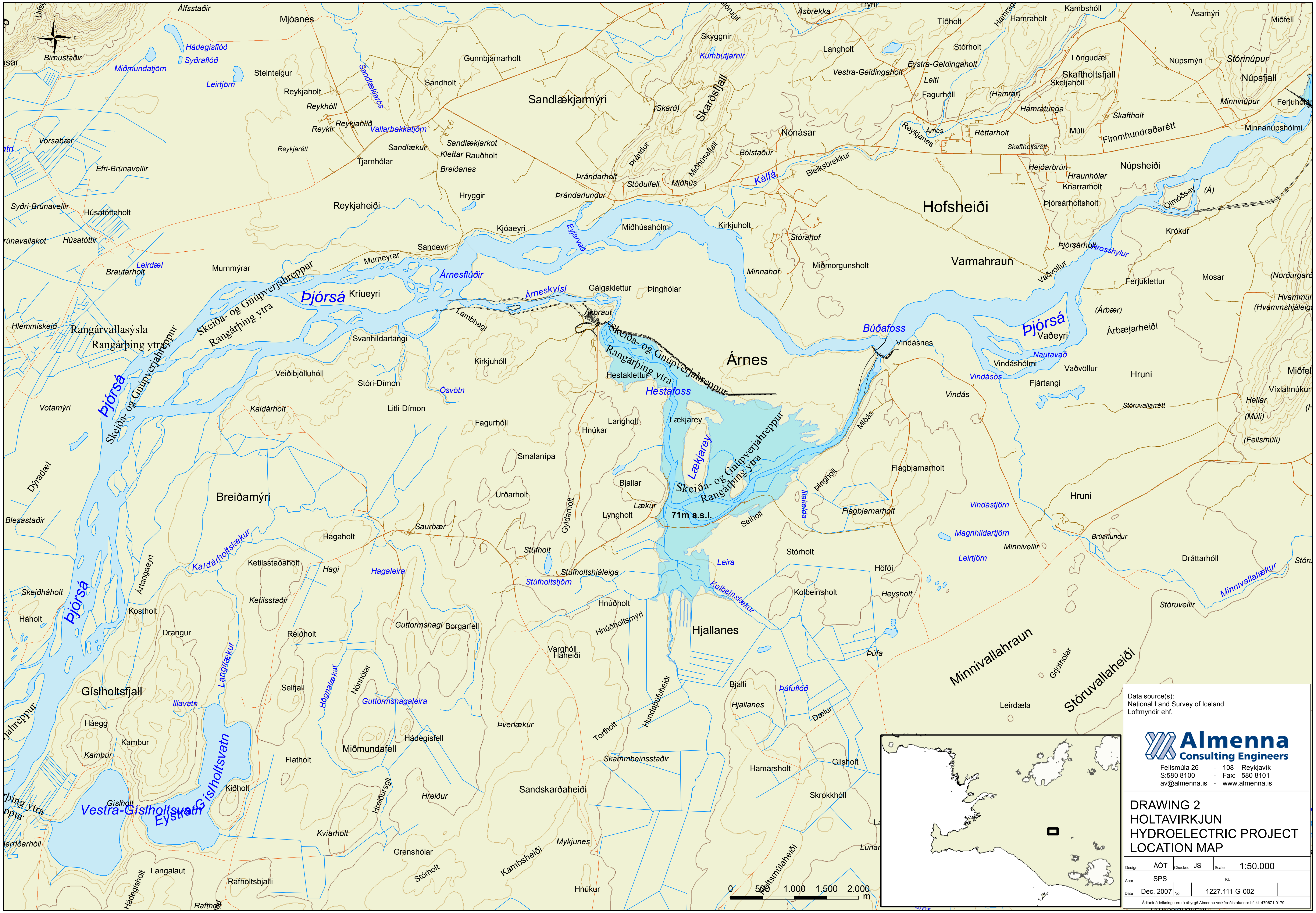
DRAWING 1
HOLTAVIRKJUN HYDROELECTRIC PROJECT
GENERAL LOCATION MAP

Design	ÁÓT	Checked SPS	Scale		
Appr.	SPS		Kt.		
Date	Dec. 2007	No.	1227.111-G-001		

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Data source(s):
National Land Survey of Iceland
Loftmyndir ehf.

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DRAWING 2
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
LOCATION MAP

Design	ÁÓT	Checked	JS	Scale	1:50.000
Appr.	SPS			Kt.	
Date	Dec. 2007	No.	1227.111-G-002		

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179

Búðafoss - Núpur

Jarðfræðikort - Geological map

THI	Búrfellshraun 1100 f.Kr.	*Burfell lava, 1100 BC*
THB	Þjórsárhraun 6600 f.Kr.	*The great Thjorsa lava, 6700 BC*
	Laust yfirborðsset og mýrlendi	*Loose overburden*
TSG	Foksandsteinn	*Aeolian sandstone (Tephra sand group)*
UTS	Siltsteinn og jökulgarðar frá síðjökultíma	*Late glacial siltstone and end-moraines*
HIB	Hlýskeiðshraun í Holtum, ól.basalt (N)	*Holt interglacial basalt*
LTS	Neðra jökulberg/silt	*Lower tillite/silt series*
HIT	Hlýskeiðsþóleiít í Hreppum(N)	*Hreppar Interglacial tholeiites*
SKH	Móberg í Skyggni	*Skyggnir hyaloclastite*
NP5	Efra Fossnesþóleiít (R)	*Upper Fossnes tholeiite*
NP4	Fossnesjökulberg	*Fossnes tillite*
NP3	Neðra Fossnesþóleiít (R)	*lower Fossnes tholeiite*
NSH	Núpsmóberg (R)	*Núpur hyaloclastite formation*
NSH	Minnanúpsþóleiít (R)	*Minninúpur tholeiite*
NSH	Núpsset	*Núpur sedimentary series*
SPG	Skarðsfjallsdílabasalt (R)	*Skarðsfjall porphyritic group*
NTG	Skarðsfjallsset	*Sedimentary layer in Skarðsfjall north*
NTG	Núpsþóleiít (R)	*Núpur tholeiite group*
SH3	Innskot í Skarðsfjalli (N)	*Skarðsfjall intrusive rock*
SH2	Skarðsfjallsmóberg (N)	*Skarðsfjall hyaloclastite*
SH1	Þjórsárholtsset	*Þjórsárholt sedimentary group*
STG	Víxlahnjúkur, dílabasdalt (N)	*Víxlahnjúkur porphyritic basalt layer*
STG	Skarðsfjallsþóleiít efri hl. (N)	*Upper Skarðsfjall tholeiitic group*
STG	Skarðsfjall, set	*Sediments inside Skarðsfjall thol. group*
STG	Skarðsfjall þóleiít Neðri hl. (N)	*Skarðsfjall lower tholeiite group*
LPG	Líparítgjóska	*Rhyolite, tuff and ignimbrite*
LPH	Líparírhraun eða innskot	*Rhyolite lava or intrusion*
GL	Geldingaholtsmyndun (innskot ofl.)	*Geldingaholt complex (basic intrusions)*
	Misgengi og sprungur	*Faults and fissures*
	Jarðskjálftasprunga	*Earthquake fissure*
	Berggangur	*Dyke*
⊥	Strik og halli	*Dip and strike*
⊙	Lind < 100 l/s	*Spring < 100 l/s*
◎	Stór lind > 100 l/s	*Spring > 100 l/s*
◉	Lindasvæði > 100 l/s	*Spring area > 100 l/s*
●	Hverir, laugar	*Hot spring*
Ⓝ	Rétt segulstefna	*Normal paleomagnetism*
Ⓡ	Öfug segulstefna	*Reverse paleomagnetism*
⊕	Borhola	*Drillhole*
⊡	Vatnsból	*Water supply*
	Jarðlagasnið	*Geologic section*

DRAWING 3
HOLTAVIRKJUN
HYDROELECTRIC ROJECT
GEOLOGICAL MAP

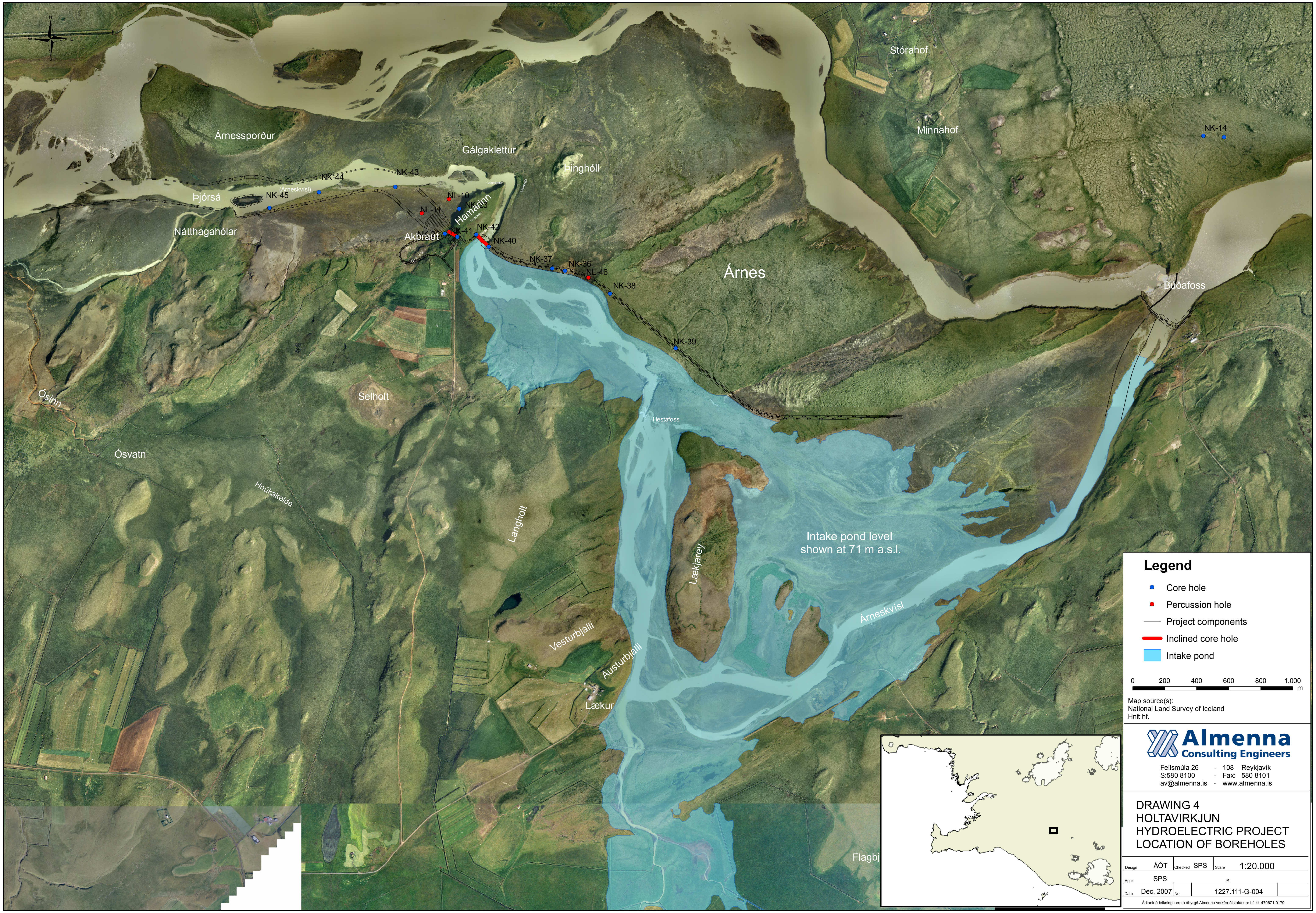
20051216

0 1 2 km

Árni Hjartarson, Páll Einarsson
og Snorri P. Snorrason 2001.
Keiluvörpun, viðmiðun ISN93
Unnið í landfræðilegu upplýsingakerfi
(Arc/Info®).

Byggt á/ Based on:
Ingvar B. Friðleifsson o.fl. 1980:
Gnúpverjahreppur, jarðfræðikort
Maryam Khodayar and Páll Einarsson 2001:
Geological map of Núpur area
Páll Einarssonar et al. 2001:
Faults and fractures near the SISZ near Þjórsá
Snorri Páll Snorrason 2002:
Núpsvirkjun Preliminary Geological Report
Orkustofnun: Borholuskrá

1227.111-G-003



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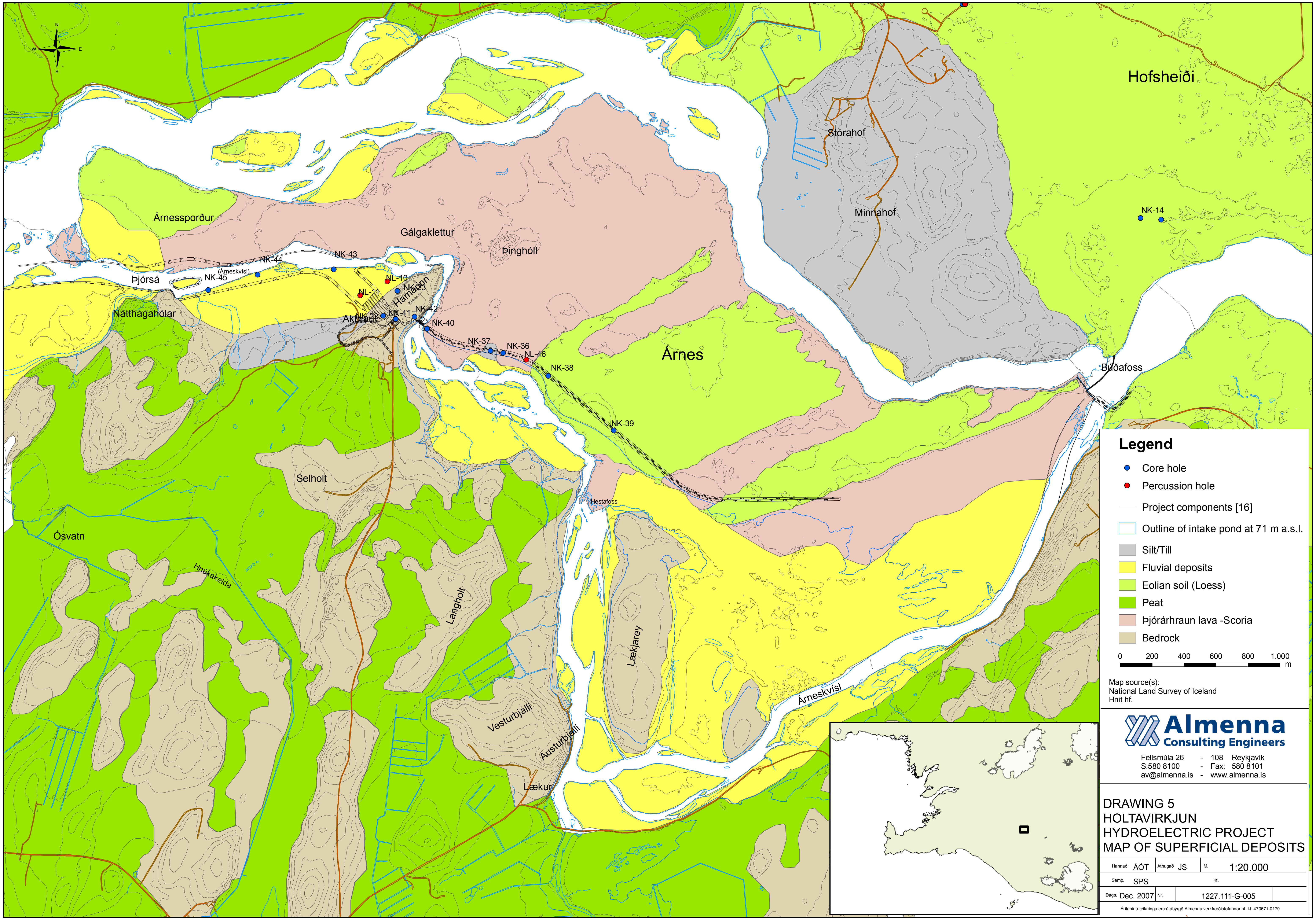
DRAWING 4
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
LOCATION OF BOREHOLES

Design	ÁÓT	Checked	SPS	Scale	1:20.000
Appr.	SPS			Kt.	
Date	Dec. 2007	No.		1227.111-G-004	

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Map source(s):
National Land Survey of Iceland
Hnit hf.

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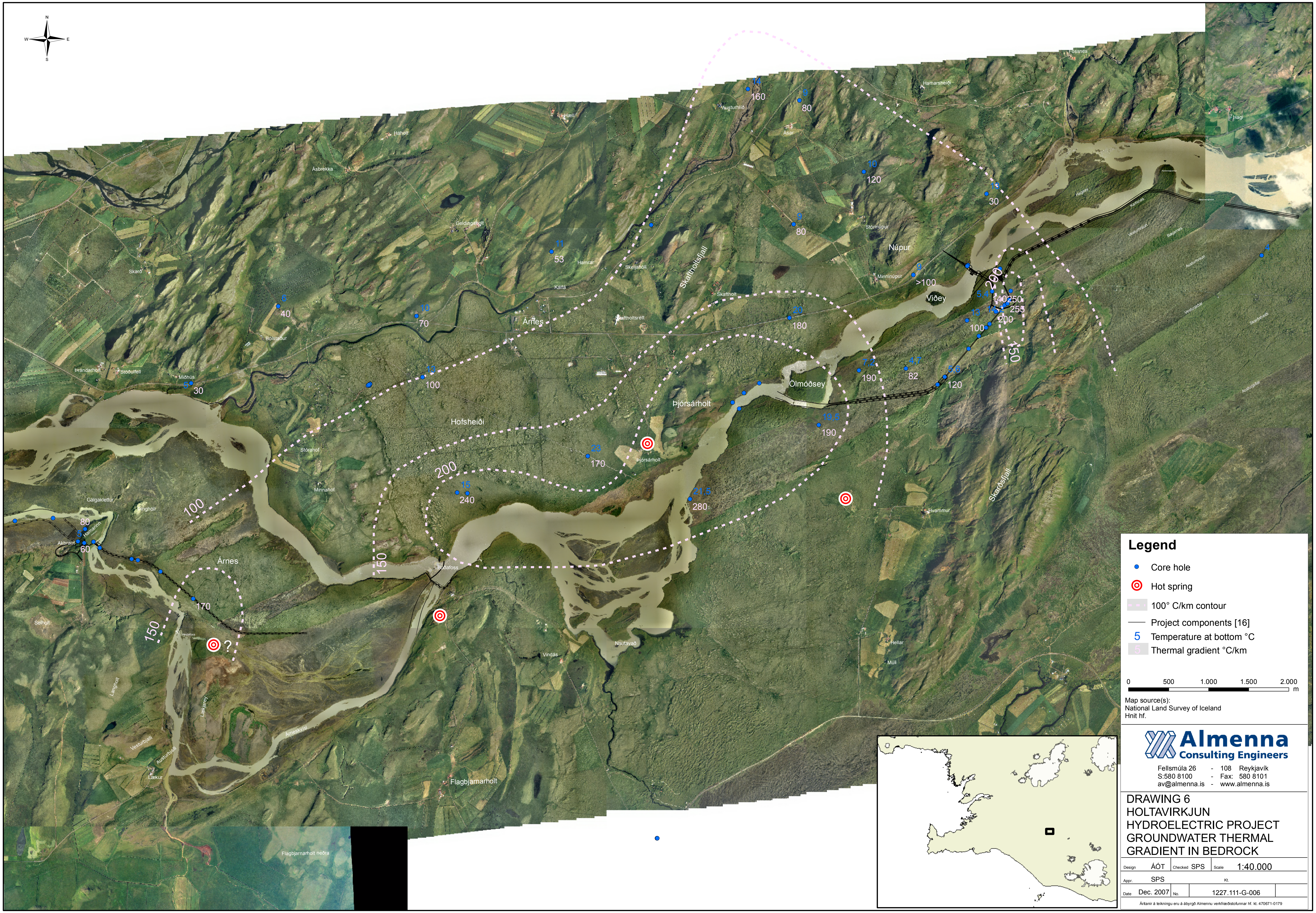
DRAWING 5
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
MAP OF SUPERFICIAL DEPOSITS

Hannað	ÁÓT	Athugað	JS	M.	1:20.000
Samþ.	SPS			Kt.	
Dags.	Dec. 2007	Nr.		1227.111-G-005	

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Legend

- ● Core hole
- ◎ Hot spring
- ▨ 100° C/km contour
- — Project components [16]
- 5 Temperature at bottom °C
- 5 Thermal gradient °C/km

0 500 1.000 1.500 2.000 m

Map source(s):
National Land Survey of Iceland
Hnit hf.

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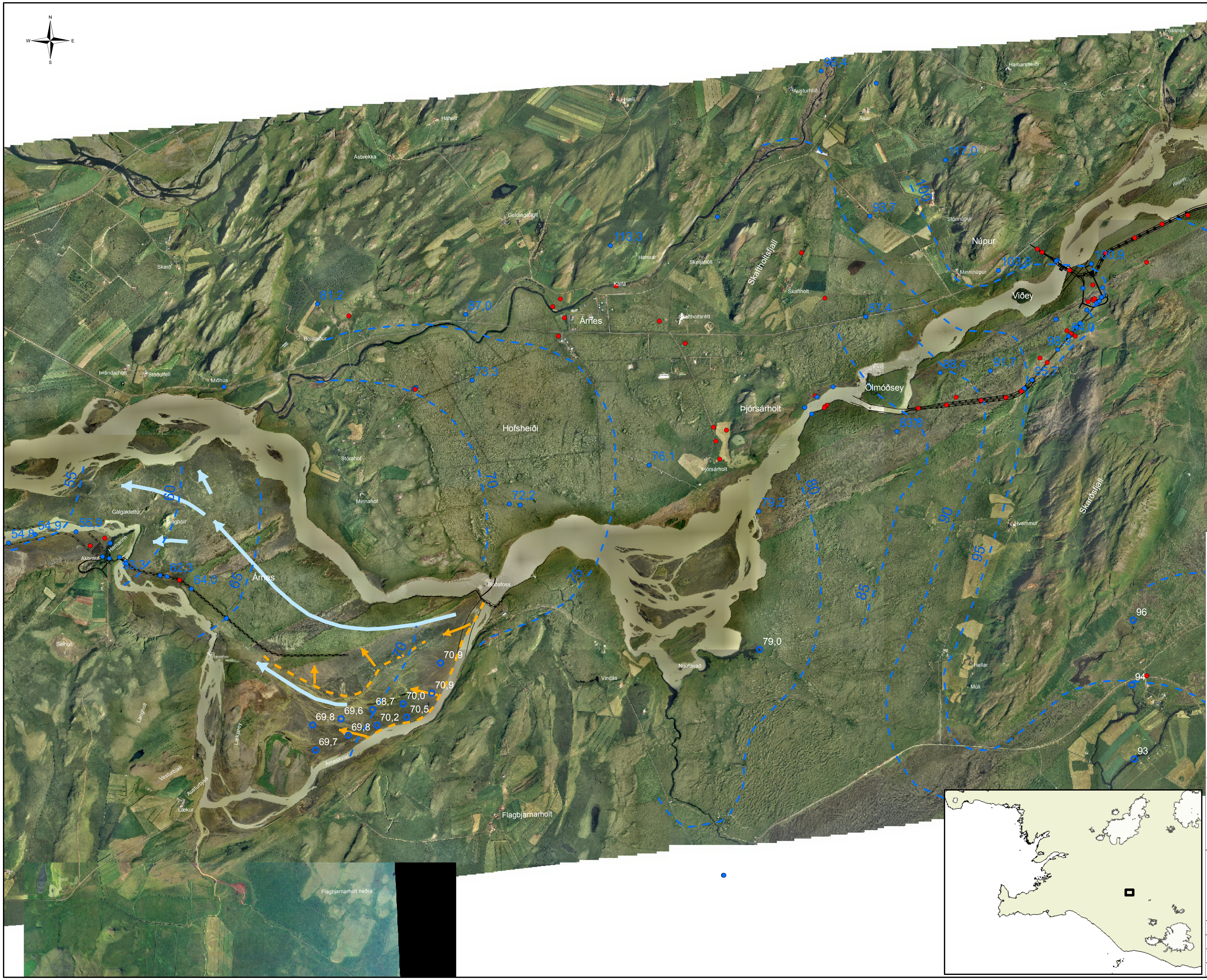
DRAWING 6
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
GROUNDWATER THERMAL GRADIENT IN BEDROCK

Design	ÁÓT	Checked	SPS	Scale	1:40.000
Appr.	SPS			Kt.	
Date	Dec. 2007	No.	1227.111-G-006		

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Legend

- ● Core hole
- ● Percussion hole
- - - Groundwater level contour m a.s.l.
- ○ Approx. groundwater level m a.s.l.
- ⇨ Direction of groundwater flow
- → Infiltration
- - - Infiltration margin
- — Project components [16]

0 500 1.000 1.500 2.000 m

Map source(s):
National Land Survey of Iceland
Hnit hf.

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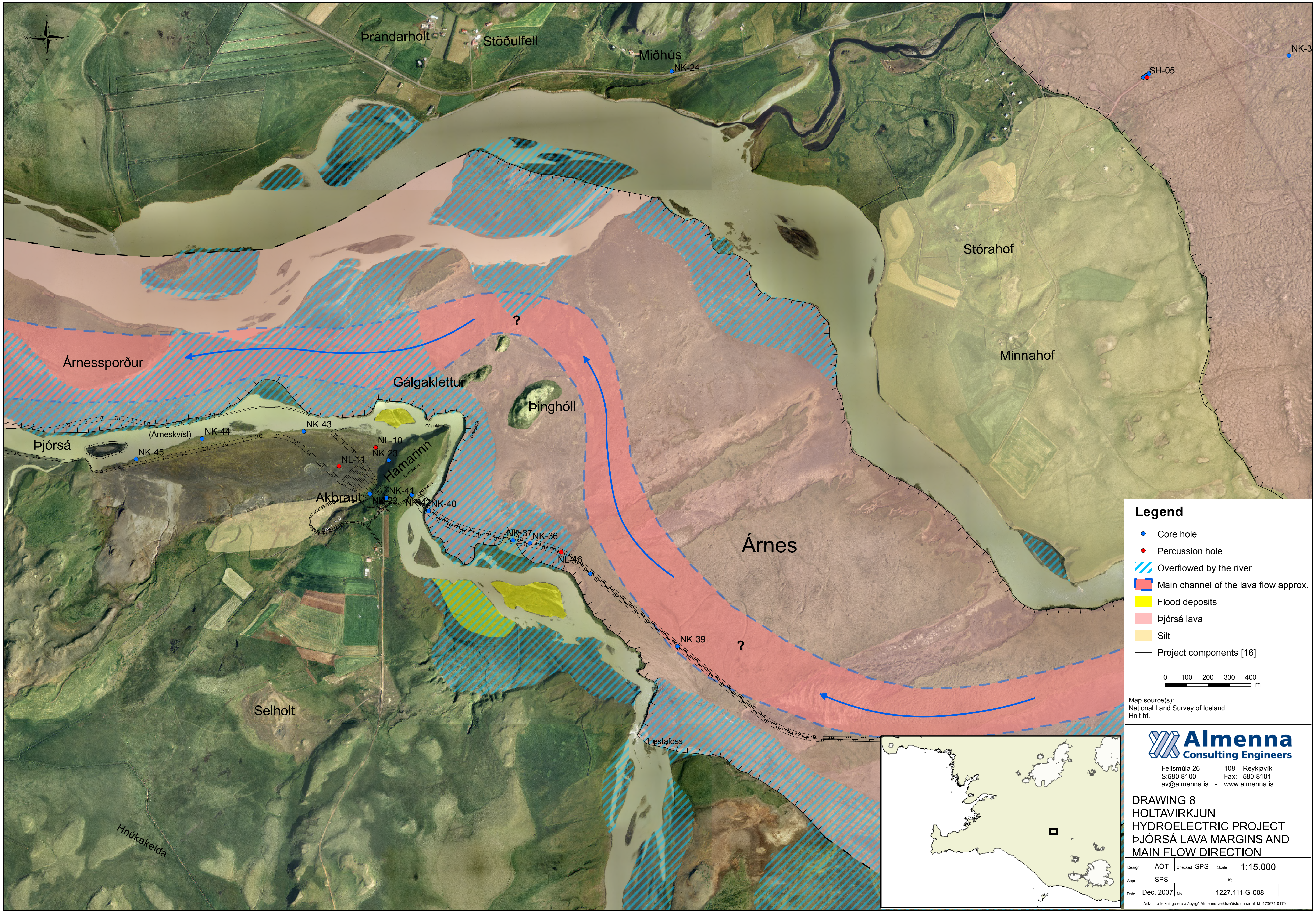
DRAWING 7
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
GROUNDWATER LEVEL

Design	ÁÓT	Checked	SPS	Scale	1:40.000
Appr.	SPS			Kt.	
Date	Dec. 2007	No.	1227.110-G-007		

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Map source(s):
National Land Survey of Iceland
Hnit hf.

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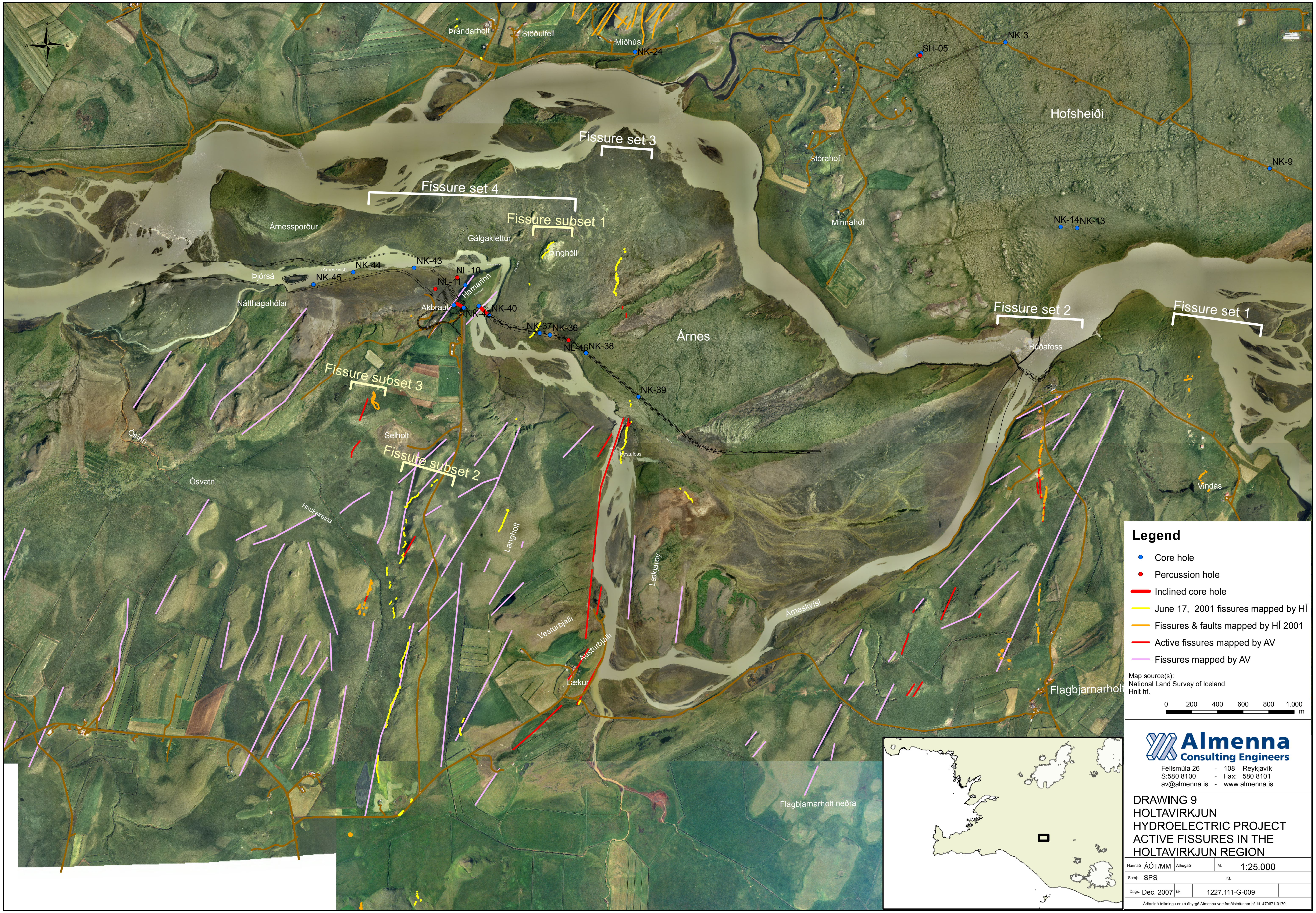
DRAWING 8
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
ÞJÓRSÁ LAVA MARGINS AND
MAIN FLOW DIRECTION

Design	ÁÓT	Checked	SPS	Scale	1:15.000
Appr.	SPS			Kt.	
Date	Dec. 2007	No.		1227.111-G-008	

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Legend

- ● Core hole
- ● Percussion hole
- ▬ Inclined core hole
- ▬ June 17, 2001 fissures mapped by HÍ
- ▬ Fissures & faults mapped by HÍ 2001
- ▬ Active fissures mapped by AV
- ▬ Fissures mapped by AV

Map source(s):
National Land Survey of Iceland
Hnit hf.

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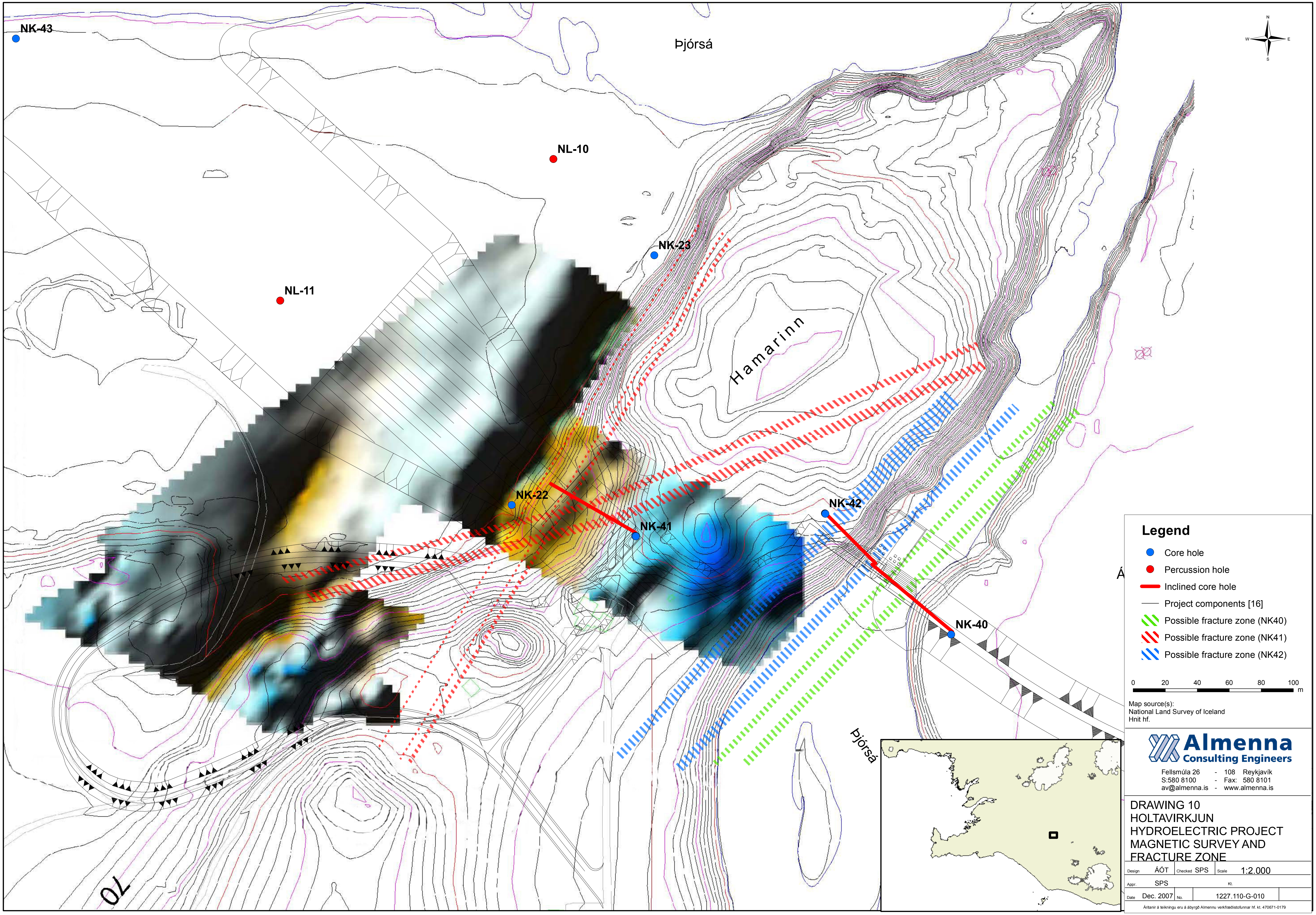
DRAWING 9
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
ACTIVE FISSURES IN THE
HOLTAVIRKJUN REGION

Hannað ÁÓT/MM
Athugað
M. 1:25.000
Samþ. SPS
Kt.
Dags. Dec. 2007
Nr. 1227.111-G-009

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Map source(s):
National Land Survey of Iceland
Hnit hf.

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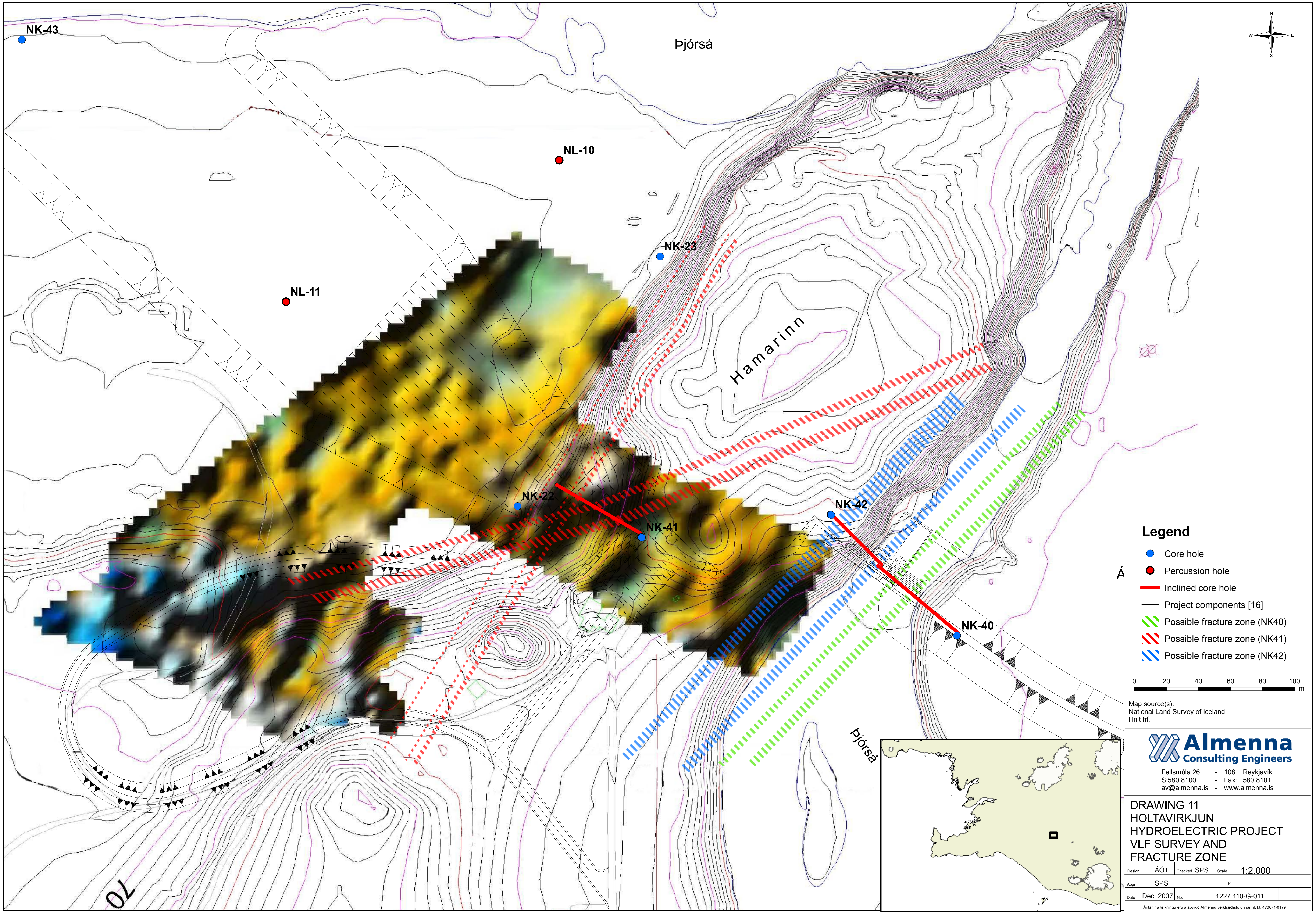
DRAWING 10
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
MAGNETIC SURVEY AND
FRACTURE ZONE

Design	ÁÓT	Checked	SPS	Scale	1:2.000
Appr.	SPS			Kt.	
Date	Dec. 2007	No.	1227.110-G-010		

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179



Map source(s):
National Land Survey of Iceland
Hnit hf.

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DRAWING 11
HOLTAVIRKJUN
HYDROELECTRIC PROJECT
VLF SURVEY AND
FRACTURE ZONE

Design	ÁÓT	Checked	SPS	Scale	1:2.000
Appr.	SPS			Kt.	
Date	Dec. 2007	No.	1227.110-G-011		

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179

Map source(s):
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DRAWING 12
HOLTAVIRKJUN HYDROELECTRIC PROJECT ACTIVE FISSURES AT THE DAM SITE AND FISSURE TRENCHES

Hannað ÁÓT/MM	Athugað	M. 1:5.000	
Samþ. SPS		Kt.	
Dags. Dec. 2007	Nr.	1227.111-G-012	

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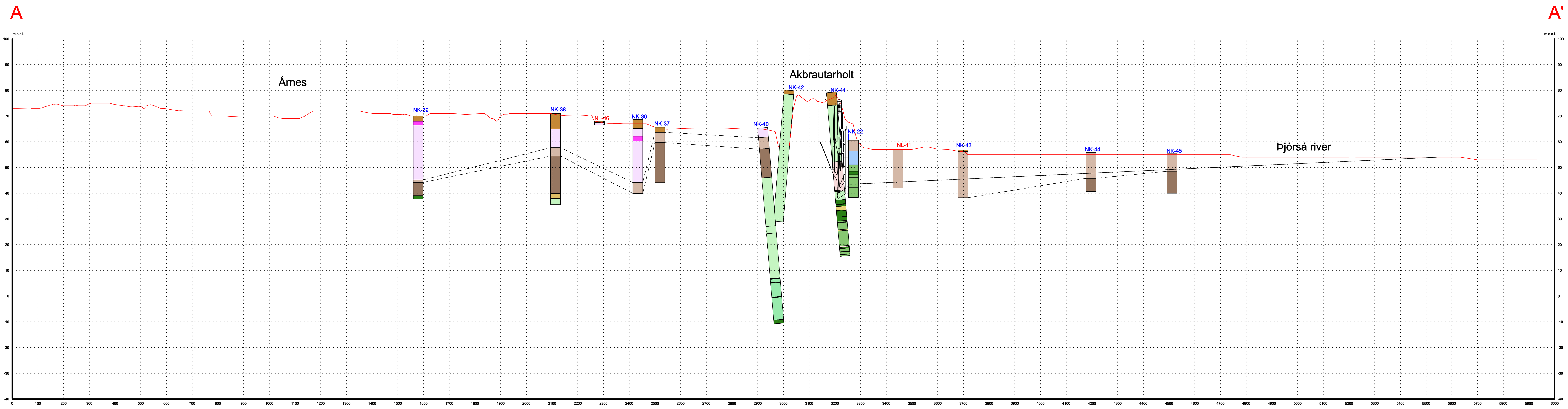

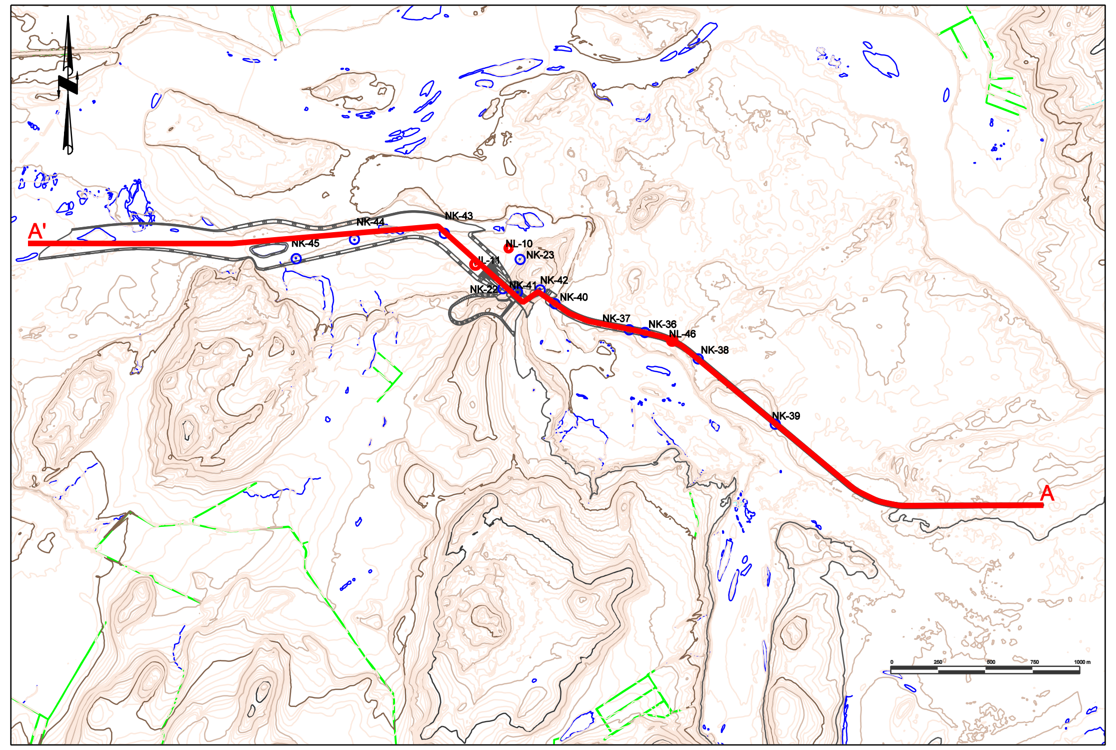

Constructions according to Project Planning Report

Legend

- 🟫 Soil
- 🟫 Tephra sand & gravel
- 🟫 Silt/siltstone
- 🟨 Tillite
- 🟪 Þjórsárhraun lava - Scoria
- 🟪 Þjórsárhraun lava
- 🟦 Tholeiite basalt
- 🟩 Akbraut Interglacial olivin basalt
- 🟩 Porphyritic basalt
- 🟩 Olivine basalt
- 🟩 Dyke
- 🟨 Conglomerate

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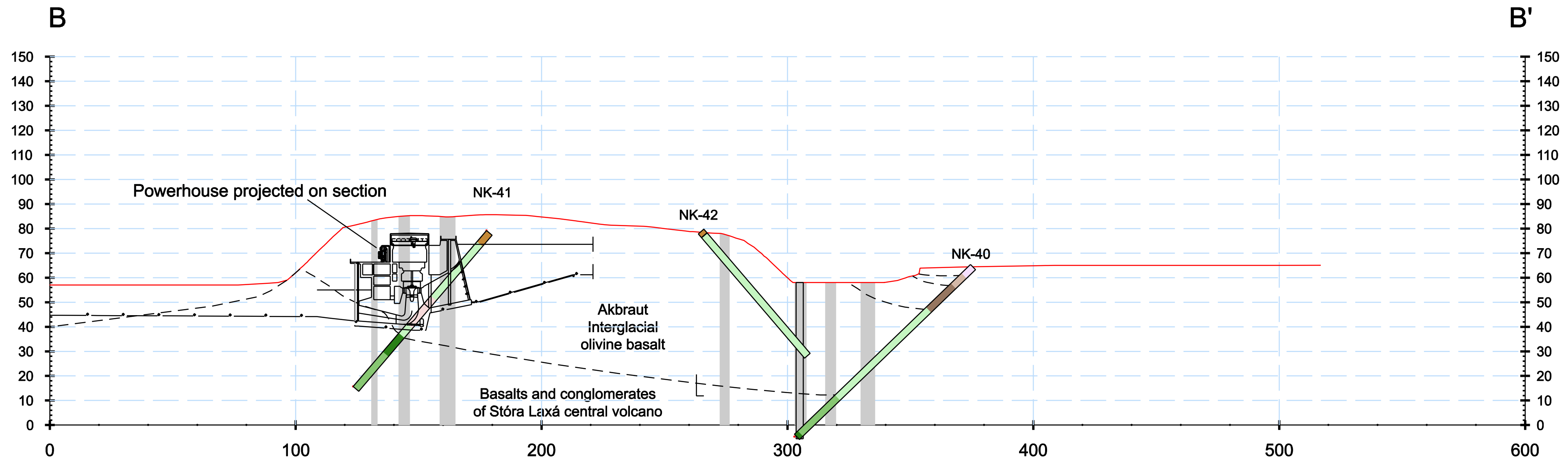
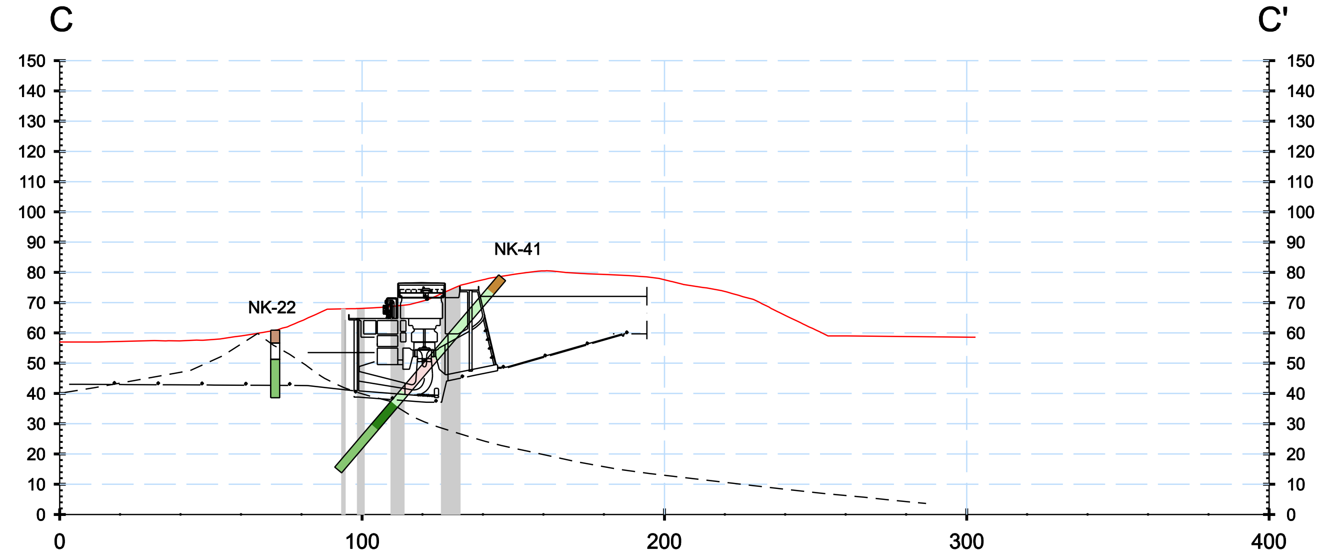
Drawing 13
Holtavirkjun HEP
Powerhouse site
Geological section A-A'

Design ÁÓT	Checked	Scale	
Appr. SPS		Kt.	
Date Dec. 2007	No.	1227.111-G-013	

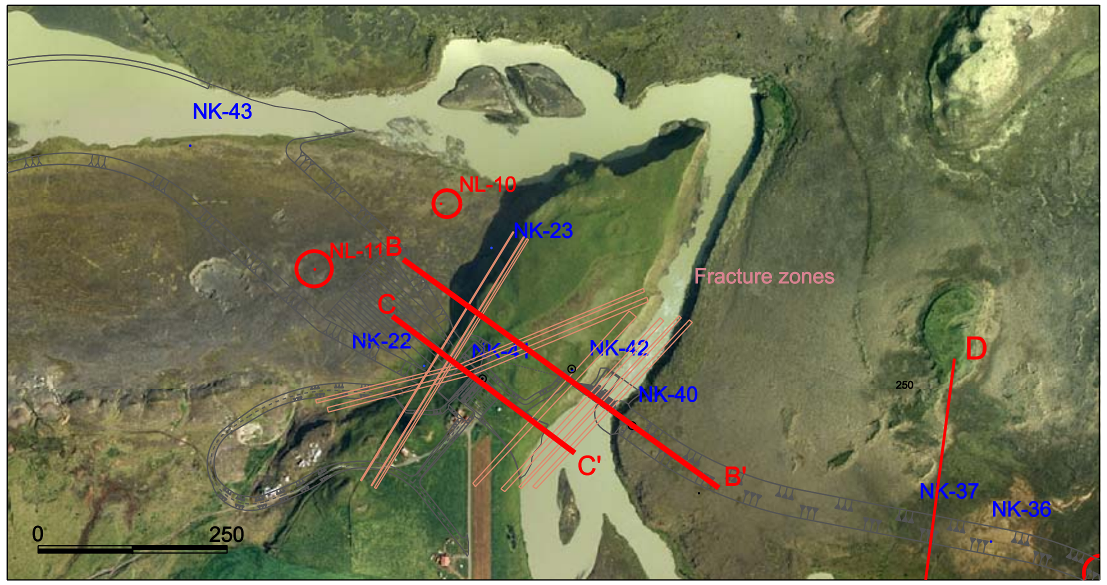
Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179





Legend

- ▮ Fracture zone
- 🟧 Soil
- 🟫 Tephra sand and gravel
- 🟫 Silt/siltstone
- 🟪 Þjórsárhraun lava
- 🟥 Þjórsárhraun lava - scoria
- 🟩 Akbraut interglacial olivine basalt
- 🟩 Porphyritic basalt
- 🟩 Dyke
- 🟩 Olivine basalt



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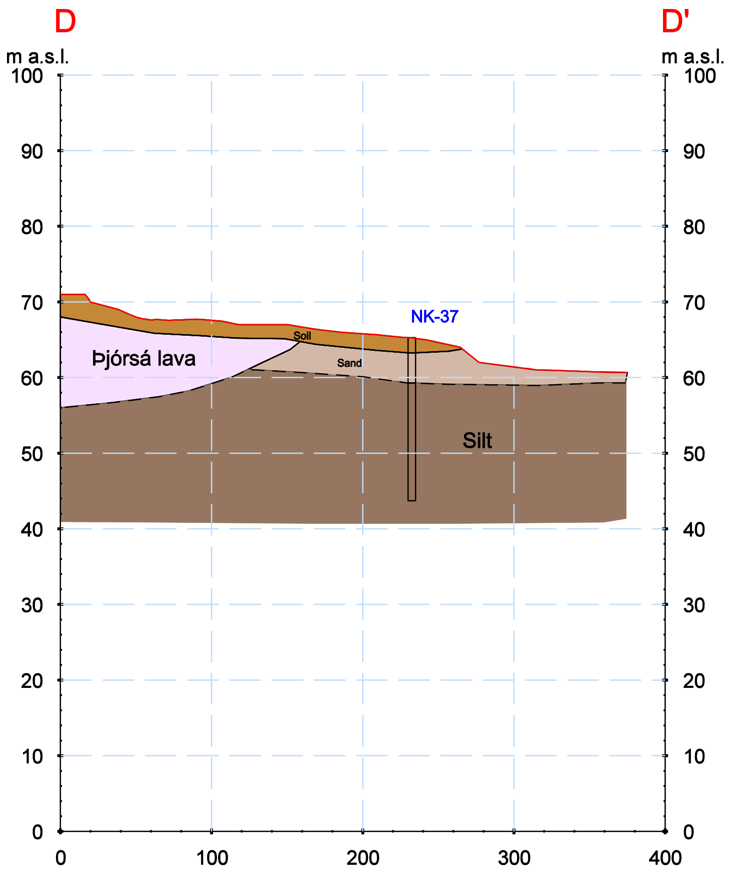
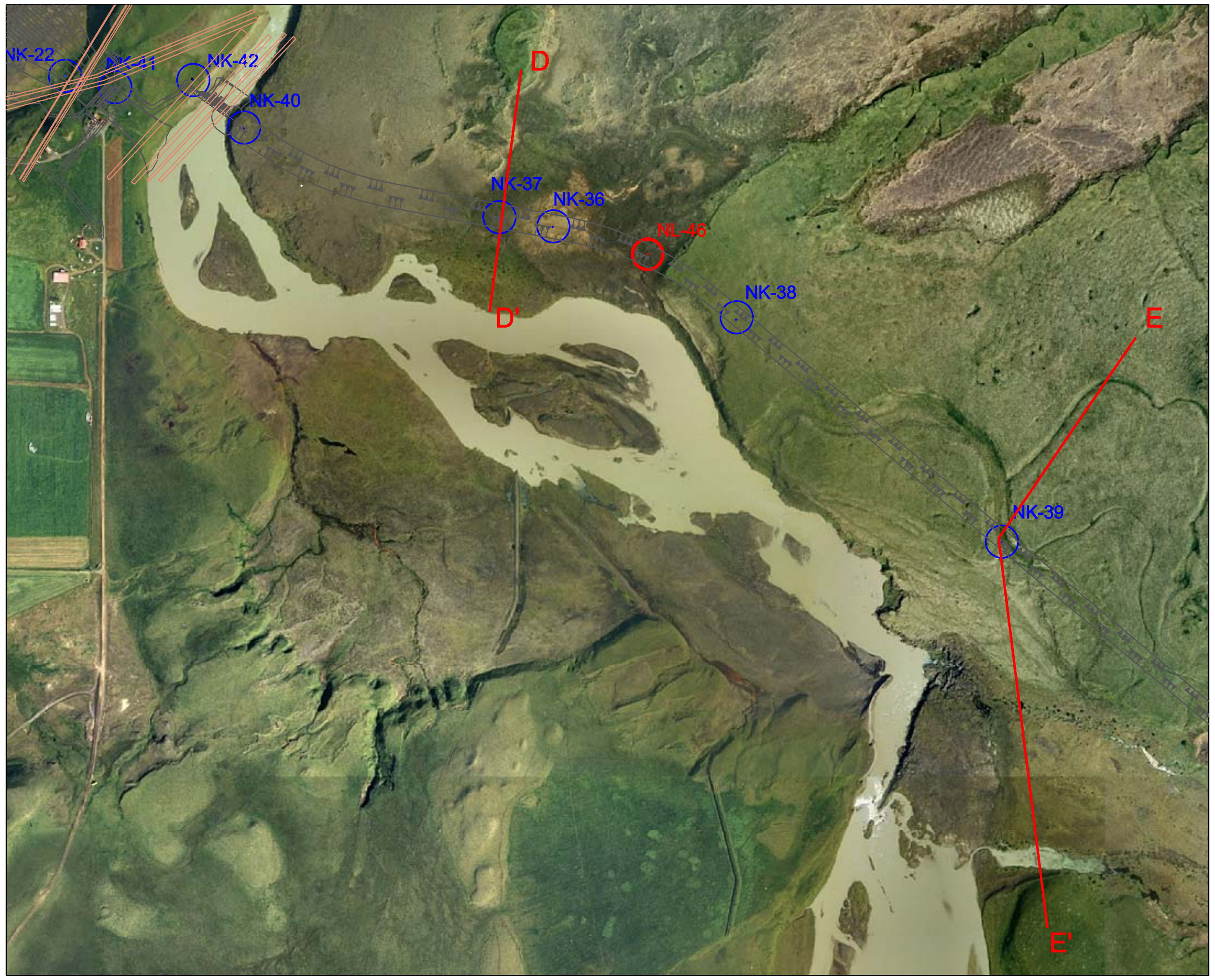
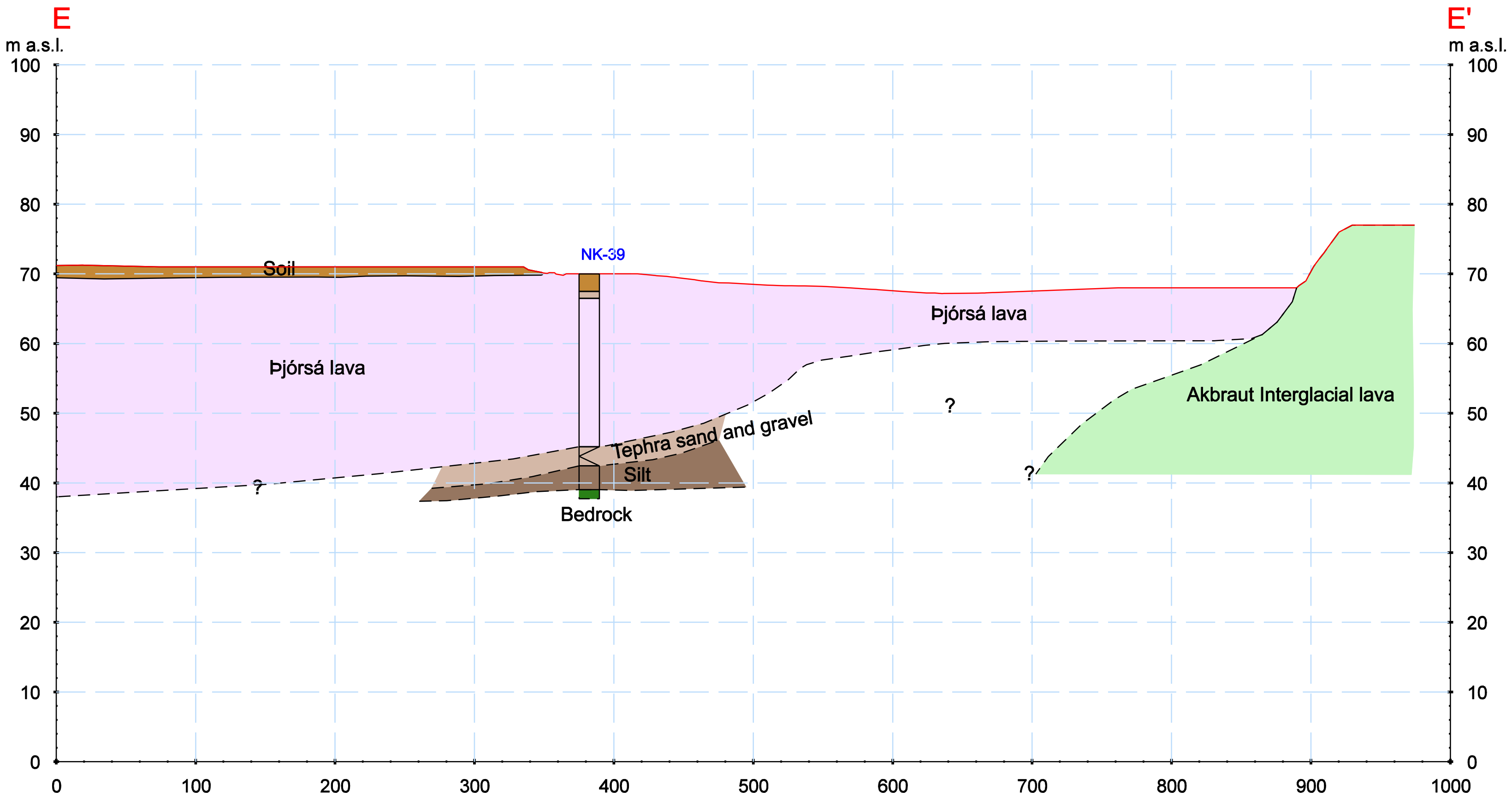
Drawing 14
Holtavirkjun HEP
Powerhouse site
Geological sections B-B' and C-C'

Design MM	Checked	Scale
Appr. SPS		Kt.
Date Dec. 2007	No.	1227.111-G-014

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179







Legend

🟧	Soil
▨	Tephra sand and gravel
▨	Þjórsárhraun lava
🟫	Silt/siltstone
🟩	Akbraut Interglacial basalt
🟩	Bedrock

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Drawing 15
Holtavirkjun HEP
Powerhouse site
Geological sections D-D' and E-E'

Design ÁÓT	Checked	Scale
Appr. SPS		Kt.
Date Dec. 2007	No.	1227.111-G-015

Almenna Consulting Engineers

Landsvirkjun

Núpsvirkjun

NK - 22

Coord. X: 433490.2 Y:391076.9 el.: 60.6 m.a.s.l. ISN 93

Contractor: RSBF&S

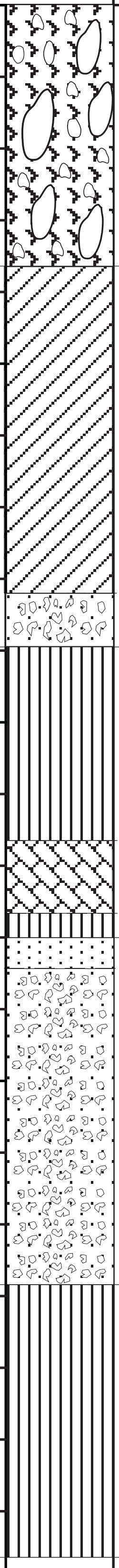
Trítill NQ/ ODEX

Site: Hvammur Landssveit

Drilled: Dec. 2001

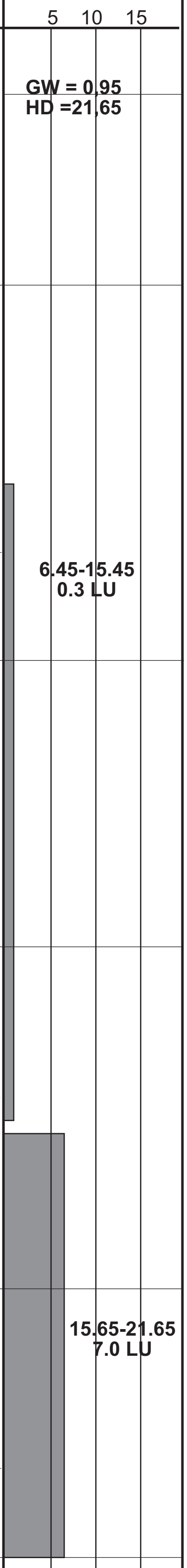
Drawn: Dec. 2001 - JÖF

Elev. m.a.s.l.	Depth m	Core/cuttings description
60.6	0	**Blocky overburden**
56.4	4.2	**Tholeiite basalt** Grey color and medium grain size. Massive with calsite in minor vesicles. Joints are coated with green and black clay. The core is fractured and joints are smooth and undulating. Joints are horizontal, vertical and inclined. 14.6 kN 142 MPa
51.83		**Scoria** Pores filled with green clay and silt.
51.03		**Olivine basalt** 5.6 kN 48 MPa Coarse grained, color: dark grey. White secondary minerals in joints and vesicles. Both zeolites and iceland spar (calsite). Joints are irregular and rough. Heavily jointed.
48.35		**Dyke** Coarse grained basalt dyke with plagioclase phenochrysts (c.a. 5%). White secondary minerals. Joints are undulating. Pyrite and calsite in joints. The dyke is almost horizontal.
		Olivine basalt cont.
46.05		**Sandstone/siltstone** Fine grained black sand or silt with pl. crystals.
		Scoria Filled with silt and clay. Zeolites in vesicles. The core is hevily jointed. Joints are rough and irregular and silt and clay are found in joints. Gets more massive near the bottom. Joints are horizontal, vertical and inclined. 2.2 kN 17 MPa
42.15	18	**Olivine basalt** Color: grey. Medium-coarse grain size, massive with light colored secondary minerals in joints. Slightly plagioclase porphyritic (c.a. 1%). Joints are smooth, undulating. 16.7 kN 157 MPa
38.35		**Total number of dykes, 1 .** **Dyke ratio in bedrock 5.5 %** **Bottom 21.65 m**



Core rec. %	RQD % 10/30/50/100
127	64/0/0/0
96	36/0/0/0
79	73/0/0/0
107	27/0/0/0
	35/0/0/0
95	36/0/0/0
	$Q = \frac{35}{12\text{-}15} x \frac{2\text{-}3}{2\text{-}3} x \frac{1}{1}$
	Q=1.5-4
44	0/0/0/0
87	29/0/0/0
	28/0/0/0
100	19/0/0/0
	$Q = \frac{28}{12\text{-}15} x \frac{2\text{-}3}{3} x \frac{1}{1}$
82	20/0/0/0
	Q=1.2-2
109	52/0/0/0
97	0/0/0/0
49	29/0/0/0
	34/10/0/0
77	23/0/0/0
	$Q = \frac{34}{9\text{-}15} x \frac{2\text{-}3}{2\text{-}3} x \frac{1}{1}$
	Q=1.5-6
97	44/20/0/0
93	68/0/0/0
	41/0/0/0
89	17/0/0/0
	$Q = \frac{41}{12\text{-}15} x \frac{2\text{-}3}{3\text{-}4} x \frac{1}{1}$
83	26/0/0/0
	Q=1-3

Water table and permeability Lhugeon units (LU)



Almenna Consulting Engineers

Landsvirkjun

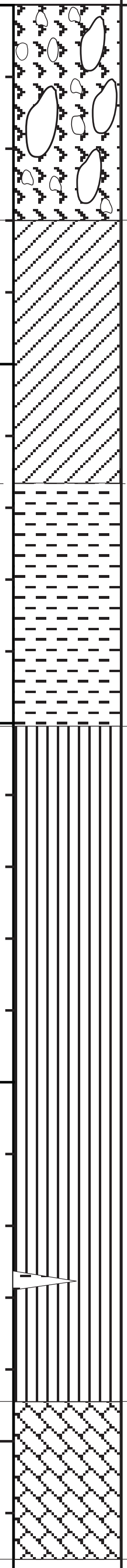
Núpsvirkjun
NK - 23

Coord. X: 433490.2 Y:391233.3 el.: 58.7 m.a.s.l. ISN 93

Contractor: RSBF&S
Trítill NQ/ ODEX
Site: Hvammur Landssveit
Drilled: Dec. 2001
Drawn: Dec. 2001 - JÖF

Elev. m.a.s.l.	Depth m	Core/cuttings description
58.7		**Blocky overburden**
55.7		**Tholeiite basalt** 25.8 kN 176 MPa Grey basalt with plagioclase micro-phenochrysts. Groundmass is medium grained, massive and fresh. Light colored clay in joints. Joints are smooth and undulating. The core is heavily jointed.
51.55		**Silt** Grey silt. Core recovery poor, only one 5 cm chunk was descovered.
47.98	10	**Olivine tholeiite** Medium-coarse grained, dark grey basalt. Vesicles filled with black clay and calsite. Joints are irregular and coated with black clay that softens the contact. White secondary minerals also in vains. Joints are vertical and inclined. 2.2 kN 21 MPa About 7 cm vug filled with green clay.
38.58	20	**Dyke** 6.7 kN 51 MPa Coarse grained basalt dyke with plagioclase phenochrysts (c.a. 5%). Groundmass dark grey.White secondary minerals. Joints are undulating. Pyrite and calsite in joints.
36.35	22	**Number of dykes, 1.** **Dyke ratio in bedrock 10 %** **Bottom 21.65 m**

Depth m | Rock column



Core rec. %	RQD % 10/30/50/100
83	16/0/0/0
	9/0/0/0
98	25/0/0/0
	$Q = \frac{9}{12\text{-}15} x \frac{2}{3\text{-}4} x \frac{1}{1}$
	Q=0.3-0.5
28	0/0/0/0
0	0/0/0/0
	10/0/0/0
14	0/0/0/0
65	0/0/0/0
93	10/0/0/0
65	15/0/0/0
73	0/0/0/0
	15/4/0/0
74	24/0/0/0
	$Q = \frac{15}{12\text{-}15} x \frac{2\text{-}3}{2\text{-}4} x \frac{1}{1}$
63	0/0/0/0
	Q=0.5-1.8
95	37/25/0/0
100	25/0/0/0
100	0/0/0/0
	5/0/0/0
	$Q = \frac{5}{12\text{-}15} x \frac{2\text{-}3}{3\text{-}4} x \frac{1}{1}$
70	5/0/0/0
	Q=0.2-0.4

Water table and permeability Lhugeon units (LU)
5 10 15

11.60-21.65
0.03 LU

Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NK-36

Contractor: RSFS

Drill: Langþráður

Site: Árnes

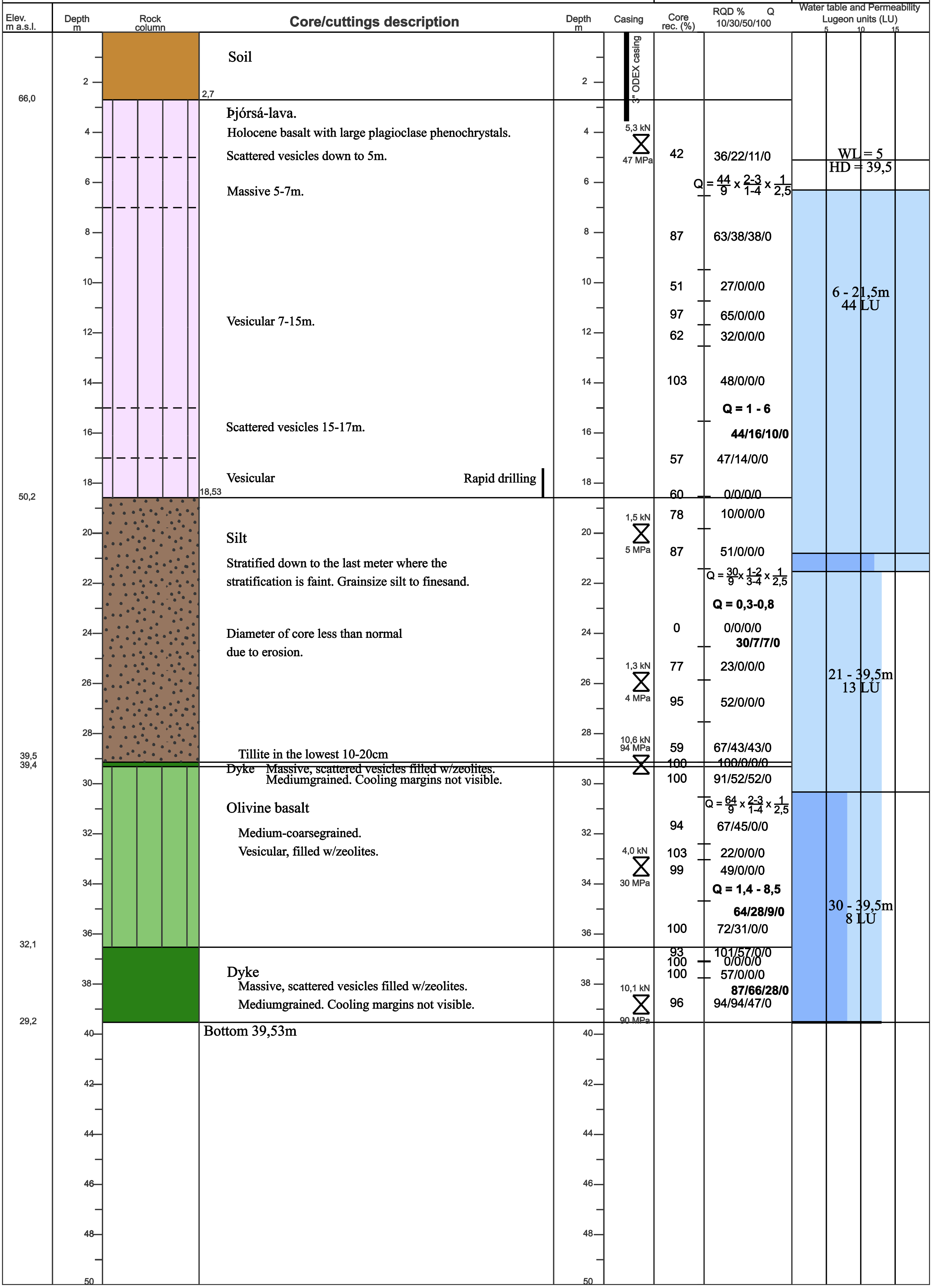
Diameter: ODEX 3"/NQTT

Date of drilling: 19-20.10.2006

Drawn: MM

Drawing no. 1 of 1

Coordinates: ISN93 X: 434151,0 Y: 390844,7 Elevation: 68,71 m a.s.l



$Q = \frac{44}{9} \times \frac{2\text{-}3}{1\text{-}4} \times \frac{1}{2,5}$

$Q = \frac{30}{9} \times \frac{1\text{-}2}{3\text{-}4} \times \frac{1}{2,5}$

$Q = \frac{64}{9} \times \frac{2\text{-}3}{1\text{-}4} \times \frac{1}{2,5}$

Soil

Þjórsá-lava.

Holocene basalt with large plagioclase phenochrystals.

Scattered vesicles down to 5m.

Massive 5-7m.

Vesicular 7-15m.

Scattered vesicles 15-17m.

Vesicular

Rapid drilling

Silt

Stratified down to the last meter where the stratification is faint. Grainsize silt to finesand.

Diameter of core less than normal due to erosion.

Tillite in the lowest 10-20cm

Dyke Massive, scattered vesicles filled w/zeolites. Mediumgrained. Cooling margins not visible.

Olivine basalt

Medium-coarsegrained.

Vesicular, filled w/zeolites.

Dyke

Massive, scattered vesicles filled w/zeolites.

Mediumgrained. Cooling margins not visible.

Bottom 39,53m

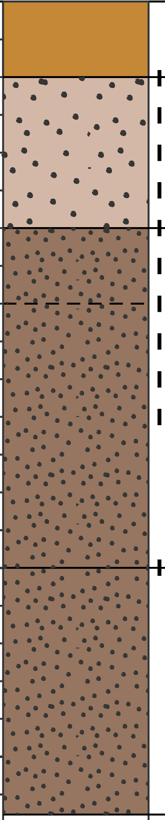
Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NK-37

Contractor: RSFS	Drill: Langþráður	Site: Árnes	Diameter: ODEX 3"/NQTT
Date of drilling: 19-20.10.2006	Drawn: MM	Drawing no. 1 of 1	

Coordinates: **ISN93** **X: 434071,8** **Y: 390858,8** **Elevation: 65,66 m a.s.l**



Elev. m a.s.l.	Depth m	Core/cuttings description	Casing	Core rec. (%)	RQD % 10/30/50/100 / Q	Water table and Permeability Lugeon units (LU)
	0-2	Soil	3" ODEX casing			
63,7	2-6	Sand and gravel Well rounded gravel pebbles of various origin. Size <1cm	3" ODEX casing			
59,7	6-15	Silt/finesand More finesand above 8m. Siltier below. Partly cemented silt. Cuttings mostly soft silt or poorly cemented silt.	3" ODEX casing			
	15-21,53	Silt/finesand Stratification visible. 15,20-15,70m, coarser lenses. Irregular stratification. Fresh joint walls, no fillings.		85 95 95	20/0/0/0 60/0/0/0 $Q = \frac{59}{9} \times \frac{1\text{-}2}{3\text{-}4} \times \frac{1}{2,5}$ **Q = 0,7 - 1,8** **59/15/0/0** 66/34/0/0	
44,1	21,53	Bottom 21,53m				

Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NK-38

Contractor: RSFS

Drill: Langbráður

Site: Árnes

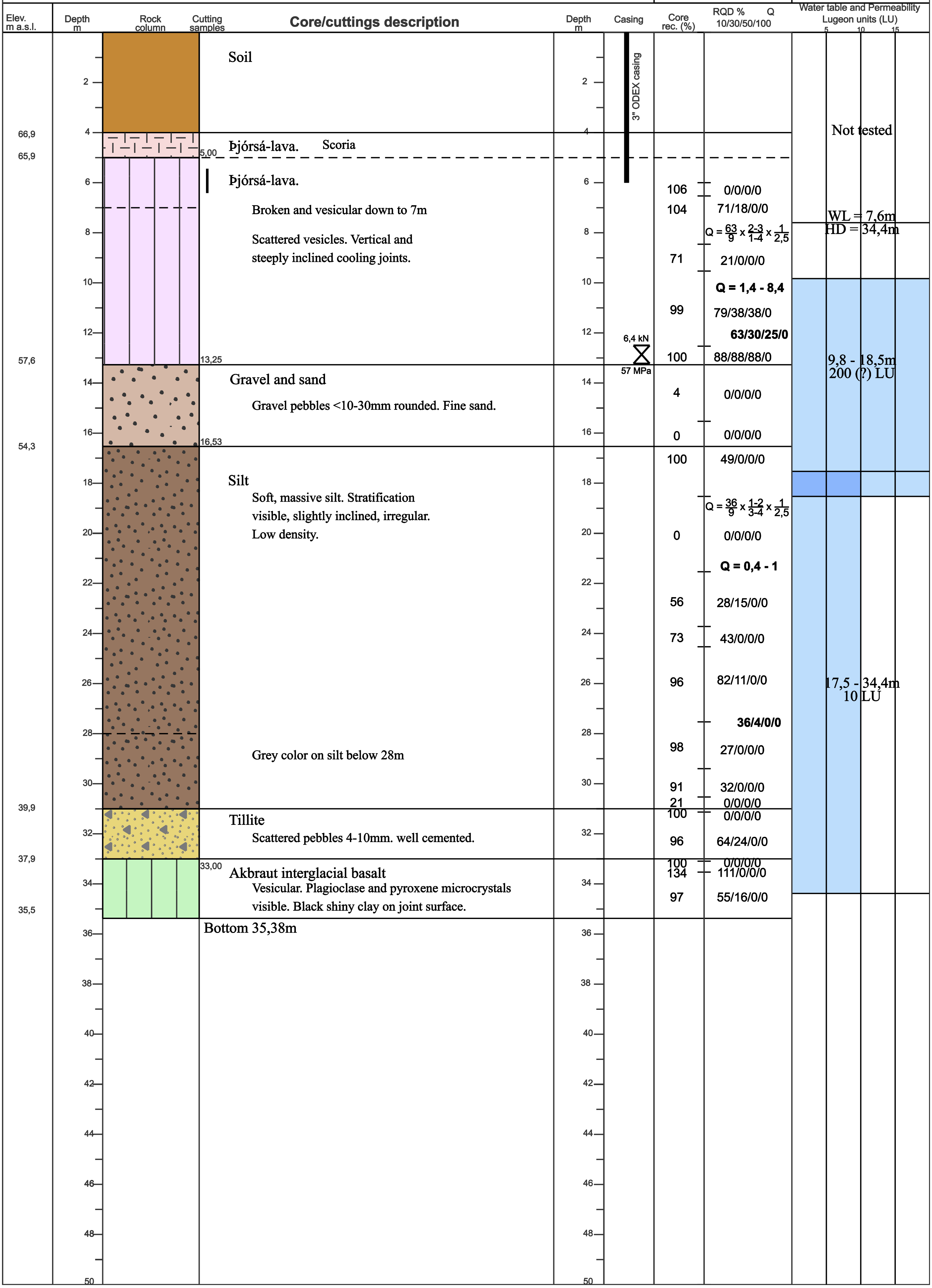
Diameter: ODEX 3"/NQTT

Date of drilling: 22.10.2006

Drawn: MM

Drawing no. 1 of 1

Coordinates: ISN93 X: 434433,2 Y:390702,2 Elevation: 70,85 m a.s.l



Soil

Þjórsá-lava. Scoria

Þjórsá-lava.

Broken and vesicular down to 7m

Scattered vesicles. Vertical and steeply inclined cooling joints.

Gravel and sand

Gravel pebbles <10-30mm rounded. Fine sand.

Silt

Soft, massive silt. Stratification visible, slightly inclined, irregular. Low density.

Grey color on silt below 28m

Tillite

Scattered pebbles 4-10mm. well cemented.

Akbraut interglacial basalt

Vesicular. Plagioclase and pyroxene microcrystals visible. Black shiny clay on joint surface.

Bottom 35,38m

Core rec. (%)	RQD % 10/30/50/100	Q
106	0/0/0/0	
104	71/18/0/0	
		$Q = \frac{63}{9} \times \frac{2\text{-}3}{1\text{-}4} \times \frac{1}{2,5}$
71	21/0/0/0	
		Q = 1,4 - 8,4
99	79/38/38/0	
	63/30/25/0	
100	88/88/88/0	
4	0/0/0/0	
0	0/0/0/0	
100	49/0/0/0	
		$Q = \frac{36}{9} \times \frac{1\text{-}2}{3\text{-}4} \times \frac{1}{2,5}$
0	0/0/0/0	
		Q = 0,4 - 1
56	28/15/0/0	
73	43/0/0/0	
96	82/11/0/0	
	36/4/0/0	
98	27/0/0/0	
91	32/0/0/0	
21	0/0/0/0	
100	0/0/0/0	
96	64/24/0/0	
100	0/0/0/0	
134	111/0/0/0	
97	55/16/0/0	

Not tested

WL = 7,6m
HD = 34,4m

9,8 - 18,5m
200 (?) LU

17,5 - 34,4m
10 LU

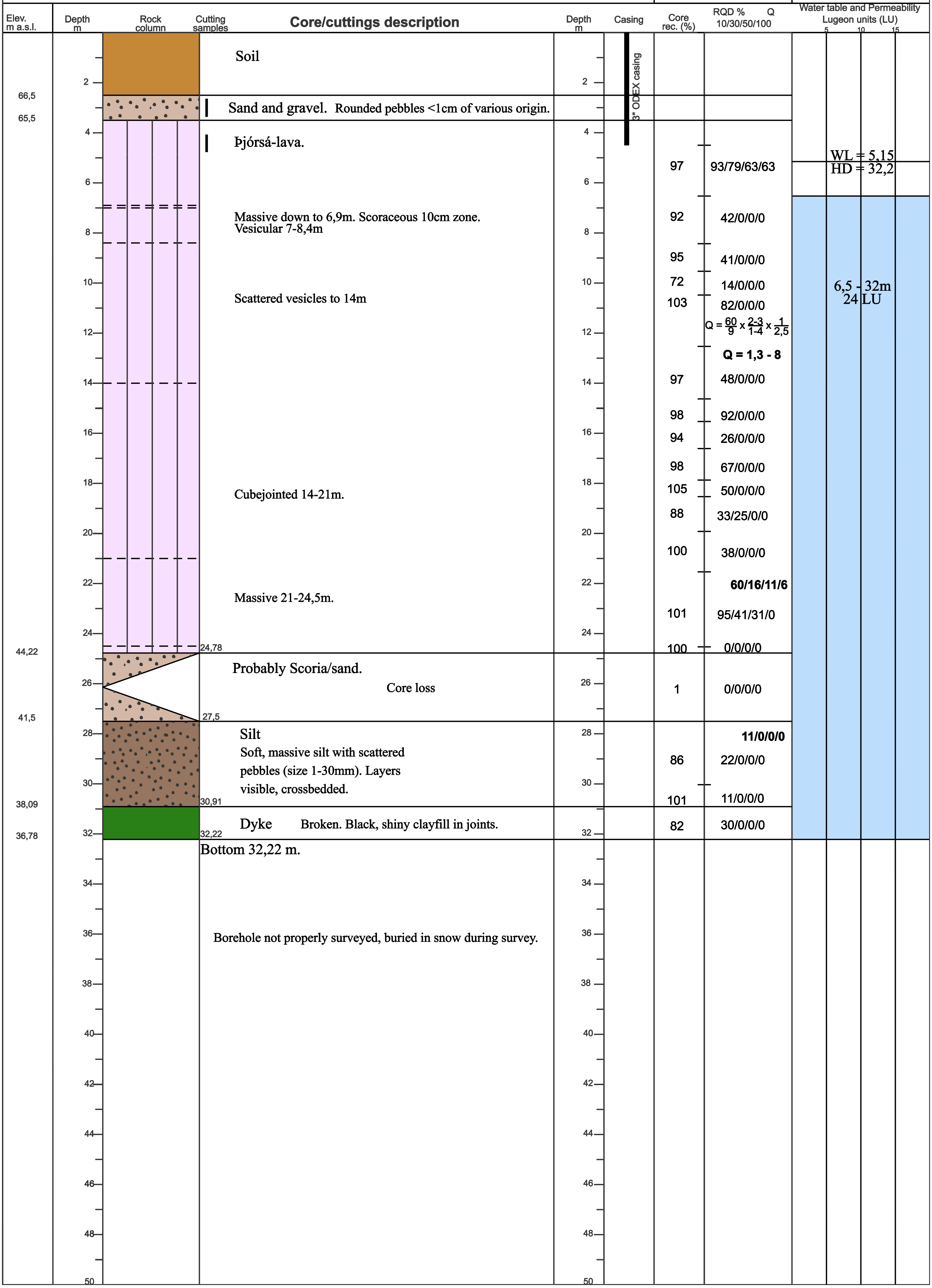
Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NK-39

Contractor: RSFS
Drill: Langþráður
Site: Árnes
Diameter: ODEX 3"/NQTT
Date of drilling: 23.10.2006
Drawn: MM
Drawing no. 1 of 1

Coordinates: ISN93 X: 434843 Y: 390360 Elevation: 69 m a.s.l



Soil

Sand and gravel. Rounded pebbles <1cm of various origin.

Þjórsá-lava.

Massive down to 6,9m. Scoraceous 10cm zone.
Vesicular 7-8,4m

Scattered vesicles to 14m

Cubejointed 14-21m.

Massive 21-24,5m.

Probably Scoria/sand.
Core loss

Silt
Soft, massive silt with scattered pebbles (size 1-30mm). Layers visible, crossbedded.

Dyke Broken. Black, shiny clayfill in joints.

Bottom 32,22 m.

Borehole not properly surveyed, buried in snow during survey.

Core rec. (%)	RQD % 10/30/50/100
97	93/79/63/63
92	42/0/0/0
95	41/0/0/0
72	14/0/0/0
103	82/0/0/0
97	48/0/0/0
98	92/0/0/0
94	26/0/0/0
98	67/0/0/0
105	50/0/0/0
88	33/25/0/0
100	38/0/0/0
	60/16/11/6
101	95/41/31/0
100	0/0/0/0
1	0/0/0/0
	11/0/0/0
86	22/0/0/0
101	11/0/0/0
82	30/0/0/0

$Q = \frac{60}{9} \times \frac{2\text{-}3}{1\text{-}4} \times \frac{1}{2,5}$

Q = 1,3 - 8

Almenna Consulting Ltd.

Landsvirkjun

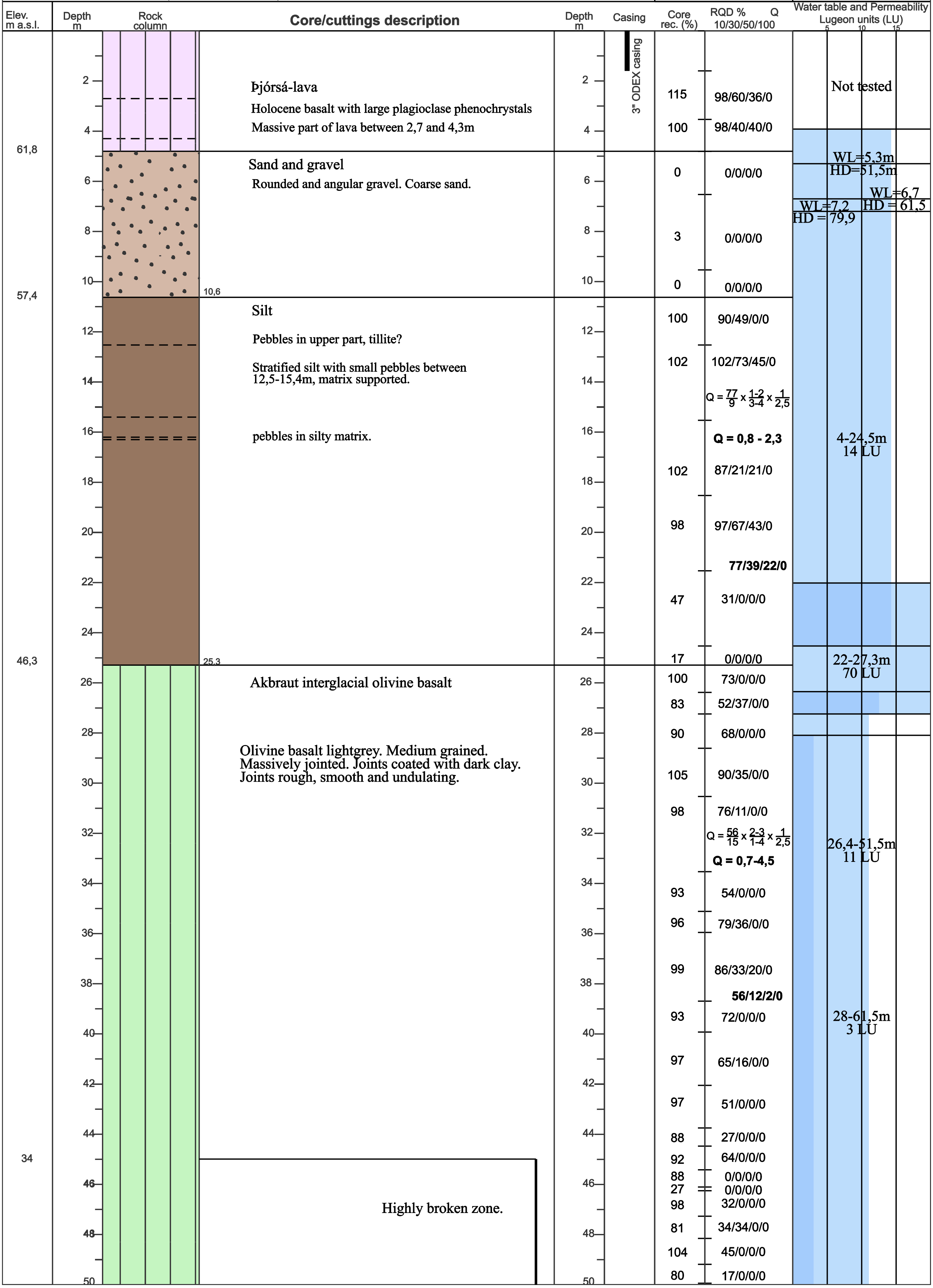
Holtavirkjun
NK-40

Contractor: RSFS	Drill: Langþráður
Site: Árnes	Diameter: ODEX 3"/NQTT
Date of drilling: 26+30-31.10.2006	Drawn: MM
Drawing no. 1 of 2	

Coordinates: ISN93 X: 433675,5 Y: 390996,1

Elevation: 65,39 m a.s.l
Inclination: 41°

Direction of inclination: 300°



Þjórsá-lava
Holocene basalt with large plagioclase phenochrystals
Massive part of lava between 2,7 and 4,3m

Sand and gravel
Rounded and angular gravel. Coarse sand.

Silt

Pebbles in upper part, tillite?

Stratified silt with small pebbles between 12,5-15,4m, matrix supported.

pebbles in silty matrix.

Akbraut interglacial olivine basalt

Olivine basalt lightgrey. Medium grained. Massively jointed. Joints coated with dark clay. Joints rough, smooth and undulating.

Highly broken zone.

Core rec. (%)	RQD % Q 10/30/50/100
115	98/60/36/0
100	98/40/40/0
0	0/0/0/0
3	0/0/0/0
0	0/0/0/0
100	90/49/0/0
102	102/73/45/0
	$Q = \frac{77}{9} x \frac{1-2}{3-4} x \frac{1}{2,5}$
	Q = 0,8 - 2,3
102	87/21/21/0
98	97/67/43/0
	77/39/22/0
47	31/0/0/0
17	0/0/0/0
100	73/0/0/0
83	52/37/0/0
90	68/0/0/0
105	90/35/0/0
98	76/11/0/0
	$Q = \frac{56}{15} x \frac{2-3}{1-4} x \frac{1}{2,5}$
	Q = 0,7-4,5
93	54/0/0/0
96	79/36/0/0
99	86/33/20/0
	56/12/2/0
93	72/0/0/0
97	65/16/0/0
97	51/0/0/0
88	27/0/0/0
92	64/0/0/0
88	0/0/0/0
27	0/0/0/0
98	32/0/0/0
81	34/34/0/0
104	45/0/0/0
80	17/0/0/0

Almenna Consulting Ltd.

Landsvirkjun

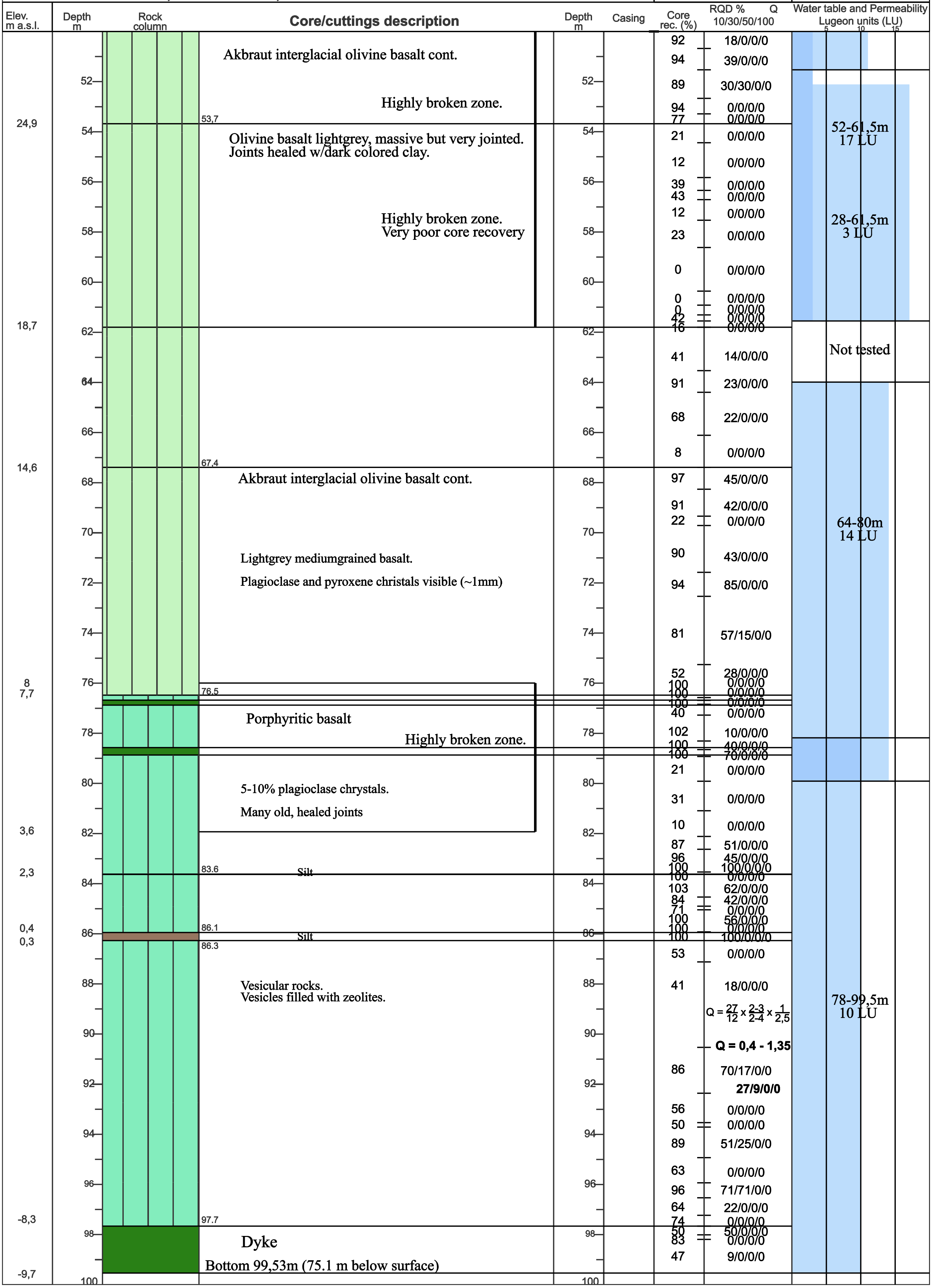
Holtavirkjun
NK-40

Contractor: RSFS	Drill: Langbráður
Site: Árnes	Diameter: ODEX 3"/NQTT
Date of drilling: 26+30-31.10.2006	Drawn: MM
Drawing no. 2 of 2	

Coordinates: ISN93 X: 433675,5 Y: 390996,1

Elevation: 65,39 m a.s.l
Inclination: 41°

Direction of inclination: 300°



Akbraut interglacial olivine basalt cont.

Highly broken zone.

Olivine basalt lightgrey, massive but very jointed. Joints healed w/dark colored clay.

Highly broken zone.
Very poor core recovery

Akbraut interglacial olivine basalt cont.

Lightgrey mediumgrained basalt.

Plagioclase and pyroxene christals visible (~1mm)

Porphyritic basalt

Highly broken zone.

5-10% plagioclase chrystals.

Many old, healed joints

Silt

Silt

Vesicular rocks.
Vesicles filled with zeolites.

Dyke

Bottom 99,53m (75.1 m below surface)

Core rec. (%)	RQD % 10/30/50/100
92	18/0/0/0
94	39/0/0/0
89	30/30/0/0
94	0/0/0/0
77	0/0/0/0
21	0/0/0/0
12	0/0/0/0
39	0/0/0/0
43	0/0/0/0
12	0/0/0/0
23	0/0/0/0
0	0/0/0/0
0	0/0/0/0
0	0/0/0/0
42	0/0/0/0
16	0/0/0/0
41	14/0/0/0
91	23/0/0/0
68	22/0/0/0
8	0/0/0/0
97	45/0/0/0
91	42/0/0/0
22	0/0/0/0
90	43/0/0/0
94	85/0/0/0
81	57/15/0/0
52	28/0/0/0
100	0/0/0/0
100	0/0/0/0
100	0/0/0/0
40	0/0/0/0
102	10/0/0/0
100	40/0/0/0
100	70/0/0/0
21	0/0/0/0
31	0/0/0/0
10	0/0/0/0
87	51/0/0/0
96	45/0/0/0
100	100/0/0/0
100	0/0/0/0
103	62/0/0/0
84	42/0/0/0
71	0/0/0/0
100	56/0/0/0
100	0/0/0/0
100	100/0/0/0
53	0/0/0/0
41	18/0/0/0
86	70/17/0/0
	27/9/0/0
56	0/0/0/0
50	0/0/0/0
89	51/25/0/0
63	0/0/0/0
96	71/71/0/0
64	22/0/0/0
74	0/0/0/0
50	50/0/0/0
83	0/0/0/0
47	9/0/0/0

$Q = \frac{27}{12} \times \frac{2\text{-}3}{2\text{-}4} \times \frac{1}{2,5}$

Q = 0,4 - 1,35

Almenna Consulting Ltd.

Landsvirkjun

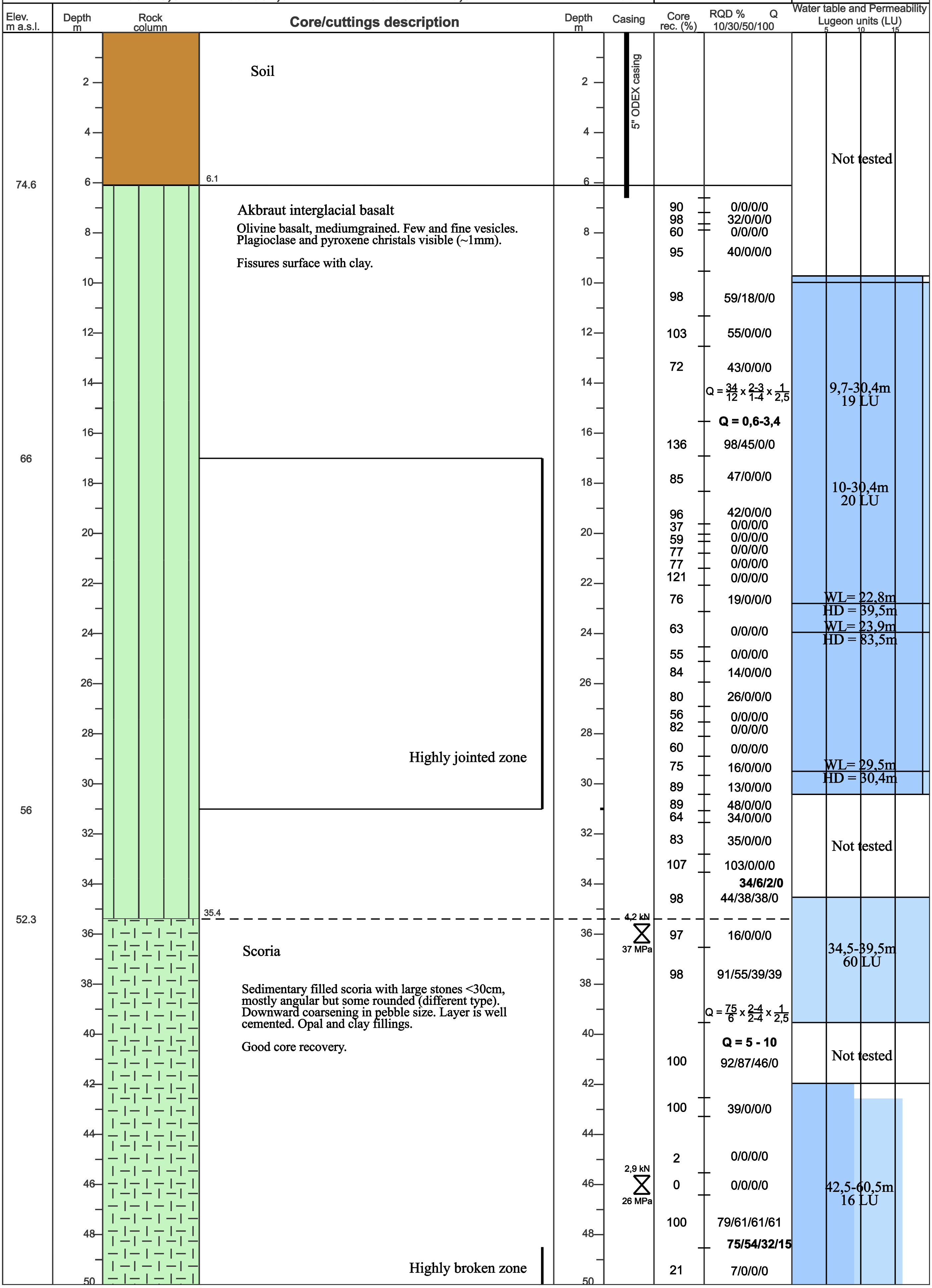
Holtavirkjun HEP
NK-41

Contractor: RSFS	Drill: Langbráður
Site: Akbraut	Diameter: ODEX 3"/NQTT
Date of drilling: 20-27.11.2006	Drawn: MM
Drawing no. 1 of 2	

Coordinates: ISN93 X: 433478,6 Y: 391057,5

Elevation: 79,21 m a.s.l.
Inclination: 40,5°

Direction of inclination: 290°



Soil

Akbraut interglacial basalt

Olivine basalt, mediumgrained. Few and fine vesicles. Plagioclase and pyroxene christals visible (~1mm).

Fissures surface with clay.

Highly jointed zone

Scoria

Sedimentary filled scoria with large stones <30cm, mostly angular but some rounded (different type). Downward coarsening in pebble size. Layer is well cemented. Opal and clay fillings.

Good core recovery.

Highly broken zone

Core rec. (%)	RQD %
90	0/0/0/0
98	32/0/0/0
60	0/0/0/0
95	40/0/0/0
98	59/18/0/0
103	55/0/0/0
72	43/0/0/0
	$Q = \frac{34}{12} \times \frac{2\text{-}3}{1\text{-}4} \times \frac{1}{2,5}$
	Q = 0,6-3,4
136	98/45/0/0
85	47/0/0/0
96	42/0/0/0
37	0/0/0/0
59	0/0/0/0
77	0/0/0/0
77	0/0/0/0
121	0/0/0/0
76	19/0/0/0
63	0/0/0/0
55	0/0/0/0
84	14/0/0/0
80	26/0/0/0
56	0/0/0/0
82	0/0/0/0
60	0/0/0/0
75	16/0/0/0
89	13/0/0/0
89	48/0/0/0
64	34/0/0/0
83	35/0/0/0
107	103/0/0/0
	34/6/2/0
98	44/38/38/0
97	16/0/0/0
98	91/55/39/39
	$Q = \frac{75}{6} \times \frac{2\text{-}4}{2\text{-}4} \times \frac{1}{2,5}$
	Q = 5 - 10
100	92/87/46/0
100	39/0/0/0
2	0/0/0/0
0	0/0/0/0
100	79/61/61/61
	75/54/32/15
21	7/0/0/0

Not tested

9,7-30,4m
19 LU

10-30,4m
20 LU

WL= 22,8m
HD = 39,5m

WL= 23,9m
HD = 83,5m

WL= 29,5m
HD = 30,4m

Not tested

34,5-39,5m
60 LU

Not tested

42,5-60,5m
16 LU

Almenna Consulting Ltd.

Landsvirkjun

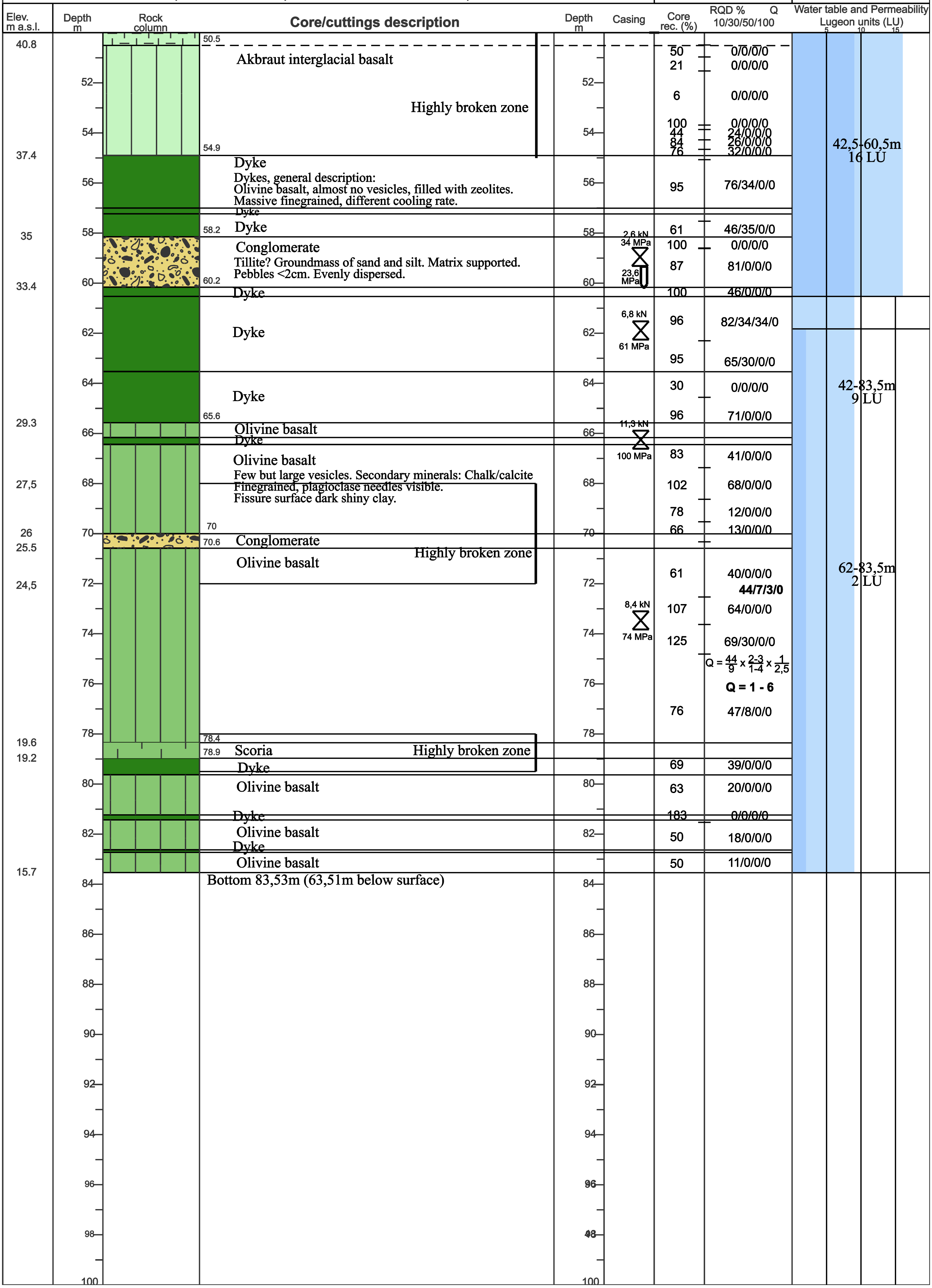
Holtavirkjun HEP
NK-41

Contractor:	RSBF&S
Drill:	Langþráður
Site:	Akbraut
Diameter:	ODEX 3"/NQTT
Date of drilling:	20-27.11.2006
Drawn:	MM
Drawing no.	2 of 2

Coordinates: ISN93 X: 433478,6 Y: 391057,5

Elevation: 79,21 m a.s.l.
Inclination: 40,5°

Direction of inclination: 290°



Elev. m a.s.l.	Depth m	Core/cuttings description	Casing	Core rec. (%)	RQD % Q 10/30/50/100	Water table and Permeability Lugeon units (LU)
40.8	50.5	Akbraut interglacial basalt Highly broken zone		50 21 6 100 44 84 76	0/0/0/0 0/0/0/0 0/0/0/0 0/0/0/0 24/0/0/0 26/0/0/0 32/0/0/0	42,5-60,5m 16 LU
37.4	54.9	Dyke Dykes, general description: Olivine basalt, almost no vesicles, filled with zeolites. Massive finegrained, different cooling rate.		95	76/34/0/0	
		Dyke				
35	58.2	Dyke	2,6 kN 34 MPa	61	46/35/0/0	
		Conglomerate Tillite? Groundmass of sand and silt. Matrix supported. Pebbles <2cm. Evenly dispersed.	23,6 MPa	100 87	0/0/0/0 81/0/0/0	
33.4	60.2	Dyke		100	46/0/0/0	
		Dyke	6,8 kN 61 MPa	96 95	82/34/34/0 65/30/0/0	42-83,5m 9 LU
		Dyke		30 96	0/0/0/0 71/0/0/0	
29.3	65.6	Olivine basalt	11,3 kN			
		Dyke	100 MPa			
27,5		Olivine basalt Few but large vesicles. Secondary minerals: Chalk/calcite Finegrained, plagioclase needles visible. Fissure surface dark shiny clay.		83 102 78 66	41/0/0/0 68/0/0/0 12/0/0/0 13/0/0/0	
26	70	Conglomerate				
25.5 24,5	70.6	Olivine basalt Highly broken zone	8,4 kN 74 MPa	61 107 125 76	40/0/0/0 **44/7/3/0** 64/0/0/0 69/30/0/0 $Q = \frac{44}{9} x \frac{2-3}{1-4} x \frac{1}{2,5}$ **Q = 1 - 6** 47/8/0/0	62-83,5m 2 LU
19.6	78.4					
	78.9	Scoria Highly broken zone				
19.2		Dyke		69	39/0/0/0	
		Olivine basalt		63	20/0/0/0	
		Dyke		183	0/0/0/0	
		Olivine basalt		50	18/0/0/0	
		Dyke				
15.7		Olivine basalt		50	11/0/0/0	

Bottom 83,53m (63,51m below surface)

Almenna Consulting Ltd.

Landsvirkjun

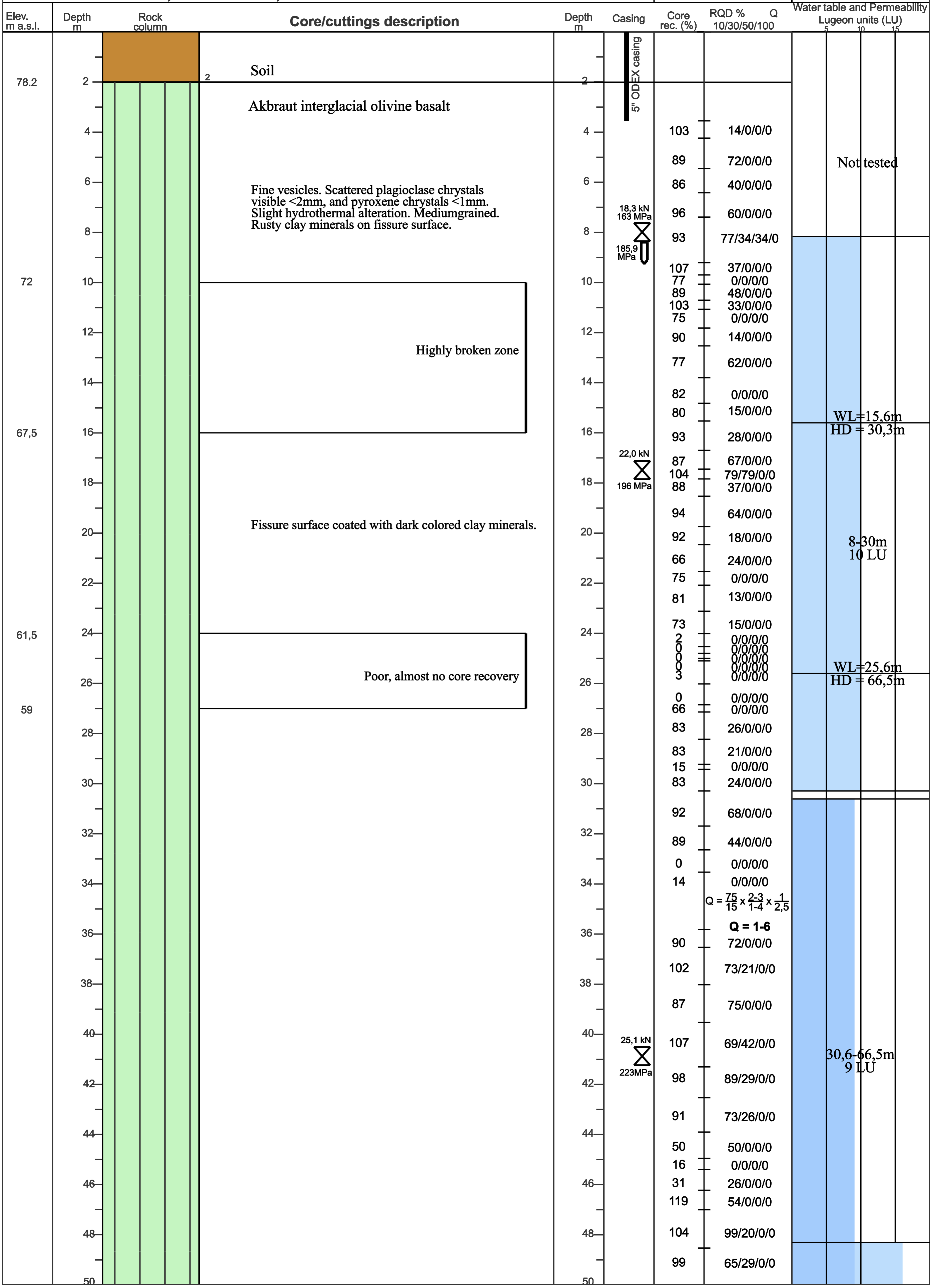
Holtavirkjun HEP
NK-42

Contractor: RSFS	Drill: Langþráður
Site: Akbraut	Diameter: ODEX 3"/NQTT
Date of drilling: 20-27.11.2006	Drawn: MM
Drawing no. 1 of 2	

Coordinates: ISN93 X: 433596,6 Y: 391071,8

Elevation: 79,77 m a.s.l.
Inclination: 40°

Direction of inclination: 130°



Soil

Akbraut interglacial olivine basalt

Fine vesicles. Scattered plagioclase chrystals visible <2mm, and pyroxene chrystals <1mm. Slight hydrothermal alteration. Mediumgrained. Rusty clay minerals on fissure surface.

Highly broken zone

Fissure surface coated with dark colored clay minerals.

Poor, almost no core recovery

Core rec. (%)	RQD % 10/30/50/100
103	14/0/0/0
89	72/0/0/0
86	40/0/0/0
96	60/0/0/0
93	77/34/34/0
107	37/0/0/0
77	0/0/0/0
89	48/0/0/0
103	33/0/0/0
75	0/0/0/0
90	14/0/0/0
77	62/0/0/0
82	0/0/0/0
80	15/0/0/0
93	28/0/0/0
87	67/0/0/0
104	79/79/0/0
88	37/0/0/0
94	64/0/0/0
92	18/0/0/0
66	24/0/0/0
75	0/0/0/0
81	13/0/0/0
73	15/0/0/0
2	0/0/0/0
0	0/0/0/0
0	0/0/0/0
0	0/0/0/0
3	0/0/0/0
0	0/0/0/0
66	0/0/0/0
83	26/0/0/0
83	21/0/0/0
15	0/0/0/0
83	24/0/0/0
92	68/0/0/0
89	44/0/0/0
0	0/0/0/0
14	0/0/0/0
90	72/0/0/0
102	73/21/0/0
87	75/0/0/0
107	69/42/0/0
98	89/29/0/0
91	73/26/0/0
50	50/0/0/0
16	0/0/0/0
31	26/0/0/0
119	54/0/0/0
104	99/20/0/0
99	65/29/0/0

$$Q = \frac{75}{15} \times \frac{2\text{-}3}{1\text{-}4} \times \frac{1}{2,5}$$

Q = 1-6

Almenna Consulting Ltd.

Landsvirkjun

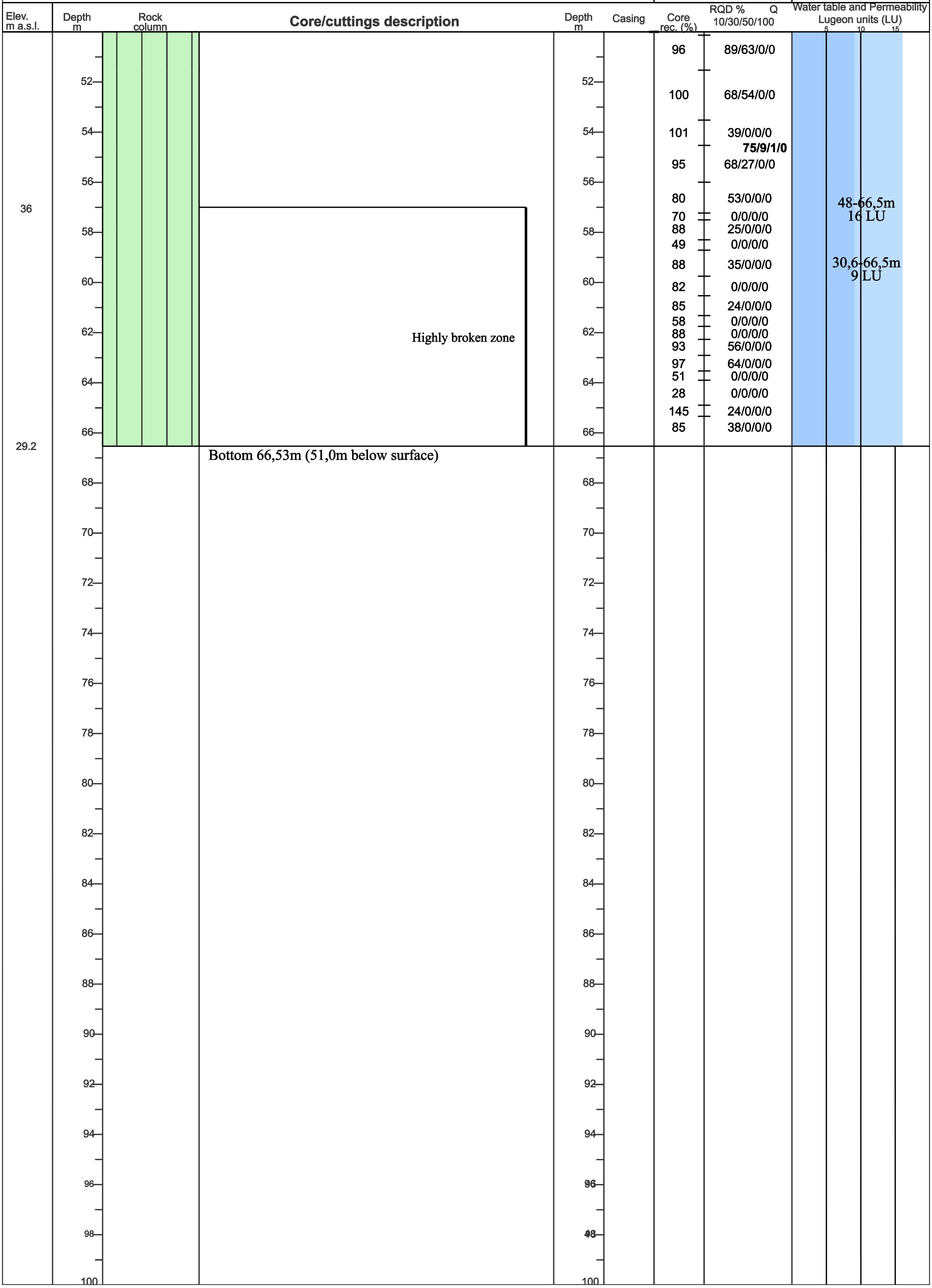
Holtavirkjun HEP
NK-42

Contractor:	RSFS
Drill:	Langþráður
Site:	Akbraut
Diameter:	ODEX 3"/NQTT
Date of drilling:	20-27.11.2006
Drawn:	MM
Drawing no.	2 of 2

Coordinates: ISN93 X: 433596,6 Y: 391071,8

Elevation: 79,77 m a.s.l.
Inclination: 40°

Direction of inclination: 130°



Highly broken zone

Bottom 66,53m (51,0m below surface)

48-66,5m
16 LU

30,6-66,5m
9 LU

Core rec. (%)	RQD % 10/30/50/100	Q
96	89/63/0/0	
100	68/54/0/0	
101	39/0/0/0	
		75/9/1/0
95	68/27/0/0	
80	53/0/0/0	
70	0/0/0/0	
88	25/0/0/0	
49	0/0/0/0	
88	35/0/0/0	
82	0/0/0/0	
85	24/0/0/0	
58	0/0/0/0	
88	0/0/0/0	
93	56/0/0/0	
97	64/0/0/0	
51	0/0/0/0	
28	0/0/0/0	
145	24/0/0/0	
85	38/0/0/0	

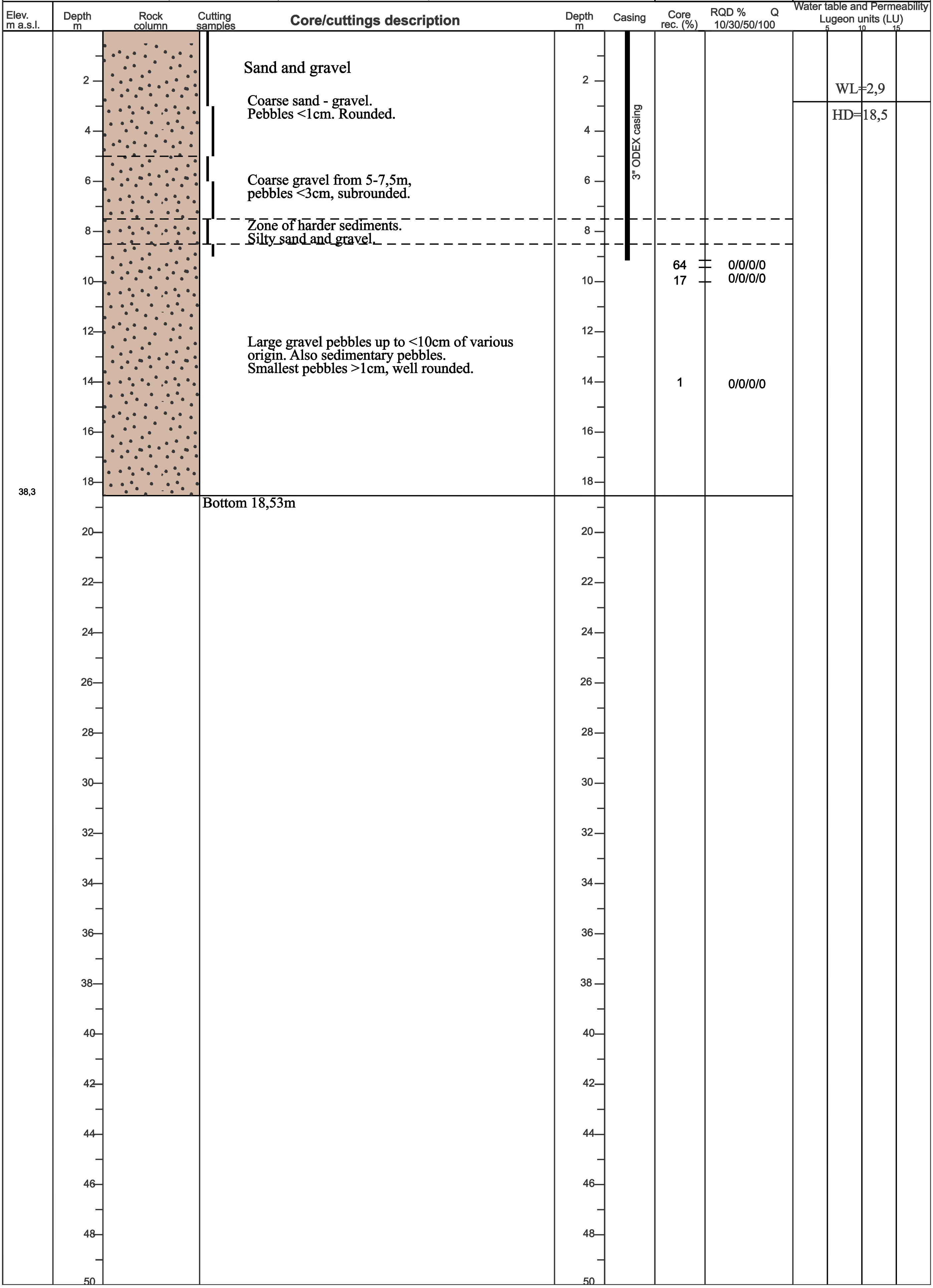
Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NK-43

Contractor:	RSFS	Drill:	Langþráður
Site:	Akbraut	Diameter:	ODEX 3"/NQTT
Date of drilling:	3.12.2006	Drawn:	MM
Drawing no.	1 of 1		

Coordinates: ISN93 **X: 433091,4** **Y: 391368,2** **Elevation: 56,81 m a.s.l.**



Sand and gravel

Coarse sand - gravel.
Pebbles <1cm. Rounded.

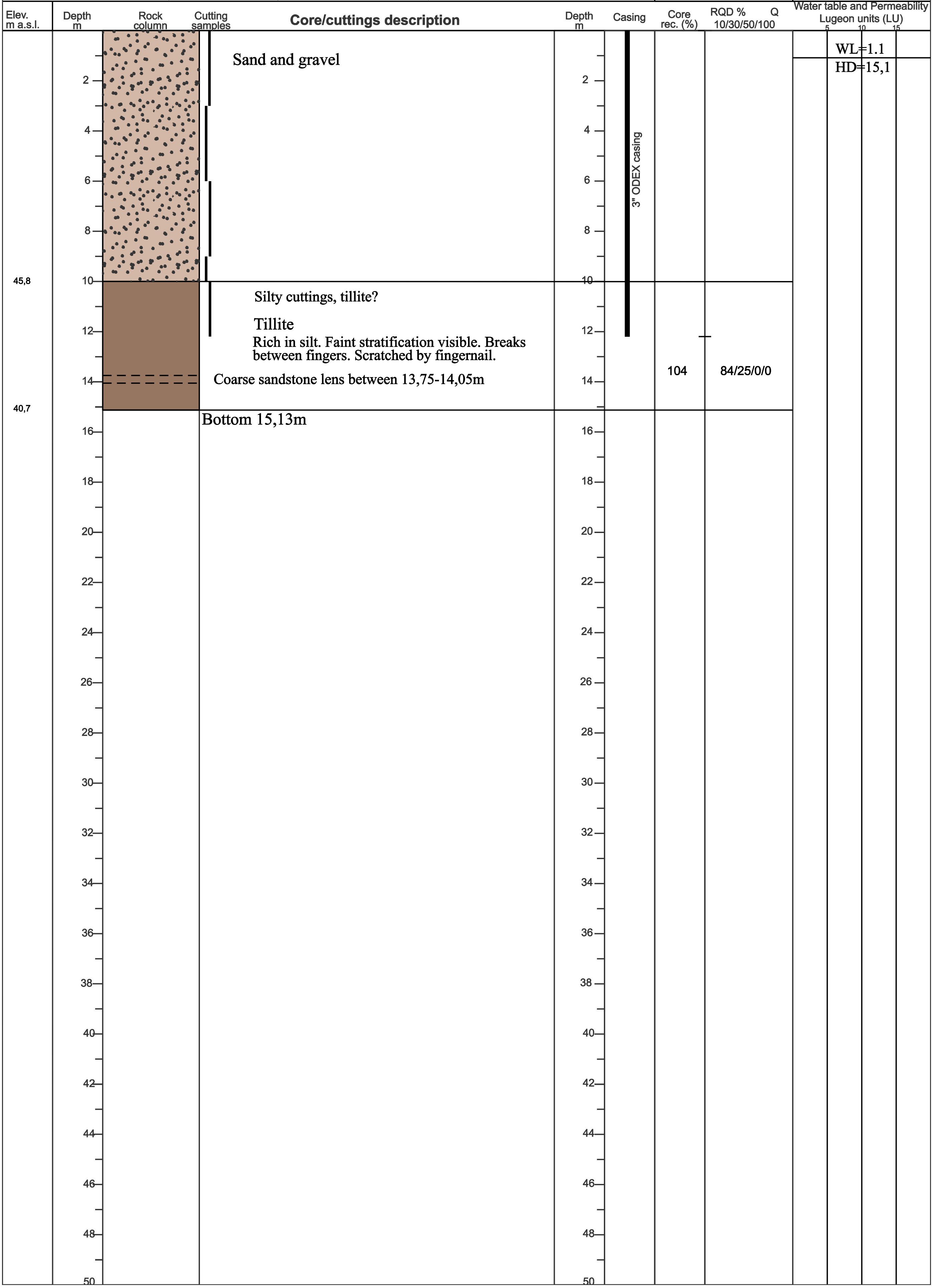
Coarse gravel from 5-7,5m,
pebbles <3cm, subrounded.

Zone of harder sediments.
Silty sand and gravel.

Large gravel pebbles up to <10cm of various origin. Also sedimentary pebbles.
Smallest pebbles >1cm, well rounded.

Bottom 18,53m

Almenna Consulting Ltd. **Landsvirkjun**	Holtavirkjun HEP NK-44	Contractor: RSFS	Drill: Langþráður
		Site: Akbraut	Diameter: ODEX 3"/NQTT
		Date of drilling: 3.-4.12.2006	Drawn: MM
Coordinates: ISN93	X: 432615,3 Y: 391335,1 Elevation: 55,81 m a.s.l.	Drawing no. 1 of 1	



Elev. m a.s.l.	Core/cuttings description	Casing	Core rec. (%)	RQD % Q 10/30/50/100	Water table and Permeability Lugeon units (LU)
	Sand and gravel	3" ODEX casing			WL=1.1 HD=15,1
45,8	Silty cuttings, tillite? Tillite Rich in silt. Faint stratification visible. Breaks between fingers. Scratched by fingernail. Coarse sandstone lens between 13,75-14,05m		104	84/25/0/0	
40,7	Bottom 15,13m				

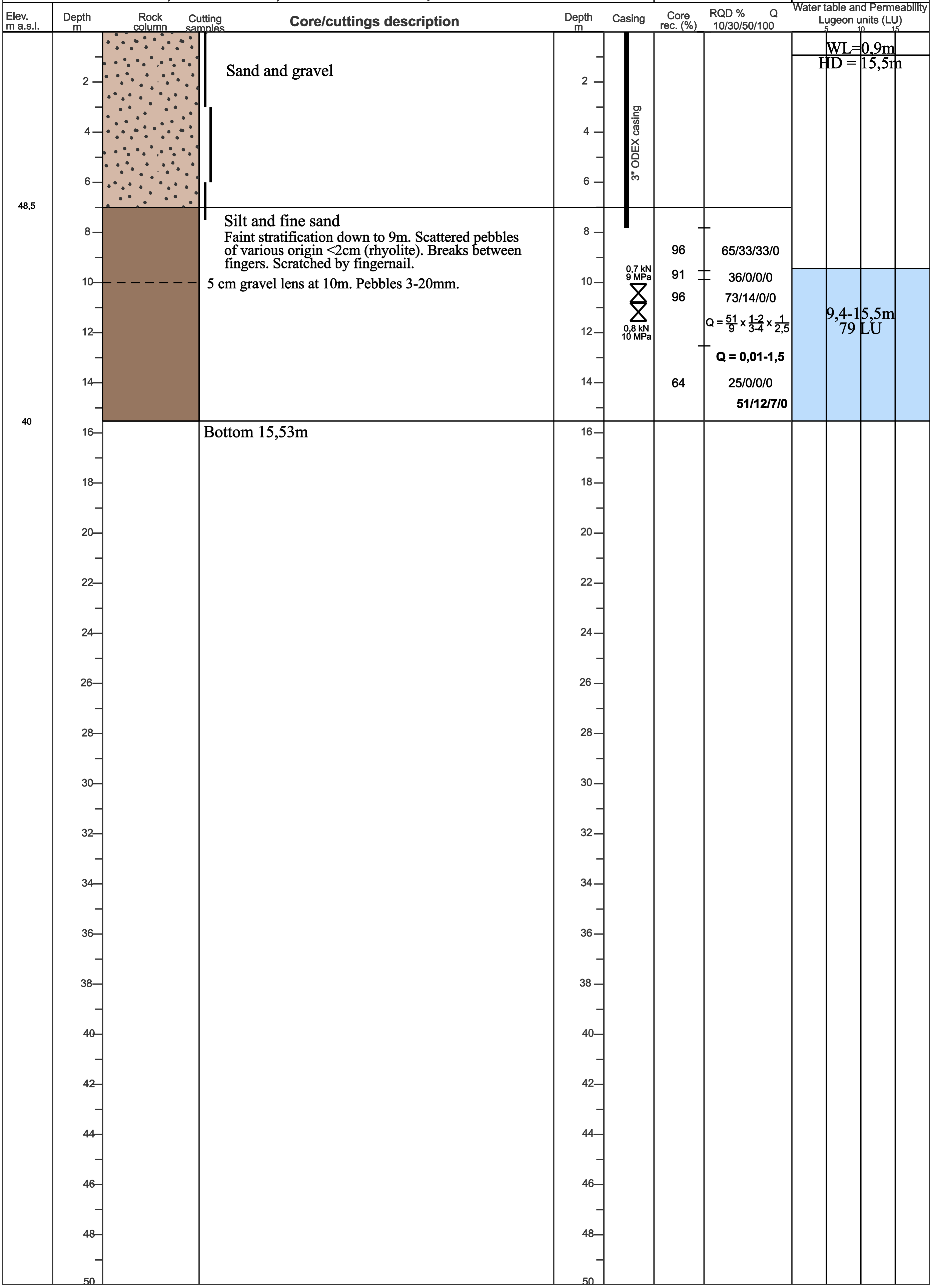
Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NK-45

Contractor: RSFS	Drill: Langþráður
Site: Akbraut	Diameter: ODEX 3"/NQTT
Date of drilling: 4.-5.12.2006	Drawn: MM
Drawing no. 1 of 1	

Coordinates:
ISN93 X: 432305,5 Y: 391238,0 Elevation: 55,54 m a.s.l.



Sand and gravel

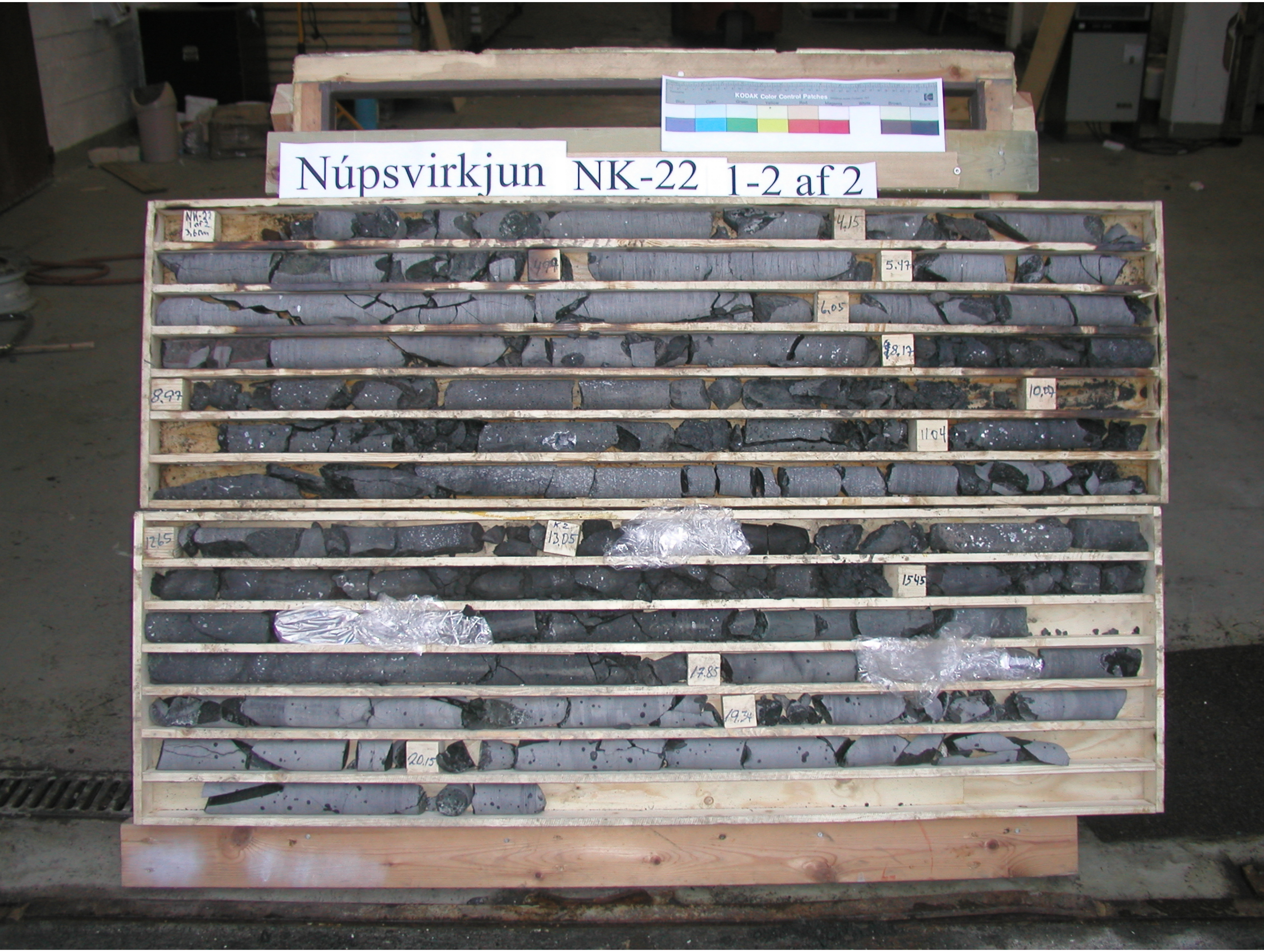
Silt and fine sand
Faint stratification down to 9m. Scattered pebbles of various origin <2cm (rhyolite). Breaks between fingers. Scratched by fingernail.

5 cm gravel lens at 10m. Pebbles 3-20mm.

$Q = \frac{51}{9} \times \frac{1\text{-}2}{3\text{-}4} \times \frac{1}{2,5}$

Q = 0,01-1,5

Bottom 15,53m


Núpsvirkjun NK-22 1-2 af 2
KODAK Color Control Patches
NK-22 1 af 2 3,60m
4,15
4,97
5,47
6,05
8,17
8,97
10,07
11,04
12,65
K2 13,05
15,45
17,85
19,34
20,15


KODAK Color Control Patches
Núpsvirkjun
NK-23
1-2 af 2
NK 23 K-1
3.00
4,16
4.60
6.45
9.65
10.54
11.90
12.85
13.82
15.30
16.30
17.80
NK H-23 K-2
18.65


Holtavirkjun
NK-36
1-2 af 4
NK-36 K-1
4,00
6,53
9,48
10,73
11,68
12.53
NK36 K2
15.53
18.53
19.82
21.42
24.53
~~23.53~~
25.86
27.53


Holtavirkjun
NK-36
3-4 af 4
30.53
MT
32.4
33.08
34.68
M
M
36.53
37.75
Nk36
K4
M
39.53


Holtavirkjun
NK-37
1
NK37 k1
15,1
13.53
18.53
21.53


Holtavirkjun
NK-38
1-2 af 3
NK-38 K-1
6,0
6,53
8.46
9.53
12.53
M
M
M
NK38 K-2
18.53
21.53
23.72
24.53
27.53
29.14
30.53


Holtavirkjun
NK-38
3
Nk38 K-3
~~31,85~~ 31,18
33,09
33,53
34,38


Holtavirkjun
NK-39
1-2 af 3
NK-39 K-1
4.50
6.53
8.43
9.53
10.48
12.53
NK-39 K-2
14.63
15.53
16.61
17.87
18.53
19.92
21.53


Holtavirkjun
NK-39
3
NK-39
K-3
24,53
27,53
32,22


Holtavirkjun
NK-40
1-2 af 9
NK-40
K-1
1,6
3,53
6,53
9,53
12,53
15,53
NK-40
K-2
18,53
21,53
24,53
26,38


Holtavirkjun
NK-40
3-4 af
9
NK40
K=3
27,24
29,61
30,53
33,57
35,11
35,95
NK-40
K-4
38,64
39,92
42,05
43,75
44,48


Holtavirkjun
NK-40
5-6 af 9
NK 40 K=5
45,42
46,10
46,25
47,26
48,15
49,18
49,94
50,68
51,53
52.67
53,29
NK K6
53,68
54,47
55,83
56,34
56,71
57,53
58,62
60,36
60,92
61,31
61,55
61.80
63,53
64.40
66,11
67,39
68,26
69,34
69,71


Holtavirkjun NK-40 7-8 9
NK-40 K-7
71,50
72,53
75,26
76,58
77,27
78,31
79,91
81,09
82,11
82,63
K/8 NK 40
83,52
84,53
84,90
85,04
86,19
87,12
90,53
92,36
93,53
93,71


Holtavirkjun NK-40 9- 9
NK 40
K/9
9493
95,73
96,53
97,23
98,17
99,53


Holtavirkjun
NK-41
1-2 af 8
NK-41 K-1
6,60
7,19
7,84
7,89
9,53
11,32
12,53
15,53
NK-41 K-2
16,91
18,32
19,62
20,03
20,32
20,79
21,39
22,07
23,12
24,53
25,11


Holtavirkjun
NK-41
3-4
af
8
NK-41
K-3
25,94
26,91
27,53
28,10
28,90
29,66
30,42
31,07
31,54
32,81
33,53
NK-41
K-4
36,53
39,53
42,53


Holtavirkjun
NK-41
5-6 af 8
NK-41
K-5
45,53
48,53
50,49
50,97
51,53
53,69
53,87
54,28
54,66
55,07
57,53
58,62
NK-41
K-6
60,53
62,30
63,53
64,56
66,16
67
68,26

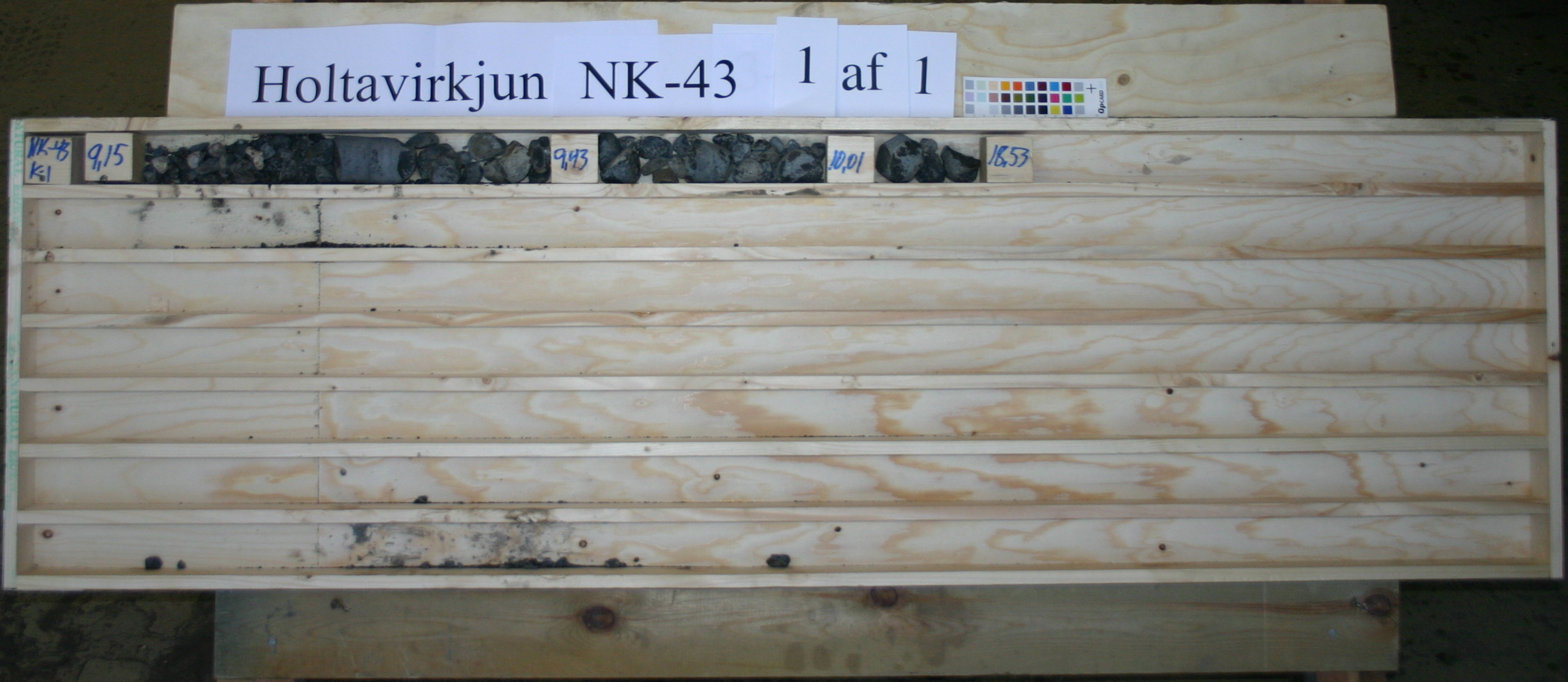

Holtavirkjun
NK-41
7-8
af
8
NK-41 K-7
69,16
69,96
72,16
73,26
74,81
78,43
NK 41-K-8
79,63
81,23
81,53
82,43
83,53


Holtavirkjun NK-42 1-2 af 7
NK-42 K-1
3,55
4,24
5,45
6,42
7,39
9,21
9,70
10,07
10,71
11,07
11,82
NK-42 K-2
12,53
13,80
14,82
15,53
16,70
17,45
17,84
18,53
19,74
20,46


Holtavirkjun NK-42
3-4
af 7
NK-42
K-3
21,53
22,08
23,12
24,01
24,53
24,80
25,00
25,10
26,02
26,85
27,14
28,23
29,23
2943
30,29
31,69
32,64
33,53
NK-42
K-4
35,82
36,53
38,02
39,53
41,30
42,53
43,90


Holtavirkjun NK-42 5-6 af 7
NK-42 K-5
44,95
45,40
46,22
47,00
48,53
50,13
51,53
NK-42 K-6
53,52
54,53
56,00
57,23
57,50
58,30
58,71
59,75
60,53
61,32
61,75
62,27

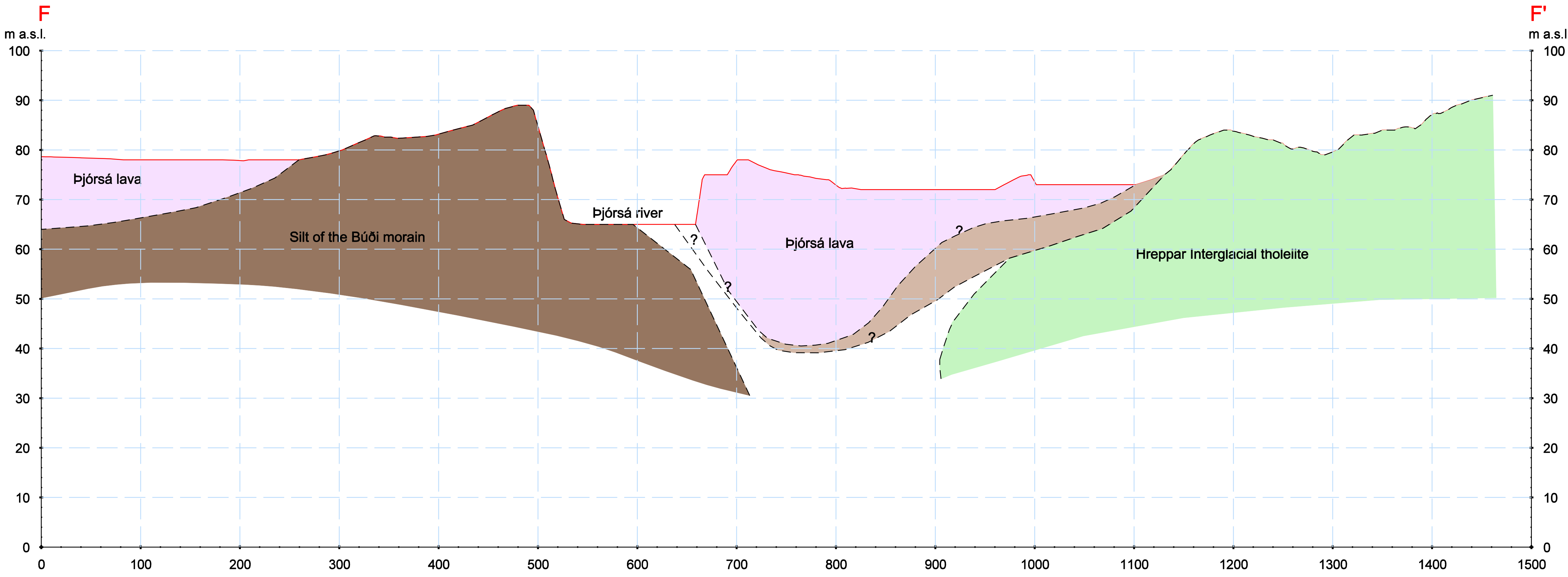

Holtavirkjun NK-42
7 af 7
NK-42
K-7
62,91
63,53
63,90
64,90
65,34
66,53


Holtavirkjun NK-43 1 af 1
NK-43 K-1
9,15
9,43
10,01
18,53


Holtavirkjun
NK-44
1 af 1
NK-44
K-1
12,20
15,13

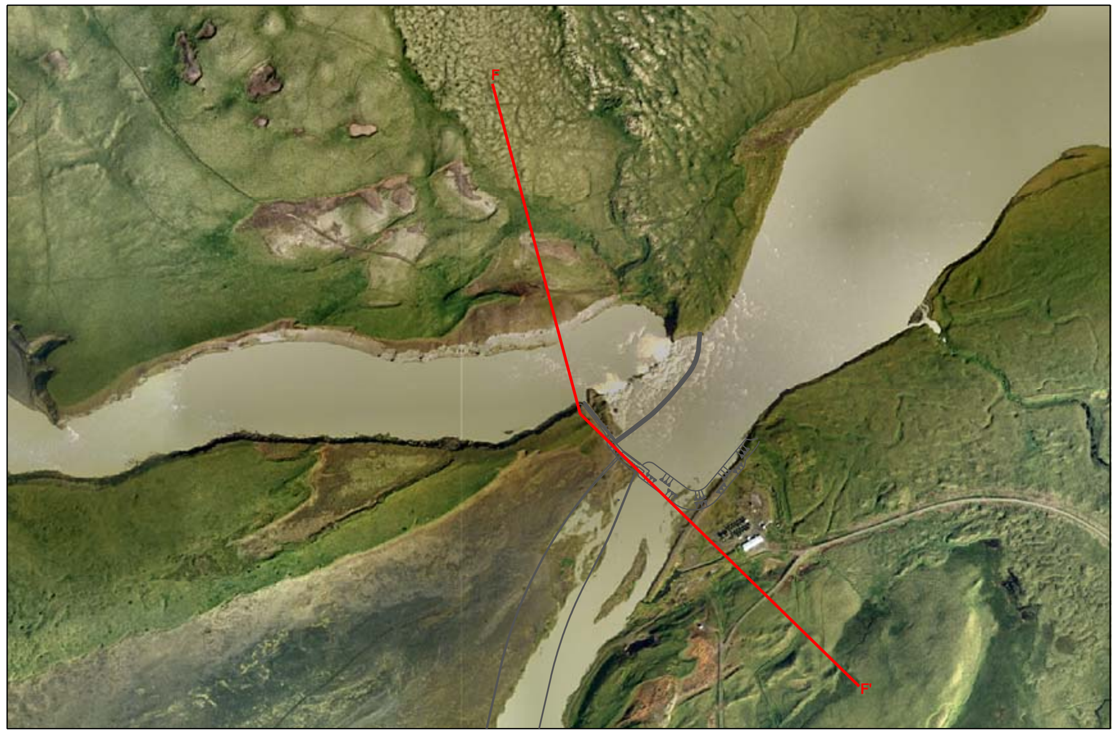

Hvammsvirkjun
NK-45
1 af 1
NK-45
K-1
7,82
9,53
9,88
12,53
15,53


Núpsvirkjun NK-22 1-2 af 2
KODAK Color Control Patches
4,15
5,97
4,97
6,05
8,17
10,00
11,04
8,97
12,65
K2 13,05
15,45
17,85
19,74
20,15



Legend

- ▨ Tephra sand and gravel
- 🟪 Þjórsárhraun lava
- 🟫 Silt/siltstone
- 🟩 Hreppar Interglacial tholeiite



Almenna Consulting Ltd.
Fellsmúla 26 - 108 Reykjavík
S: 580 8100 - Fax: 580 8101
av@almenna.is - www.almenna.is

Drawing 16
Holtavirkjun HEP
Powerhouse site
Geolgical section F-F'

Design ÁÓT
Checked
Scale
Appr. SPS
Kt.
Date Dec. 2007
No. 1227.111-G-016

Áritanir á teikningu eru á ábyrgð Almennu verkfræðistofunnar hf. kt. 470671-0179

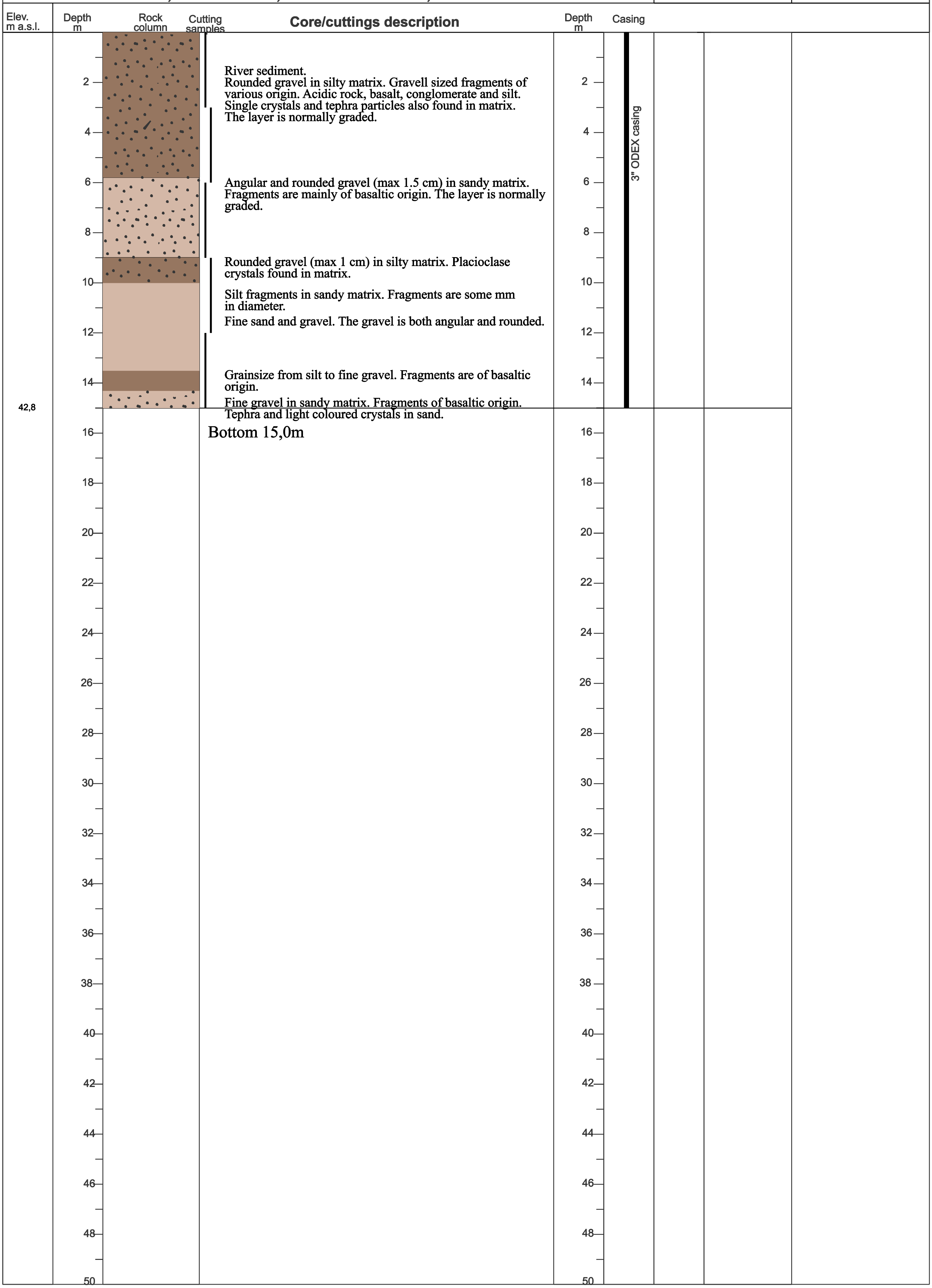
Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NL-10

Contractor: RSFS	Drill: Trítill
Site: Akbraut	Diameter: ODEX 3"/NQ
Date of drilling: 22.11.2001	Drawn: GBÞ
Drawing no. 1 of 1	

Coordinates: **ISN93** **X: 433423,4** **Y: 391291,5** **Elevation: 57,83 m a.s.l.**



River sediment.
Rounded gravel in silty matrix. Gravell sized fragments of various origin. Acidic rock, basalt, conglomerate and silt. Single crystals and tephra particles also found in matrix. The layer is normally graded.

Angular and rounded gravel (max 1.5 cm) in sandy matrix. Fragments are mainly of basaltic origin. The layer is normally graded.

Rounded gravel (max 1 cm) in silty matrix. Placioclase crystals found in matrix.

Silt fragments in sandy matrix. Fragments are some mm in diameter.

Fine sand and gravel. The gravel is both angular and rounded.

Grainsize from silt to fine gravel. Fragments are of basaltic origin.

Fine gravel in sandy matrix. Fragments of basaltic origin. Tephra and light coloured crystals in sand.

Bottom 15,0m

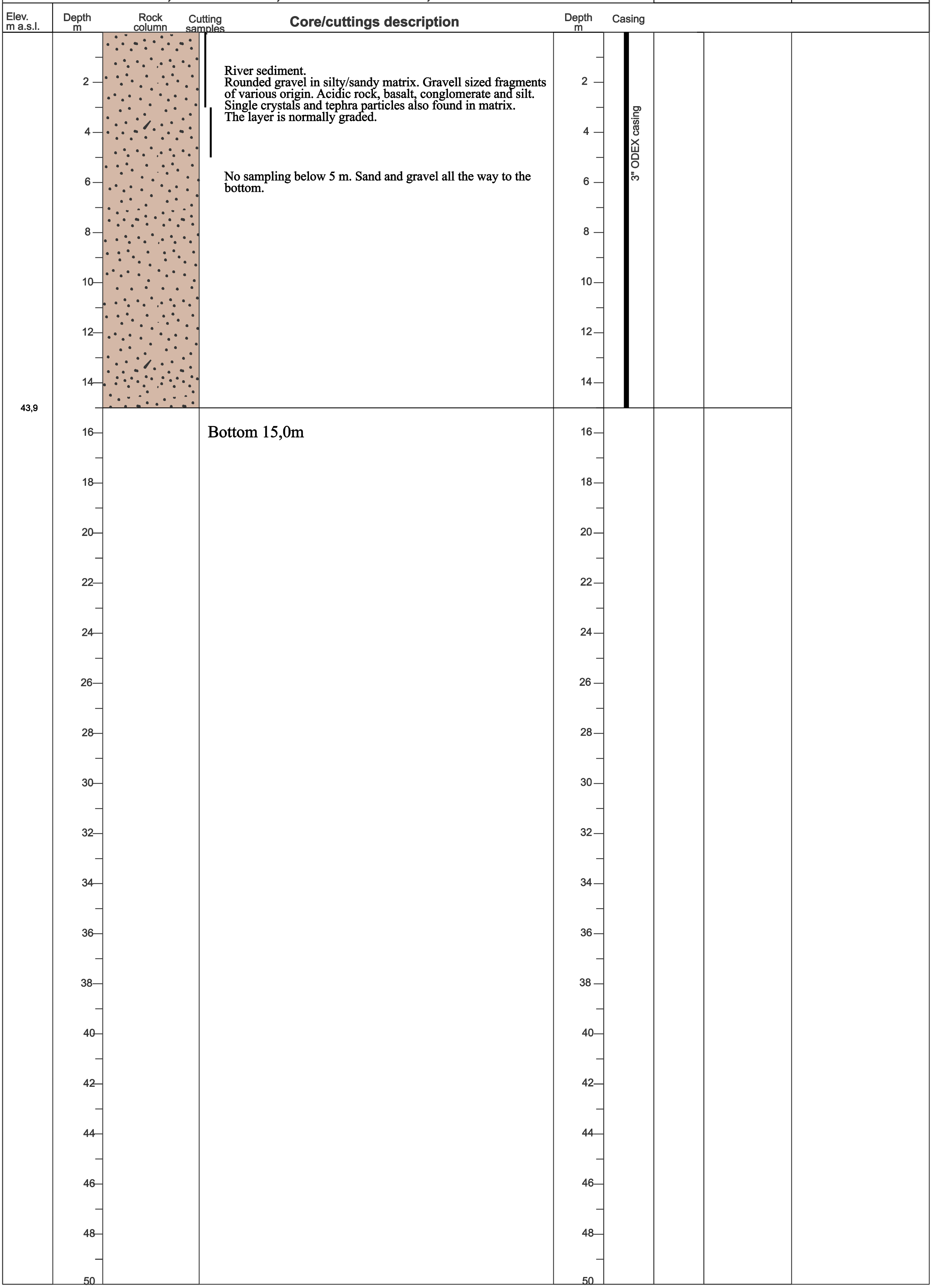
Almenna Consulting Ltd.

Landsvirkjun

Holtavirkjun HEP
NL-11

Contractor: RSFS	Drill: Trítill
Site: Akbraut	Diameter: ODEX 3"/NQ
Date of drilling: 22.11.2001	Drawn: GBÞ
Drawing no. 1 of 1	

Coordinates: ISN93 X: 433256,4 Y: 391204,6 Elevation: 58,92 m a.s.l.



River sediment.
Rounded gravel in silty/sandy matrix. Gravell sized fragments of various origin. Acidic rock, basalt, conglomerate and silt. Single crystals and tephra particles also found in matrix.
The layer is normally graded.

No sampling below 5 m. Sand and gravel all the way to the bottom.

Bottom 15,0m

Almenna Consulting Ltd.

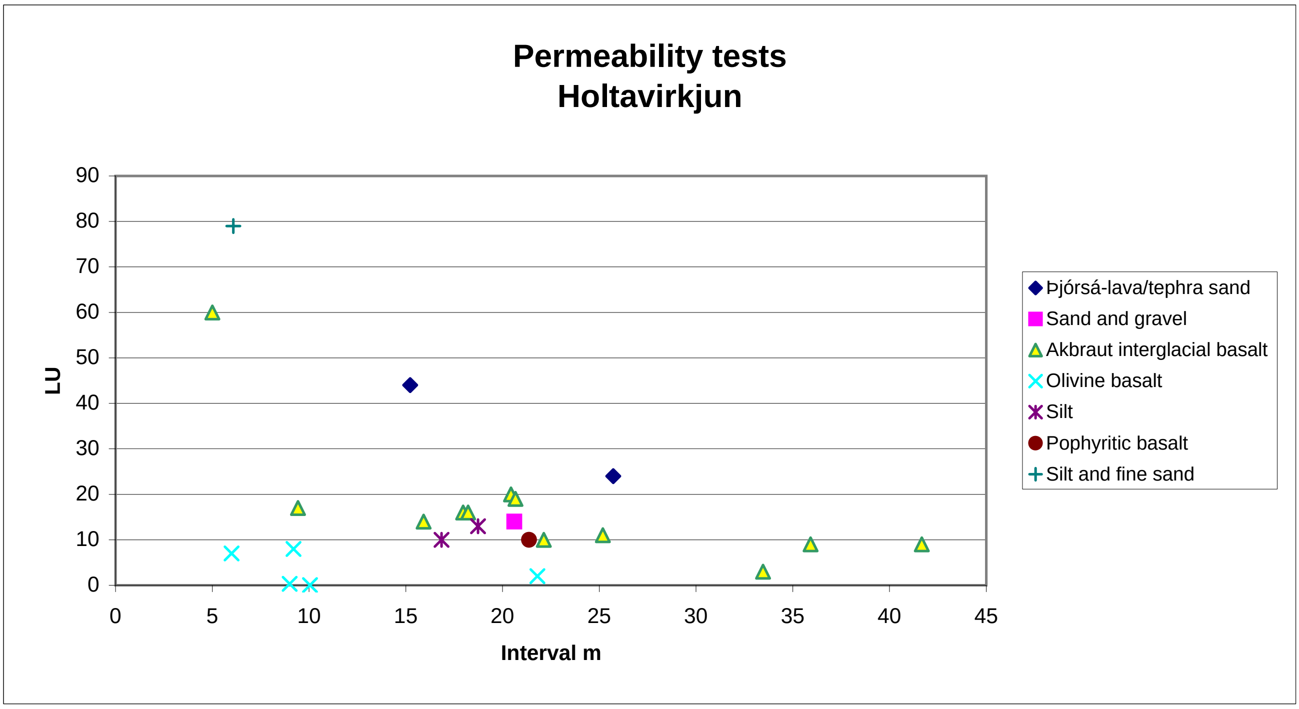
Landsvirkjun

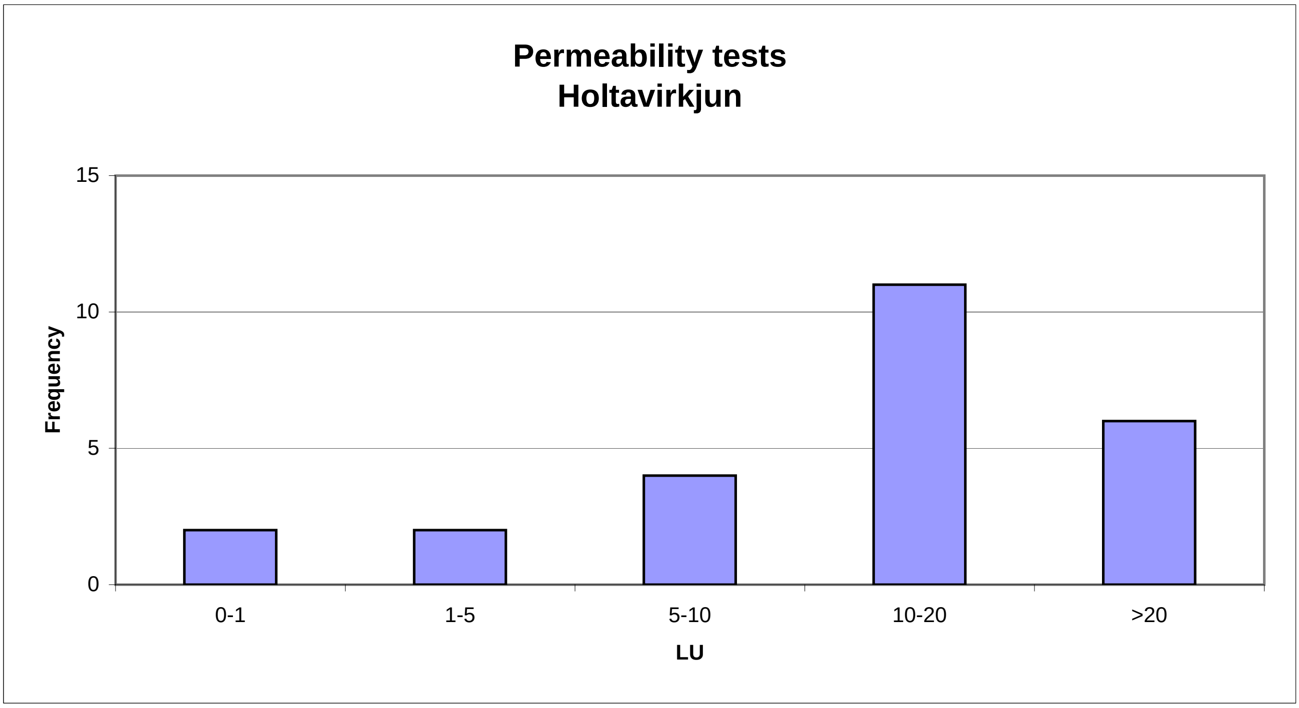
Holtavirkjun HEP
NL-46

Contractor: RSFS	Drill: Langþráður
Site: Árnes	Diameter: ODEX 3"/NQ
Date of drilling: 22.10.2006	Drawn: MM
Drawing no.	

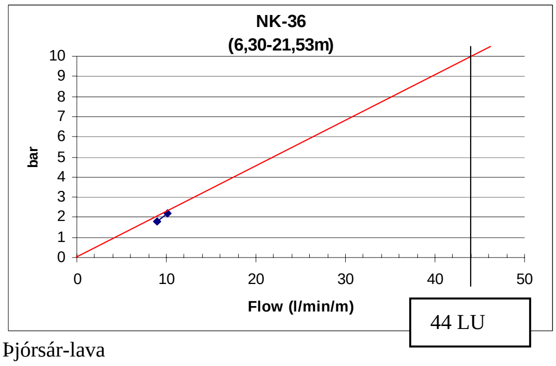
Coordinates:
ISN93 X: 434297 N: 390803 Elevation: 67 m a.s.l.

Elev. m a.s.l.	Depth m	Rock column	Cutting samples	Core/cuttings description	Depth m	Casing
		🟫		Soil		3" ODEX casing
65,5		▨		Þjórsá-lava Scoria fragm. w/plg phenochrystals		
	2				2	
	4				4	
	6				6	
	8				8	
	10				10	
	12				12	
	14				14	
	16				16	
	18				18	
	20				20	
	22				22	
	24				24	
	26				26	
	28				28	
	30				30	
	32				32	
	34				34	
	36				36	
	38				38	
	40				40	
	42				42	
	44				44	
	46				46	
	48				48	

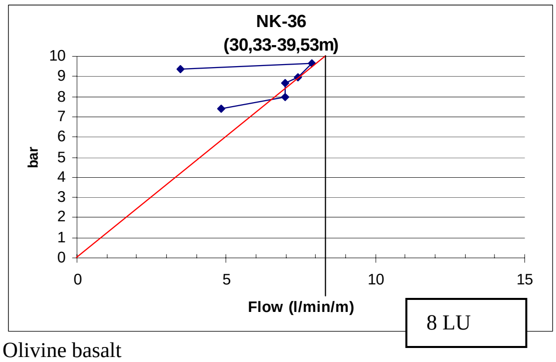

Permeability tests
Holtavirkjun
LU
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
Interval m
◆ Þjórsá-lava/tephra sand
■ Sand and gravel
△ Akbraut interglacial basalt
✕ Olivine basalt
✱ Silt
● Pophyritic basalt
+ Silt and fine sand


Permeability tests
Holtavirkjun
Frequency
15
10
5
0
0-1
1-5
5-10
10-20
>20
LU

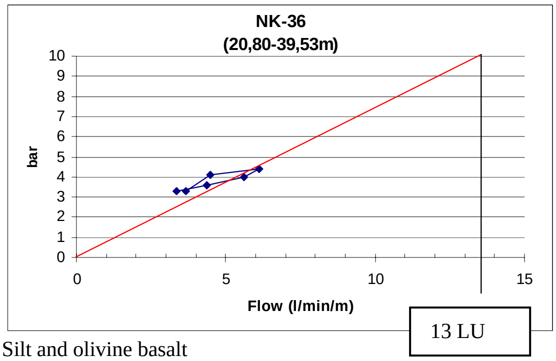
Permeability of NK-36



Þjórsár-lava

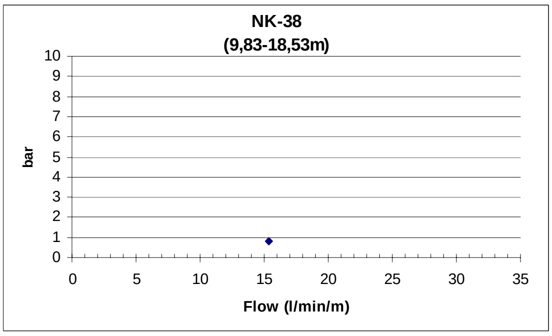


Olivine basalt

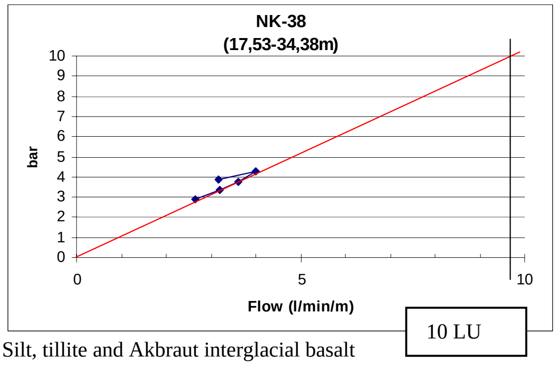


Silt and olivine basalt

Permeability of NK-38

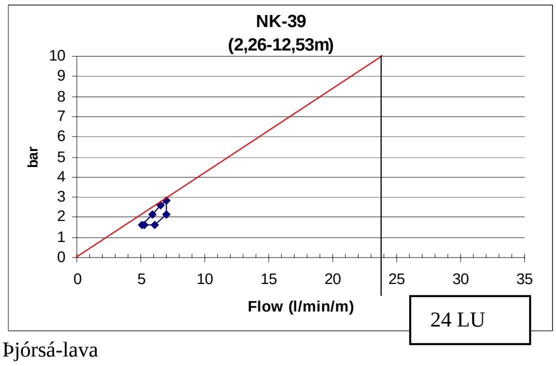


Þjórsá-lava, gravel & sand and silt
pressure does not build.



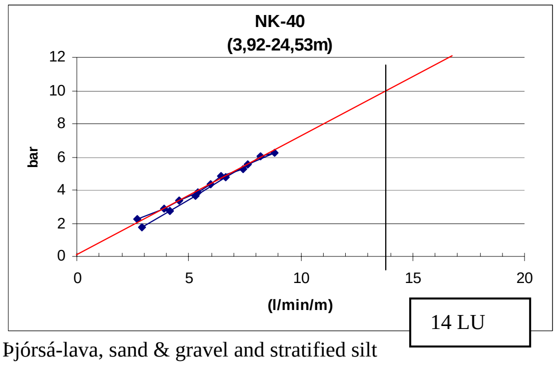
Silt, tillite and Akbraut interglacial basalt

Permeability of NK-39

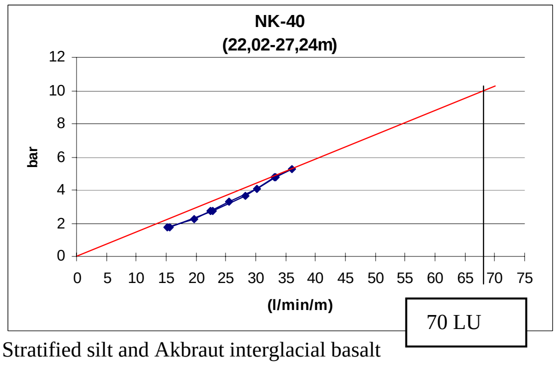


Þjórsá-lava

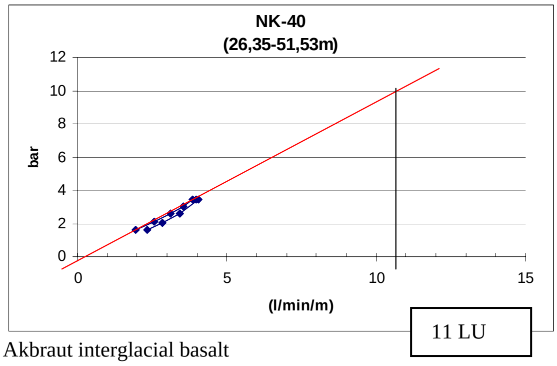
Permeability of NK-40



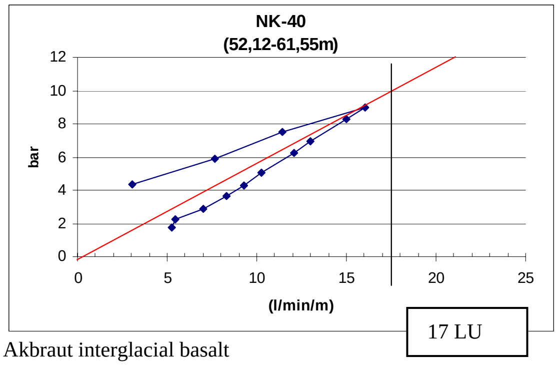
Þjórsá-lava, sand & gravel and stratified silt



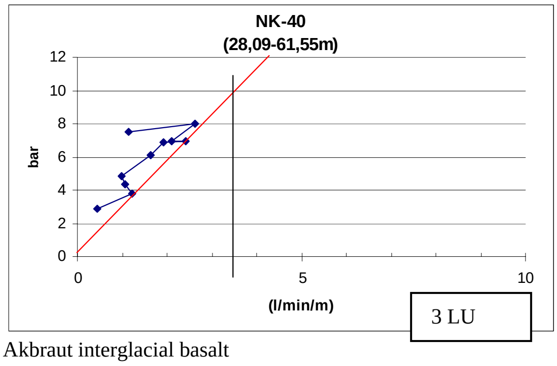
Stratified silt and Akbraut interglacial basalt



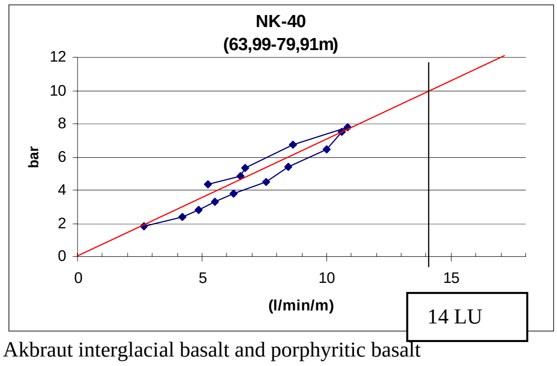
Akbraut interglacial basalt



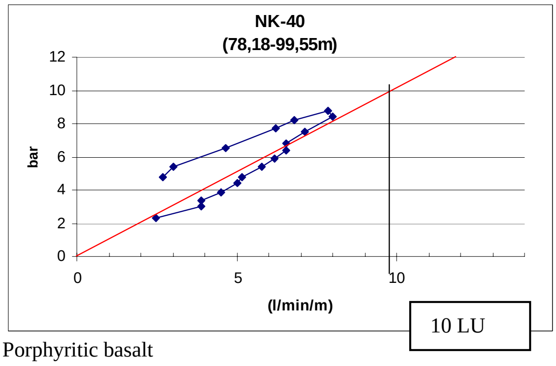
Akbraut interglacial basalt



Akbraut interglacial basalt

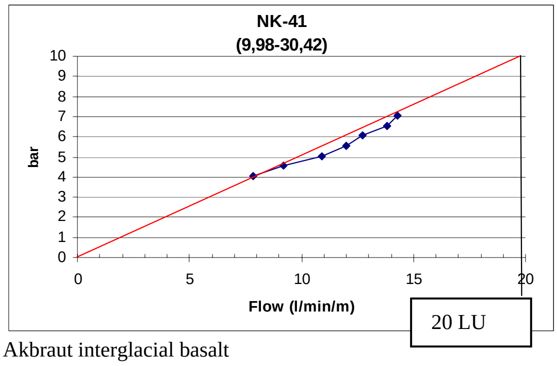


Akbraut interglacial basalt and porphyritic basalt

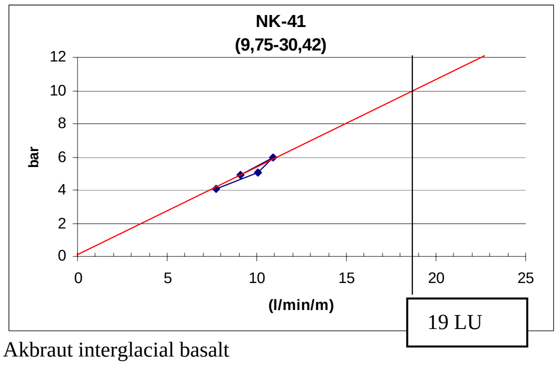


Porphyritic basalt

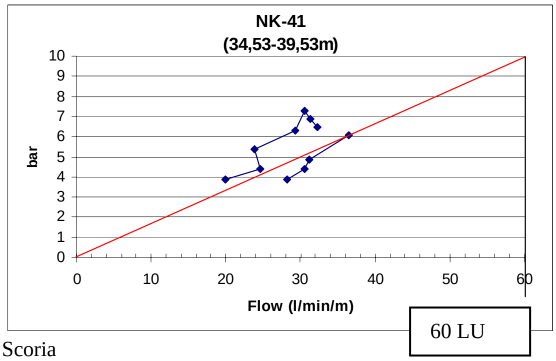
Permeability of NK-41



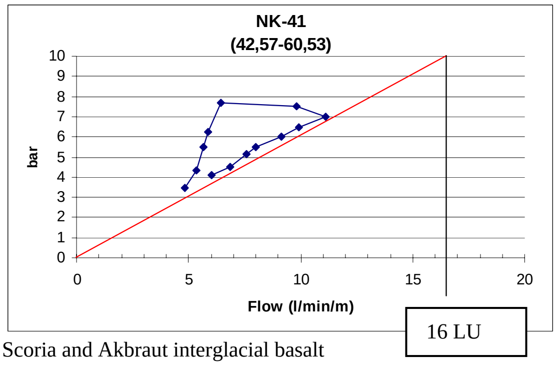
Akbraut interglacial basalt



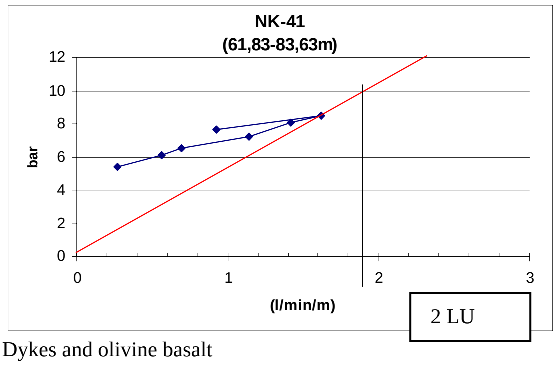
Akbraut interglacial basalt



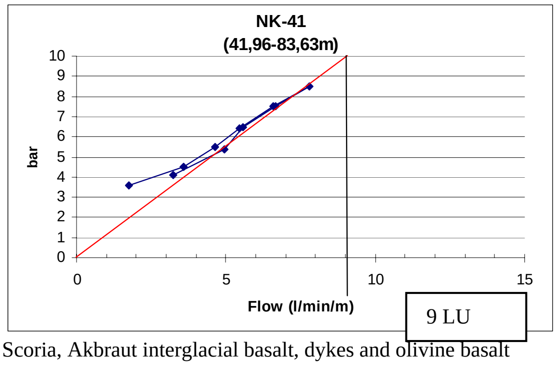
Scoria



Scoria and Akbraut interglacial basalt

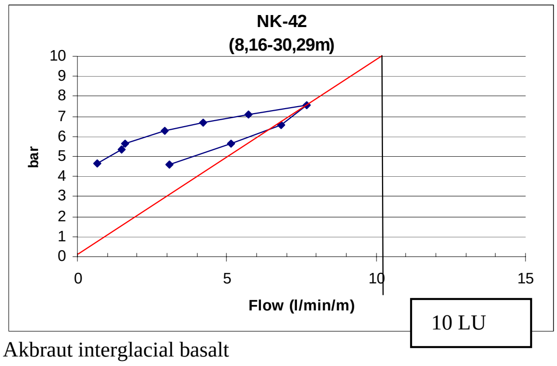


Dykes and olivine basalt

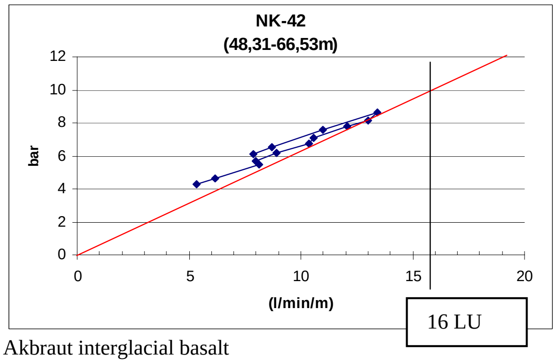


Scoria, Akbraut interglacial basalt, dykes and olivine basalt

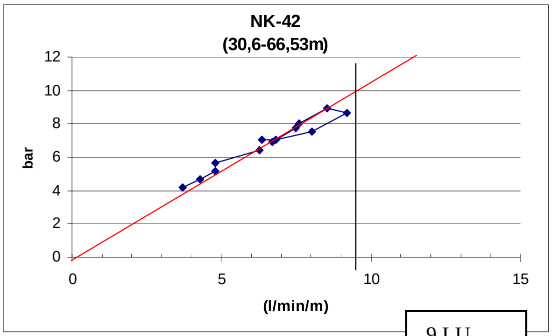
Permeability of NK-42



Akbraut interglacial basalt



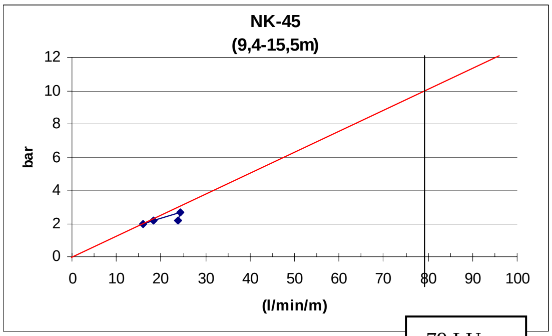
Akbraut interglacial basalt



9 LU

Akbraut interglacial basalt

Permeability of NK-45

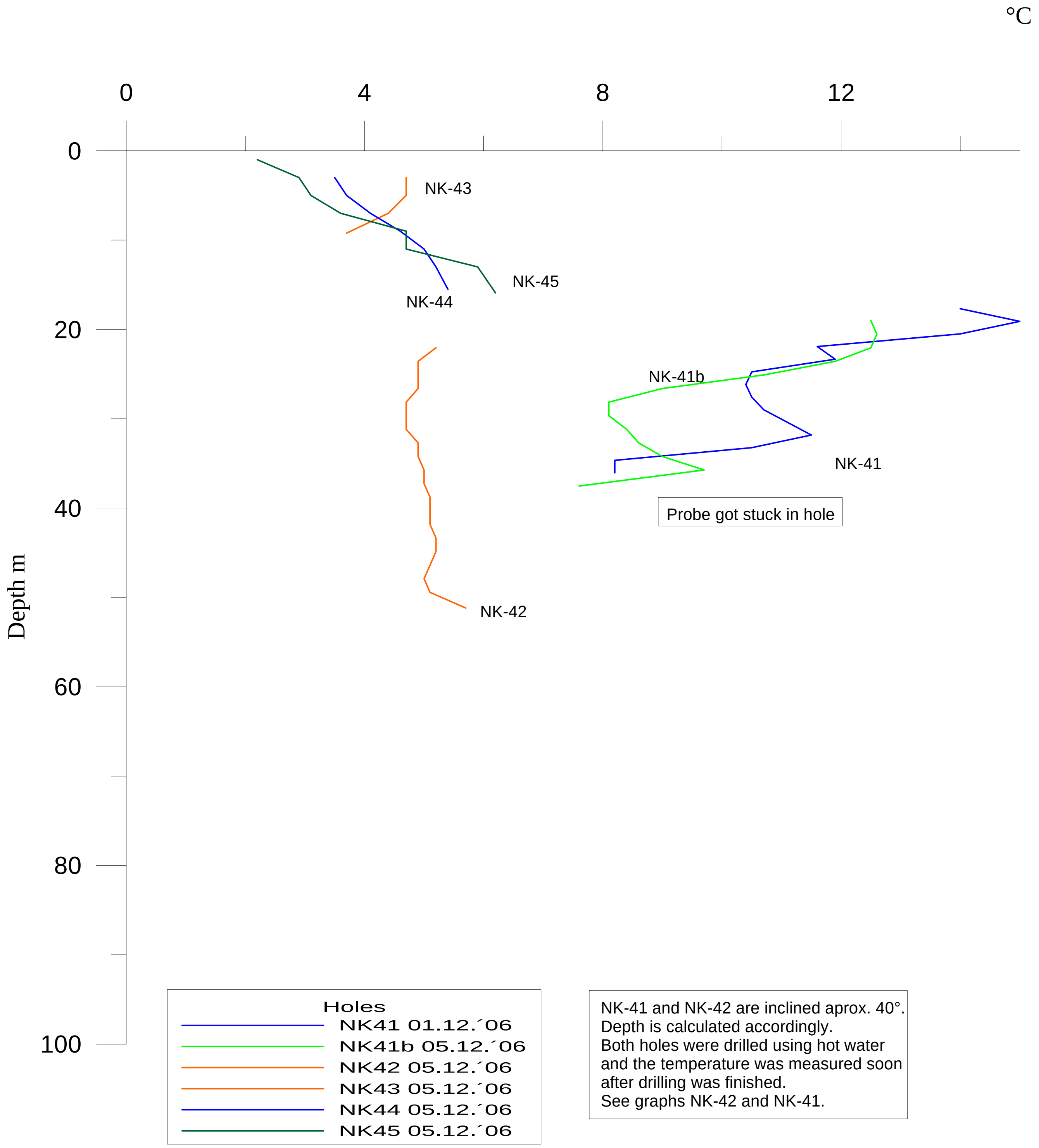


79 LU

Silt and fine sand

Holtavirkjun hydroelectrical project
Temperature readings in boreholes

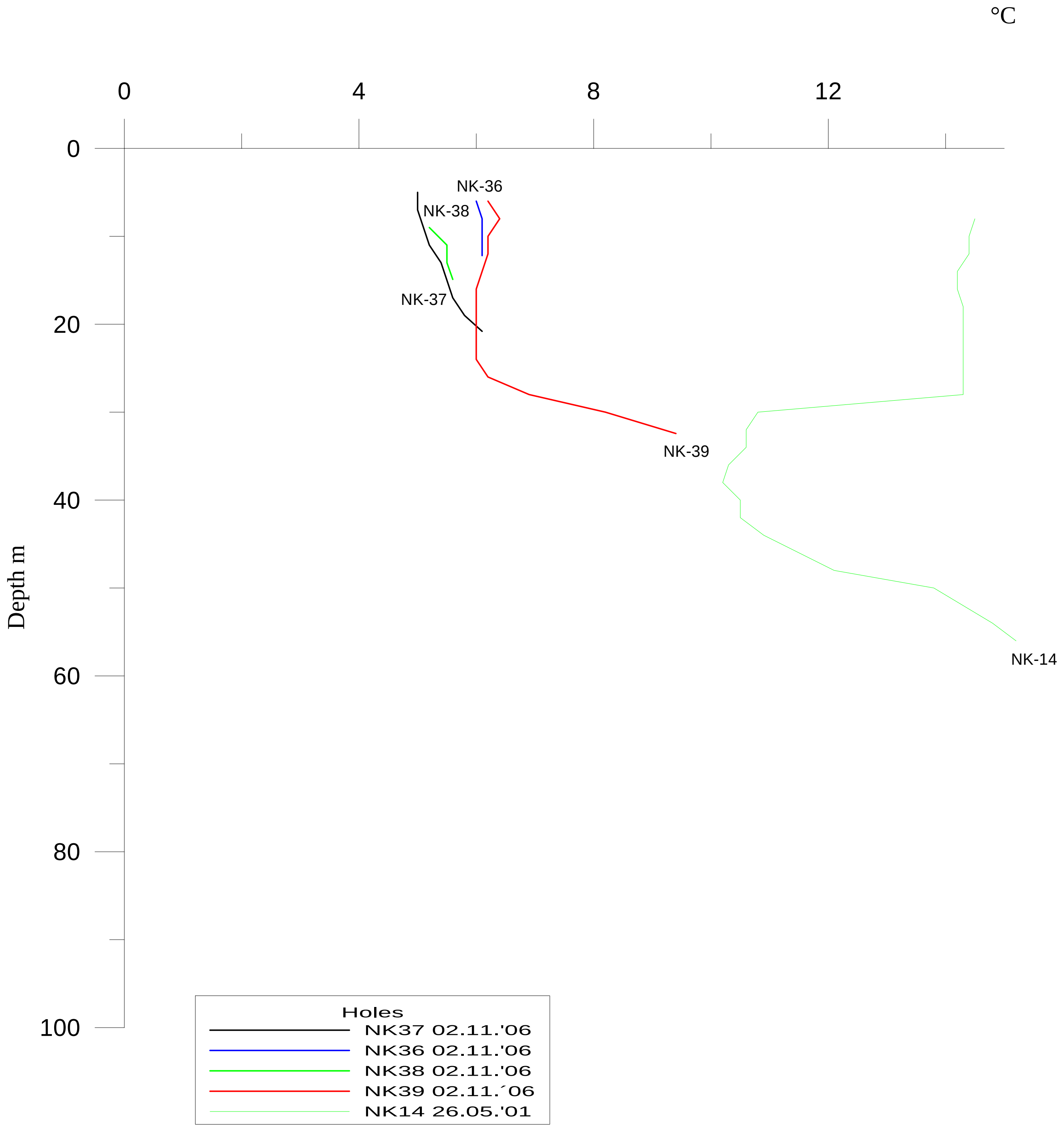
Akbraut



NK-41 and NK-42 are inclined aprox. 40°.
Depth is calculated accordingly.
Both holes were drilled using hot water
and the temperature was measured soon
after drilling was finished.
See graphs NK-42 and NK-41.

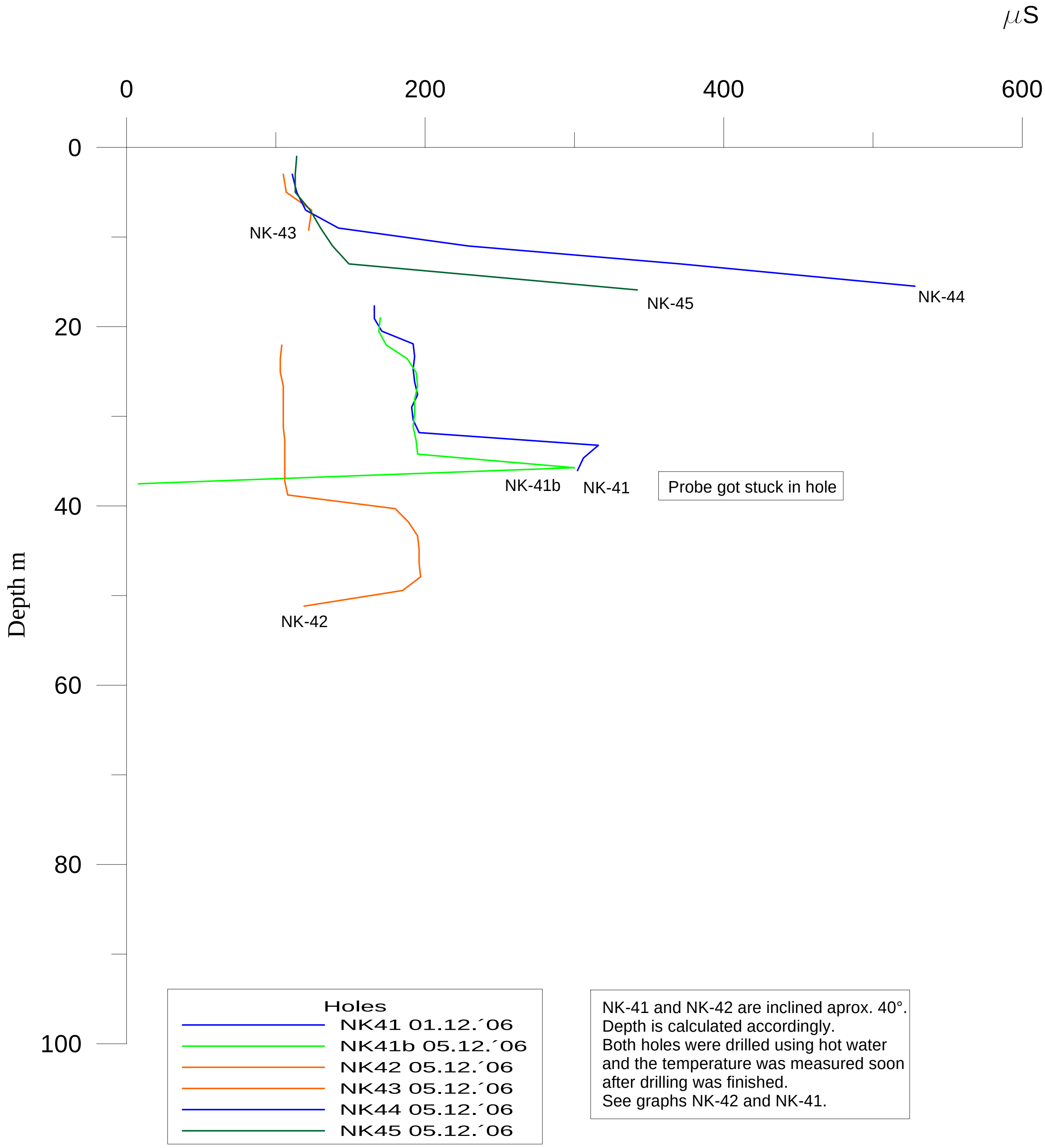
Holtavirkjun hydrelectrical project
Temperature readings in boreholes

Árnes island



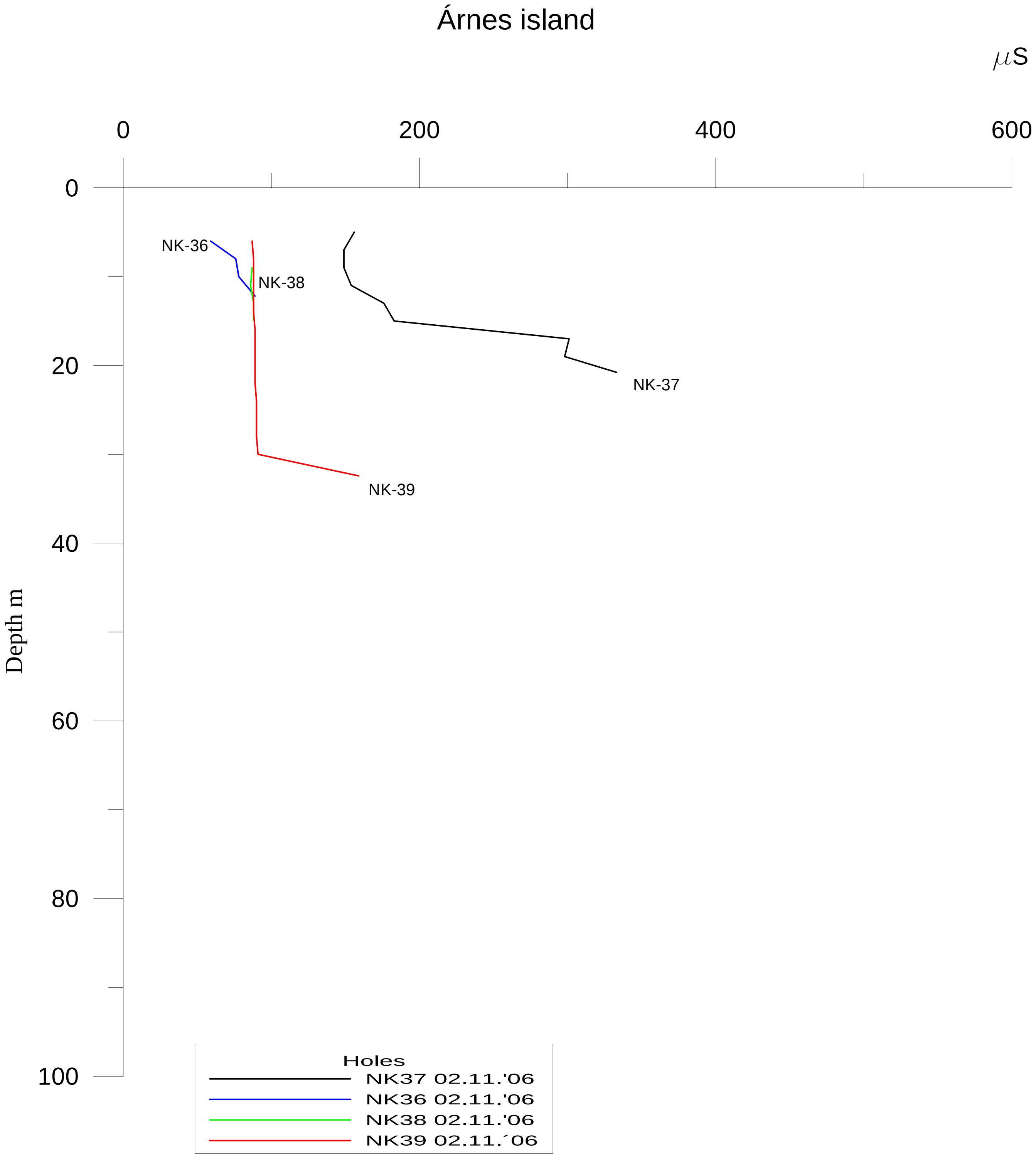
Holtavirkjun hydroelectrical project
Electrical conductivity readings in boreholes

Akbraut



NK-41 and NK-42 are inclined aprox. 40°.
Depth is calculated accordingly.
Both holes were drilled using hot water
and the temperature was measured soon
after drilling was finished.
See graphs NK-42 and NK-41.

Holtavirkjun hydrelectrical project
Electrical conductivity readings in boreholes



Temperature and conductivity in boreholes

NK-36		
date 2.11.06		
Ec	temp.	depth
µS	C°	m
		0
		2
		4
59	6	6
76	6.1	8
78	6.1	10
89	6.1	12.2

NK-37		
date 2.11.06		
Ec	temp.	depth
µS	C°	m
		0
		1
		3
156	5	5
149	5	7
149	5.1	9
154	5.2	11
176	5.4	13
183	5.5	15
301	5.6	17
298	5.8	19
333	6.1	20.8

NK-38		
date 2.11.06		
Ec	temp.	depth
µS	C°	m
		1
		3
		5
		7
87	5.2	9
86	5.5	11
88	5.5	13
88	5.6	14.9

NK-39		
date 2.11.06		
Ec	temp.	depth
µS	C°	m
		0
		2
		4
87	6.2	6
88	6.4	8
88	6.2	10
88	6.2	12
88	6.1	14
89	6	16
89	6	18
89	6	20
89	6	22
90	6	24
90	6.2	26
90	6.9	28
91	8.2	30
159	9.4	32.4

NK-41			
date 1.12.06		Corr.	Uncorr.
Ec	temp.	depth	depth
µS	C°	m	m
		0	0
		0.7	1
		2.1	3
		3.5	5
		4.9	7
		6.4	9
		7.8	11
		9.2	13
		10.6	15
		12.0	17
		13.4	19
		14.8	21
		16.3	23
166	14	17.7	25
166	15	19.1	27
171	14	20.5	29
192	11.6	21.9	31
193	11.9	23.3	33
192	10.5	24.7	35
193	10.4	26.2	37
195	10.5	27.6	39
191	10.7	29.0	41
192	11.1	30.4	43
196	11.5	31.8	45
316	10.5	33.2	47
306	8.2	34.6	49
302	8.2	36.0	50.95

NK-41			
date 5.12.06		Corr.	Uncorr.
Ec	temp.	depth	depth
µS	C°	m	m
		0	0
		0.8	1
		2.3	3
		3.8	5
		5.3	7
		6.8	9
		8.4	11
		9.9	13
		11.4	15
		12.9	17
		14.4	19
		16.0	21
		17.5	23
170	12.5	19.0	25
169	12.6	20.5	27
174	12.5	22.1	29
188	11.9	23.6	31
194	10.7	25.1	33
195	9	26.6	35
193	8.1	28.1	37
193	8.1	29.7	39
192	8.4	31.2	41
194	8.6	32.7	43
195	9	34.2	45
300	9.7	35.7	47
8	7.6	37.5	49.37

NK-42			
date 5.12.06		Corr.	Uncorr.
Ec	temp.	depth	depth
µS	C°	m	m
		0.0	0
		0.8	1
		2.3	3
		3.8	5
		5.3	7
		6.8	9
		8.4	11
		9.9	13
		11.4	15
		12.9	17
		14.4	19
		16.0	21
		17.5	23
		19.0	25
		20.5	27
104	5.2	22.1	29
103	4.9	23.6	31
103	4.9	25.1	33
105	4.9	26.6	35
105	4.7	28.1	37
105	4.7	29.7	39
105	4.7	31.2	41
106	4.9	32.7	43
106	4.9	34.2	45
106	5	35.7	47
106	5	37.3	49
108	5.1	38.8	51
180	5.1	40.3	53
189	5.1	41.8	55
195	5.2	43.3	57
196	5.2	44.9	59
196	5.1	46.4	61
197	5	47.9	63
185	5.1	49.4	65
119	5.7	51.2	67.31

NK-43		
date 5.12.06		
Ec	temp.	depth
µS	C°	m
		0
		1
105	4.7	3
107	4.7	5
124	4.4	7
122	3.7	9.22

NK-44		
date 5.12.06		
Ec	temp.	depth
µS	C°	m
		0
		1
111	3.5	3
114	3.7	5
120	4.1	7
142	4.6	9
229	5	11
371	5.2	13
528	5.4	15.5

NK-45		
date 5.12.06		
Ec	temp.	depth
µS	C°	m
		0
114	2.2	1
113	2.9	3
113	3.1	5
123	3.6	7
130	4.7	9
138	4.7	11
149	5.9	13
342	6.2	15.9

Ec = Electrical conductivity in µS
temp. = temperature in °C
depth= depth in meters

Holtavirkjun hydroelectric powerplant

Temperature readings in test pits

Date: 2.11.2006

Test pits	Heat °C
L1A	5,7-5,9
L1B	6.0
L21E	6,2-6,4
L22A	6,1-6,5
L22B	6,4-6,5
L22C	6,0-6,4
L22D	6,5-6,6
L22E	6,4-6,6
L23A	6.4
L23B	6.7
L23C	6,5-6,7
L23D	6.4
S3A	6.5
S3B	5.6

Groundwater level in Holtavirkjun

Borehole	Test pit	Date	Time	Water level
NK-37		2.11.2006	09:55	**3.888**
NK-36		2.11.2006	10:00	**5.499**
NK-38		2.11.2006	10:14	**7,467**
NK-39		2.11.2006	10:25	**5.209**
	L22D	2.11.2006	10:55	**2.862**
	L22B	2.11.2006	11:02	**2.249**
	L22C	2.11.2006	11:12	**2.904**
	L22A	2.11.2006	11:18	**1.498**
	L22E	2.11.2006	11:26	**1.326**
	L21E	2.11.2006	11:31	**2.130**
	L23D	2.11.2006	11:40	**2.083**
	L23C	2.11.2006	11:45	**1.305**
	L23A	2.11.2006	11:58	**1.628**
	L23B	2.11.2006	11:53	**1.677**
	L1A	2.11.2006	12:58	**2.281**
	L1B	2.11.2006	13:03	**2.83**
	S3B	2.11.2006	13:18	**1.608**
	S3A	1.12.2006	13:22	**2.733**
NK-42		2.12.2006	09:41	**25.575**
NK-41		5.12.2006	11:18	**24.324**
NK-42		5.12.2006	11:43	**27.655**
NK-43		5.12.2006	12:15	**2.829**
NK-44		5.12.2006	12:22	**1.085**
NK-44		5.12.2006	12:34	**0.934**

Point load tests

NK-22

Depth (m)	Rock type	Number of tests	P (kN)	Point load strength (IS)	Is (50) (Mpa)	Apparent UCS (Mpa)
5	Tholeiite	4	14.6125	7.2	6.9	130
9.4	Ol. Basalt	5	5.628	2.8	2.7	50
17.05	Scoria	7	2.19	1.1	1	20
20.2	Ol. Basalt	5	16.716	8.3	7.9	149

NK-23

Depth (m)	Rock type	Number of tests	P (kN)	Point load strength (IS)	Is (50) (Mpa)	Apparent UCS (Mpa)
3.5	Tholeiite	5	18.032	8.9	8.5	160
16.6	Ol. Basalt	5	2.226	1.1	1	20
19.5	Dyke	4	6.7025	3.3	3.2	59

NK-36

Depth (m)	Rock type	Number of tests	P (kN)	Point load strength (IS)	Is (50) (Mpa)	Apparent UCS (Mpa)
4.5	Þjórsár-lava	7	5.3	2.6	2.5	47
20.0	Silt	6	1.5	0.7	0.7	13
25.9	Silt	6	1.3	0.7	0.6	12
29.7	Dyke	6	10.6	5.2	5.0	94
33.3	Ol. Basalt	4	4.0	2.0	1.9	36
38.8	Dyke	7	10.1	5.0	4.8	90

NK-38

Depth (m)	Rock type	Number of tests	P (kN)	Point load strength (IS)	Is (50) (Mpa)	Apparent UCS (Mpa)
12.9	Þjórsár-lava	12	6.4	3.1	3.0	57

NK-41

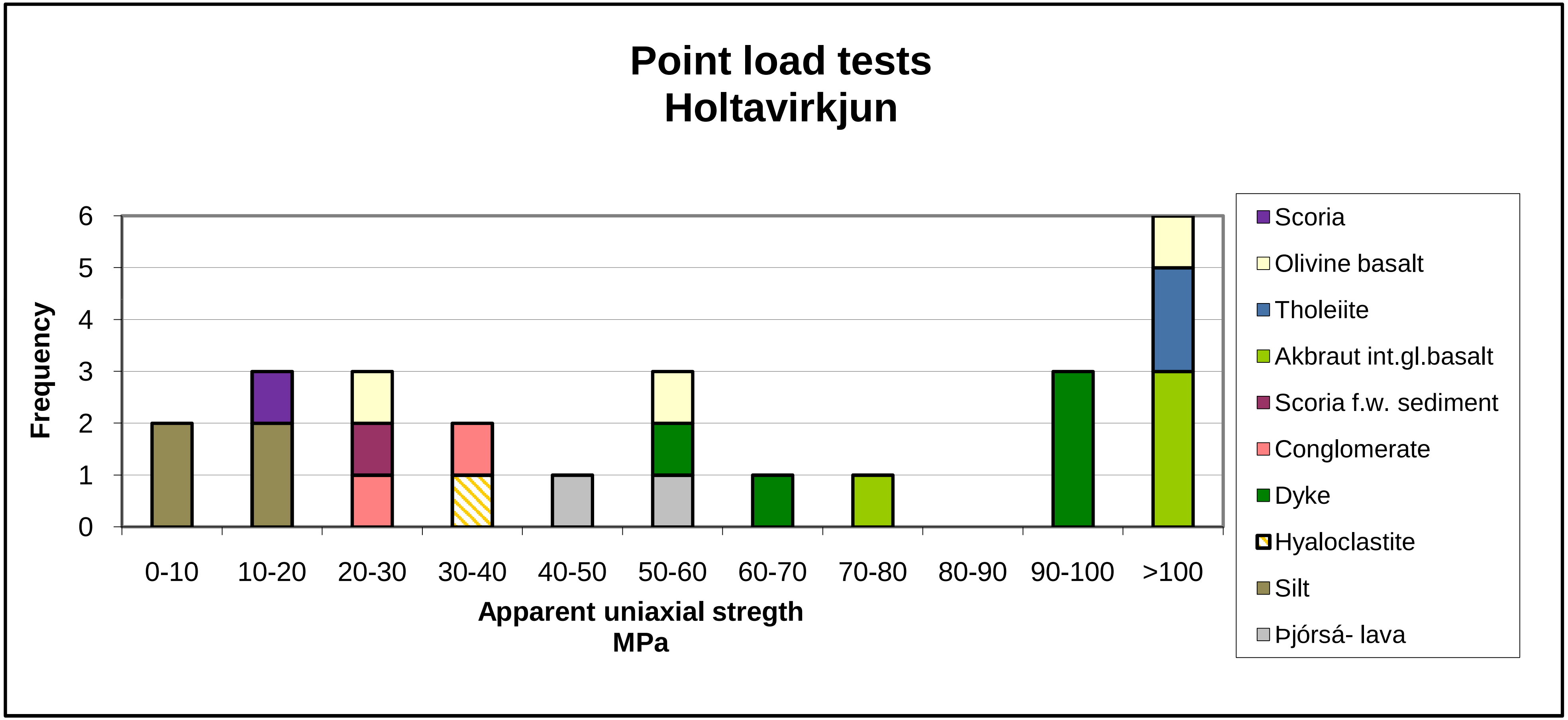
Depth (m)	Rock type	Number of tests	P (kN)	Point load strength (IS)	Is (50) (Mpa)	Apparent UCS (Mpa)
36.0	Sediment filled scoria	11	4.2	2.1	2.0	37
46.0	Sediment filled scoria	9	2.9	1.4	1.4	26
59.5	Conglomerate	7	2.6	1.3	1.2	23
61.9	Dyke	11	6.8	3.4	3.2	61
66.3	Dyke	5	11.3	5.6	5.3	100
73.4	Akbraut int.gl.basalt	6	8.4	4.1	3.9	74

NK-42

Depth (m)	Rock type	Number of tests	P (kN)	Point load strength (IS)	Is (50) (Mpa)	Apparent UCS (Mpa)
8	Akbraut int.gl.bas.	10	18.3	9.0	8.6	163
17.5	Akbraut int.gl.bas.	6	22.0	10.9	10.4	196
41.8	Akbraut int.gl.bas.	7	25.1	12.4	11.8	223

NK-45

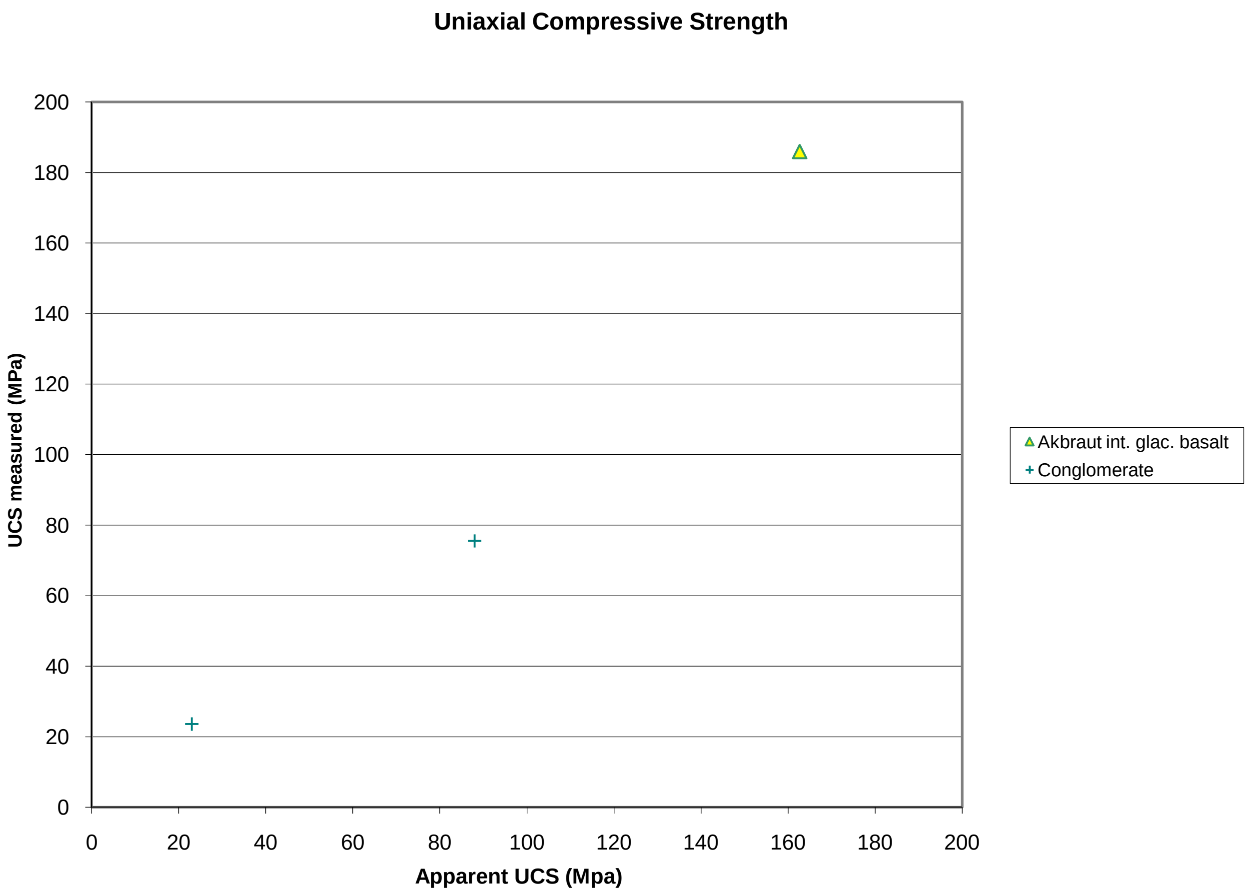
Depth (m)	Rock type	Number of tests	P (kN)	Point load strength (IS)	Is (50) (Mpa)	Apparent UCS (Mpa)
10.5	Silt	7	0.7	0.3	0.3	6
11.0	Silt	5	0.8	0.4	0.4	7

Point load tests
Holtavirkjun
Frequency
0
1
2
3
4
5
6
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
>100
Apparent uniaxial stregth
MPa
Scoria
Olivine basalt
Tholeiite
Akbraut int.gl.basalt
Scoria f.w. sediment
Conglomerate
Dyke
Hyaloclastite
Silt
Þjórsá- lava

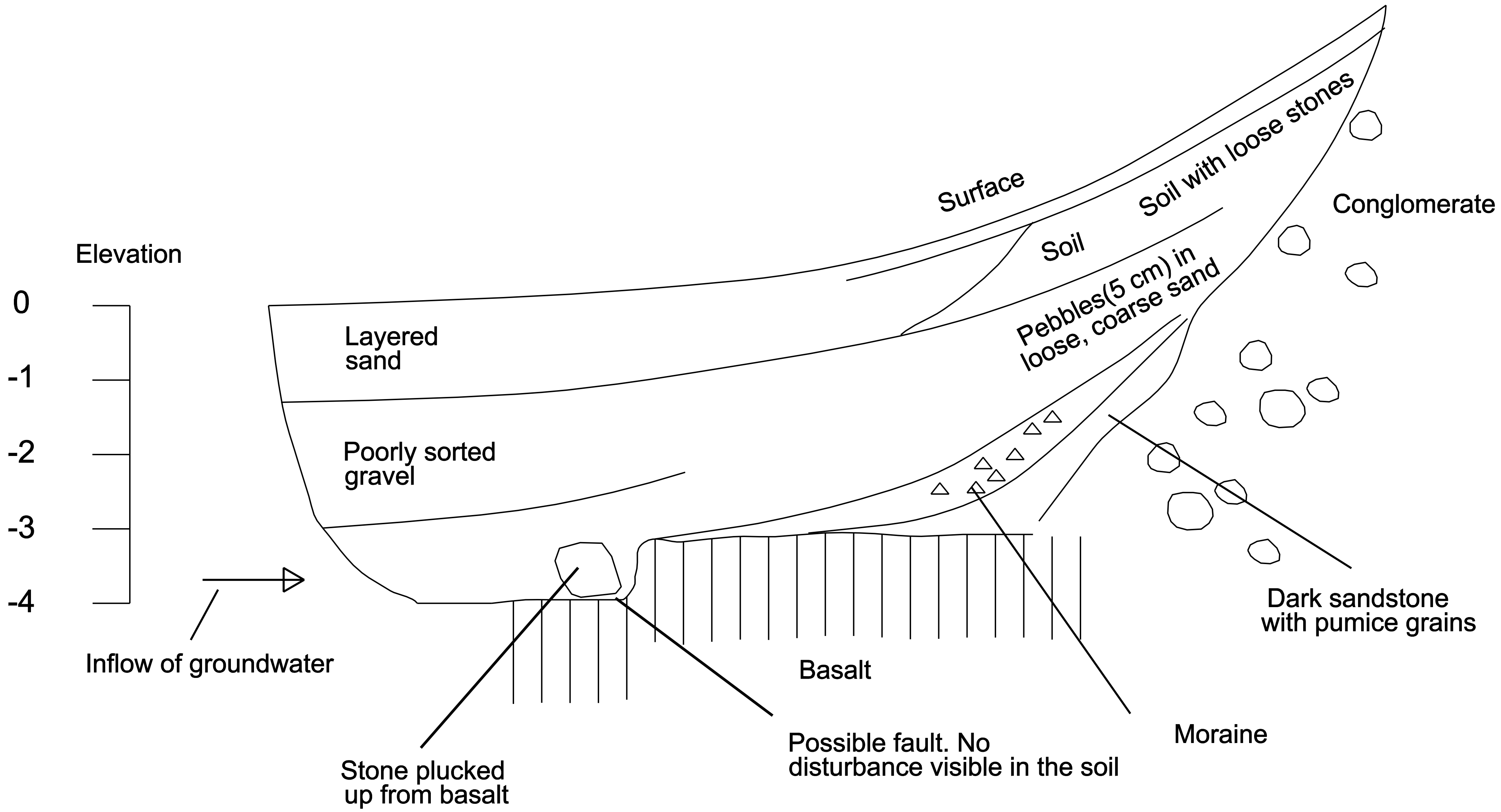
Uniaxial compressive strength test (UCS) **Stress-Strain meas.**

Sample	Bore hole	Depth	Rock type	Length (mm)	Diam. (mm)	Ax.load (kg)	L/D	UCS (MPa)	Sample moist. (%)	Weights Water (g)	Ssd (kg/m3)	UCS (MPa)	Youngs E-ax (Gpa)	E-dia (Gpa)	Pois. ratio
1	NK-41	60	Conglom.	-	45.0	3830	2.0	23.6	-	163.9	2248.0				
1-2	42	8.5	Akbr.Int.gl.bas	-	45.0	30170	2.0	185.9	-	269.1	2945.5				
NBS-08	NK-20	33.8	Conglom.	94.01	44.71	12100	2.10	75.61	6.98	202.4	2374.1	110	64.62	124.2	0.52

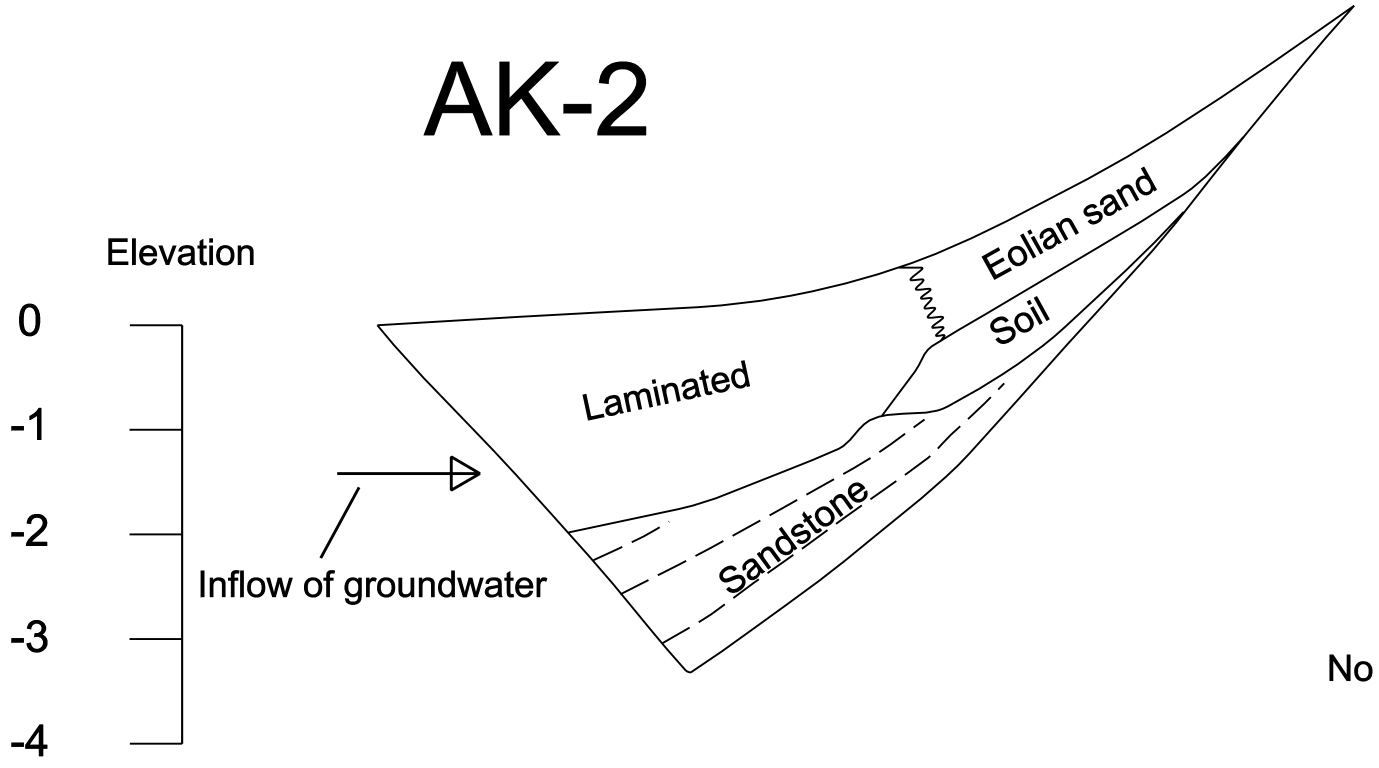
* Tested by Icelandic building research institude



AK-1

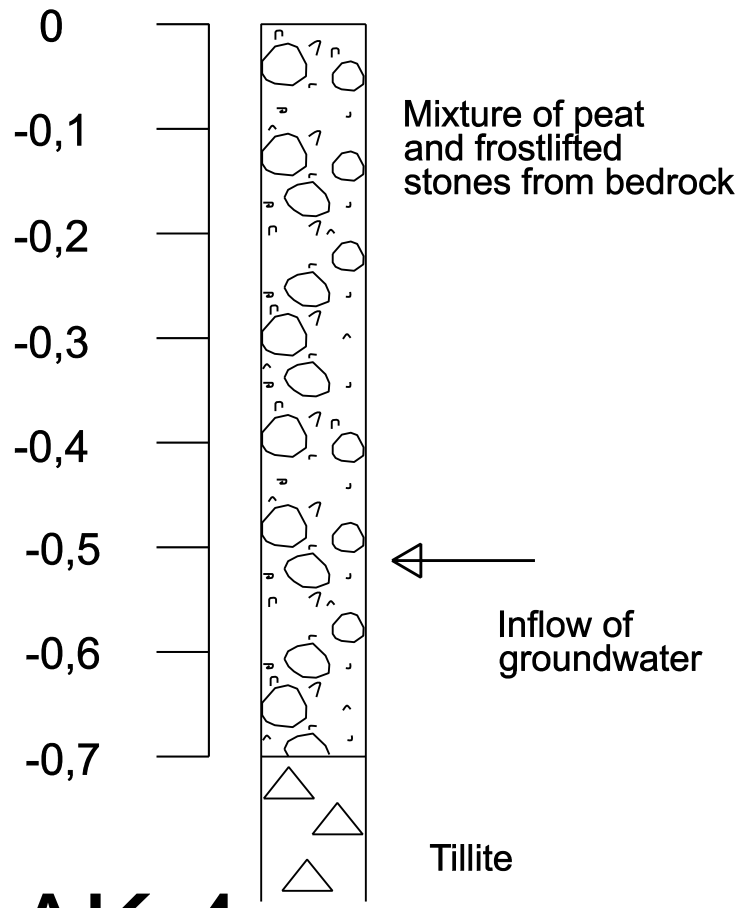


AK-2

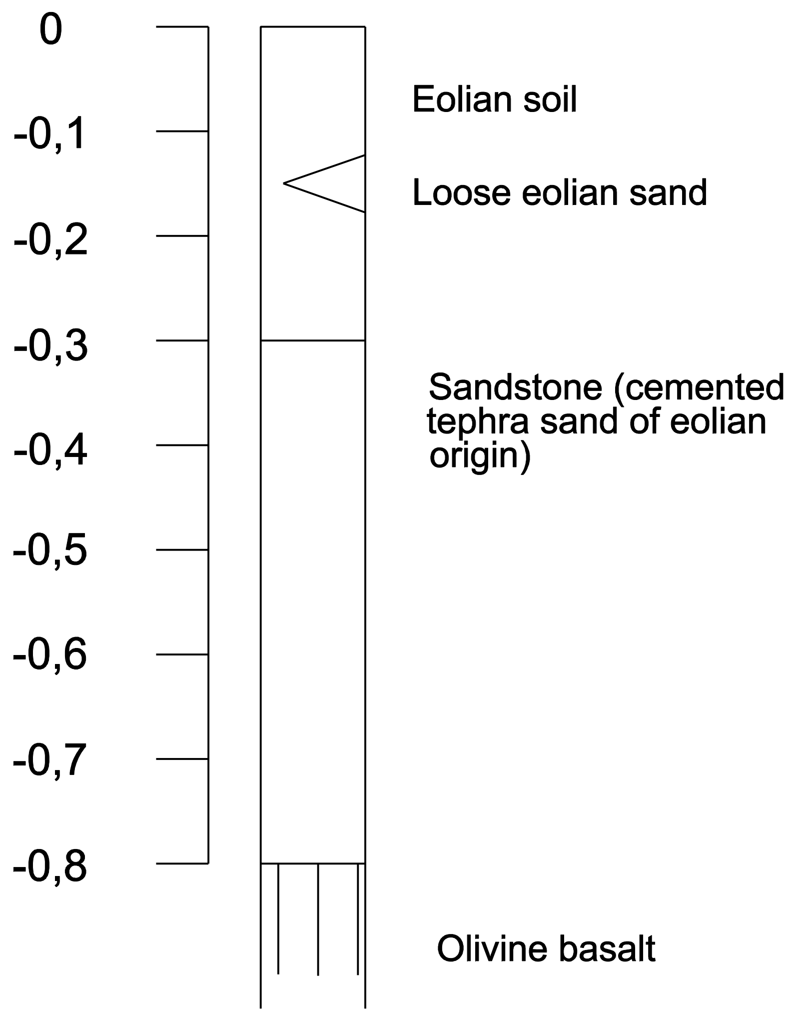


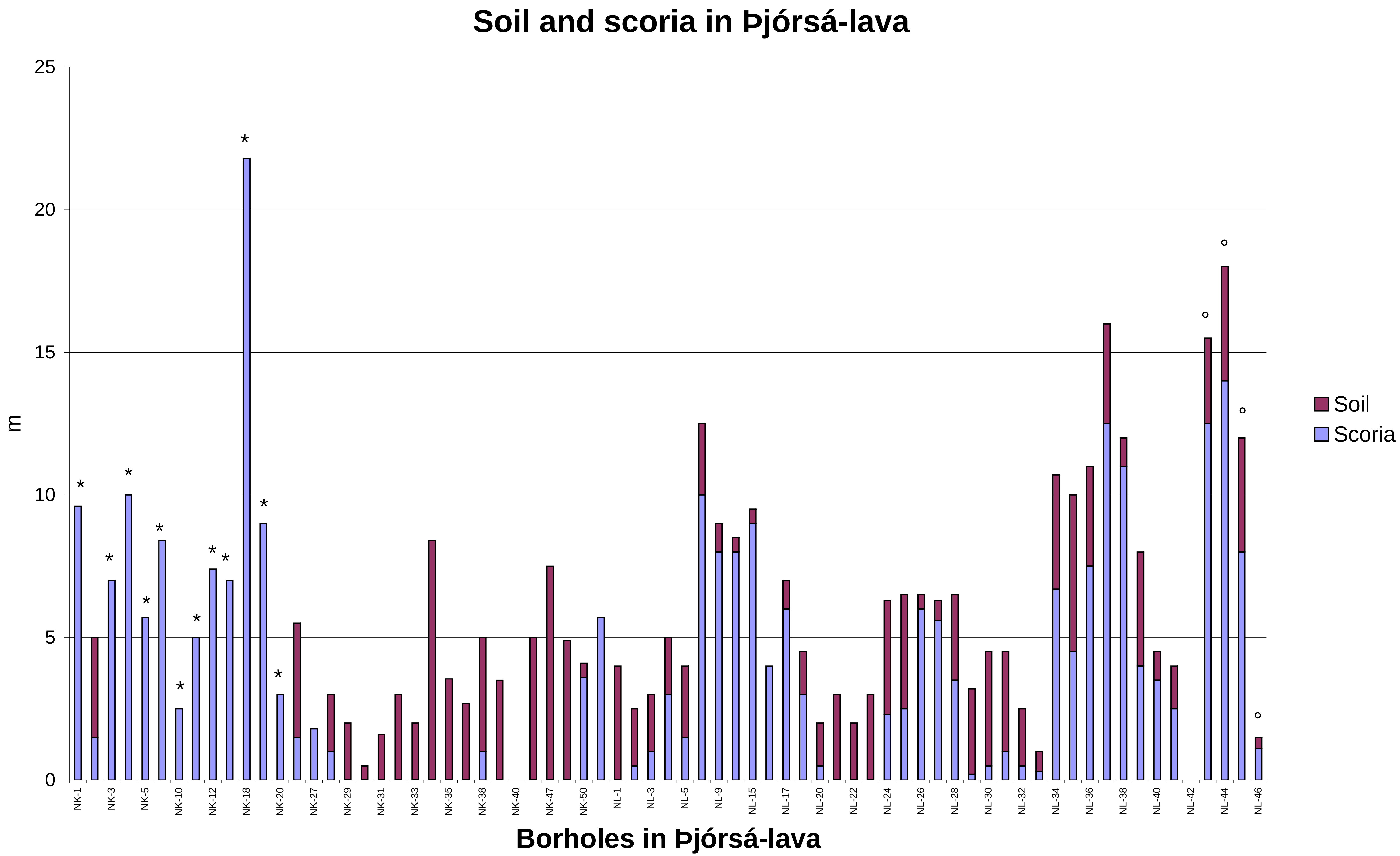
No sign of fissures/faults found
in AK-2, AK-3, AK-4

AK-3



AK-4





*** No data on difference between soil and scoria** **° Holes do not reach through scoria**