Dýrafjörður Road Tunnel

Aðstæður til jarðgangagerðar milli Rauðsstaða og Dranga

English translation 2016

Geological Conditions for a Road Tunnel between Arnarfjörður and Dýrafjörður NW Iceland

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1 Summary

This report is translation of a report written in Icelandic, expressing the geological environment in the mountains between Dýrafjörður and Arnarfjörður in Northwest Iceland. It also describes and evaluates tunnelling conditions through the mountain chain between the innermost part of Dýrafjörður and Borgarfjörður, which is an appendix fjord in the innermost part of Arnarfjörður.

The tunnelling area is characterised by relatively well stratified lava pile containing scattered and most frequently thin sedimentary interbeds. At approximately 200 m a.s.l. the lava pile dips gently about 5° towards SSE (direction 150°) but at sea level the dip increases to about 6°. The basalt lavas mainly consist of porphyritic basalt with small plagioclase crystals. The character of the basalt is somewhere between the characters which G.P.L. Walker has described for Tholeiite and Olivine basalts in East Iceland (probably more like the character of olivine basalt). The most common basalt thicknesses are in the range of 5-15 m with about 10 m average thickness.

According to some 6°dip of strata the tunnel will transect some 400 thick strata containing approximately 40 basaltic rock layers and the same number of layer contacts which often contain thin (< 2m) sedimentary interbeds. At least one almost 10 m thick sedimentary layer exist in the boreholes at the tunnel alignment and the tunnel will traverse this sediment at a relatively short distance inside the north portal at Drangar.

The bedrock is saturated with groundwater and most probably the ground water table (GWT) generally exists at 400-500 m a.s.l. in the planned tunnel area. The GWT is inclined rising eastwards, towards the highland of Sjónfríð and Gláma. Generally, the permeability of the bedrock decreases with increased depth. Permeability tests using packers in boreholes shoved mainly permeability values below 2 LU (1 LU is a flow of 1 litre/minute at a pressure of 10 bars), but higher permeability values were encountered at joints in borehole ARN-02 at the south portal at Rauðsstaðir.

The tectonic lineaments have a strong NE-SW trend but the tectonic directions cover a relatively wide sector. At the mountain edge on the south side, there are several basaltic dykes, perpendicular to the tunnel routs and these are also heading towards the Gláma highland.

Geological conditions at the portals are briefly as follows: At Rauðsstaðir in Arnarfjörður the portal is designed at elevation about 35 m a.s.l. The bedrock is covered with bogs and frontal parts of talus zones. The surficial layers are in the range of 5-8 m thick, wet soil and peat resting on thin glacial moraine and talus. At Drangar on the Dýrafjörður side the portal will be at 70 m a.s.l where the surficial layers consist of 3-5 m thick moraine. The moraine is rich of silt and might turn to a creeping mud if excavated during wet periods

1.1 Introduction

A primitive road was made between Arnarfjörður and Dýrafjörður in the late fifties of the twentieth century. During the recent three to four decades, discussions have been rising about the need for a road tunnel between the fjords. The first investigations for a possible tunnel were carried out by the staff from Vegagerðin and the results were published (by Hreinn Haraldsson and Sveinn Björnsson) in 1984. In this report, two areas were briefly described, firstly the mountain ridge between the innermost part of the fjords and secondly a short tunnel under the present road over Hrafnseyrarheiði.

The information in the present report was obtained using three main methods.

1. Review of different scientific papers about the geology of NW Iceland published by different scientists during the last several decades.

2. Fieldwork, inspection of aerial photos. Interpretation of the geological information and fieldwork performed discontinuously by the present author during the period 1975 through 2007.

3. Investigational cored drilling and percussion drilling in the portal areas in addition to minor geological mapping in Dýrafjörður and Arnarfjörður 2006.

4. Several test pits were excavated in the proposed portal areas at Rauðsstaðir and Drangar in the summer of 2007.

In 1975, two young geologists Ágúst Guðmundsson and Jóhann Helgason mapped and described several stratigraphical profiles in the inner part of the fjords Dýrafjörður and Arnarfjörður. The results of their work, is a part of the paper: Magnetostratigraphy and Geochronology of Northwest Iceland by Ian MCDougall et al 1984. (Some of the profiles from that paper are reproduced in Appendix C). Part of the investigation was a detailed mapping of magnetic polarity of the rock and dating by the K/Ar^{40} method. This paper was a great step forwards in increasing the knowledge of the bedrock of NW-Iceland.

In 1999, the present author carried out (for Vegagerðin) geological investigations in the area between Dýrafjörður and Arnarfjörður, mainly focusing on the area between the innermost parts of Dýrafjörður and Arnarfjörður and also near the present road over the pass Hrafnseyrarheiði. Additionally, several portal areas were inspected during this period. (See report by Jarðfræðistofa ÁGVST 2000).

Later Vegagerðin decided to focus only on a tunnel alignment between the mountain ridge between the innermost parts of Dýrafjörður and Arnarfjörður. All investigations, core drilling, percussion drilling and field inspection in the autumn of 2006 were focused on this area (see locations on Drawings 1, 4 and 5). The bedrock has been described in several stratigraphical profiles (see Appendix C) and a few marker horizons connected through the mountain (see Drawings 6 and 7).

The Jarðfræðistofan (GEOICE) carried out the investigations for Vegagerðin. Geologists were Ágúst Guðmundsson Sarah Kaiser, Timothy Ward and Haraldur Hallsteinsson. The drilling contractor was ALVARR (Friðfinnur K. Danielsson) and subcontractor the drilling company SMOY from Finland.

2 Schematic Geology of Northwest Iceland

The bedrock of the NW peninsula of Iceland consists of numerous lavas forming approximately 7 to 7.5 km thick gently inclined lava pile which were formed by volcanic activity over the period 10-16,5 million years ago. The volcanism there was not continuous as may be seen in different types of sedimentary interbeds, formed on the plateau during calm periods. There are a few unconformities showing periods of considerable intermission in the volcanism in different areas where relatively thick sedimentary interbeds are found and even showing some erosion on the surface of the older strata. Additionally, several old central volcanoes are found buried in the strata in areas of more intense volcanism. During their activity, they were forming broad volcanoes of "volcanic massifs" rising over the regional basalt plateau. These volcanoes were gradually buried by dispersed eruptions of the regional volcanism.

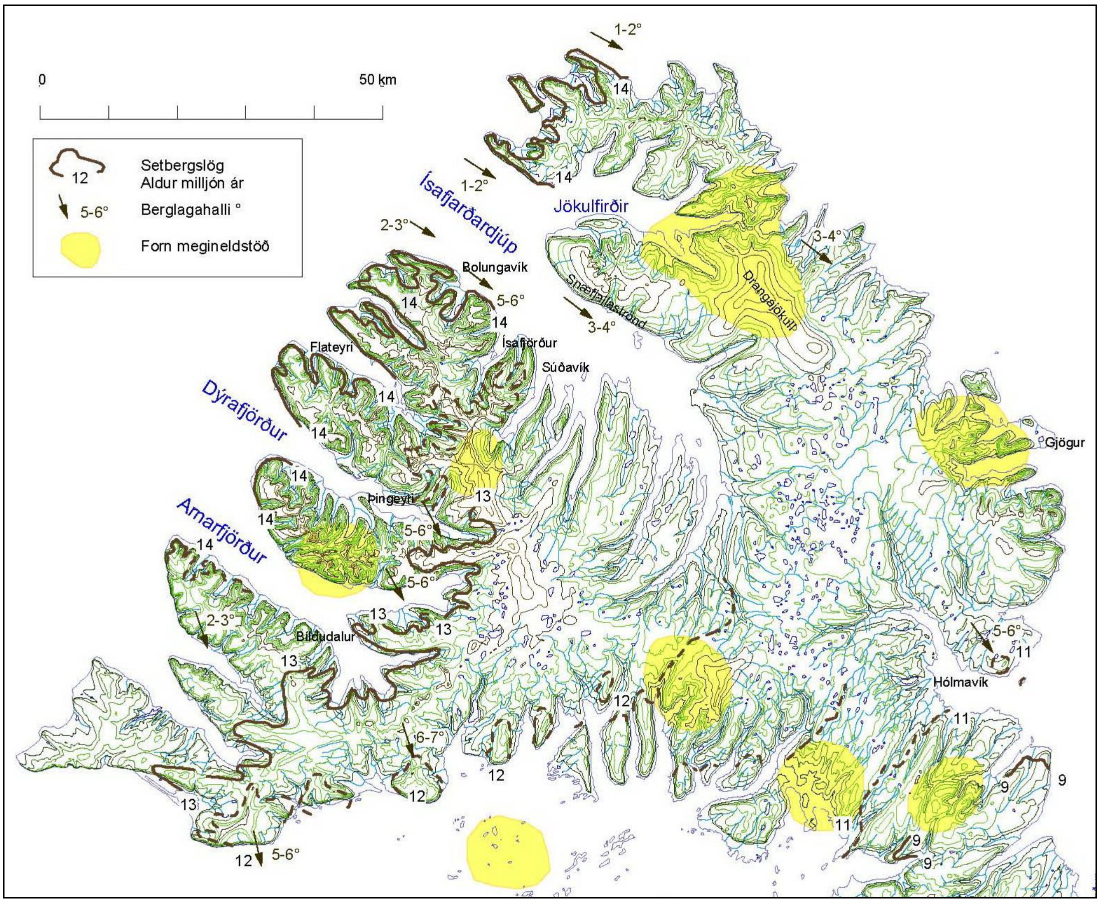

Fig. 1. Schematic geological bedrock map of NW Iceland.

The most prominent unconformities are seen in the strata of the outermost peninsulas in the northern part on both sides of the major fjord Ísafjarðardjúp on the Hornstrandir in the north to Sléttanes and Kópanes (on the west entrance of Arnarfjörður) in the west. There are two unconformities in the strata, very close to each other and the lower one forms an erosional shelf (named Breiðhilla) in the steep sloped mountain. The sediments in the unconformities contain organic plant remains like lignite and this was excavated as "a fuel" during the first world war (1914-1918). The strata below the Breiðhilla horizon was formed 15-16,5 million years ago.

On the top of the Breiðhilla unconformity there are thick piles of tholeiite lavas. Individual basalt layers in the lower part of this pile are relatively thick and the Breiðadals-Botnsheiði tunnel were excavated through this stratum in the years 1991-1995. Higher up in the strata are thick series of thinner tholeiite layers erupted in the flanks of two tertiary central volcanoes. One of these volcanoes is the Lambadalur central volcano, buried in the mountain ridges between Álftafjörður and Lambadalur, which was producing basaltic lavas (and some layers of intermediate and acidic rock) in addition to volcanic tephra. Some volcanic sedimentary layers from the Lambadalur volcano are found in the innermost part of Dýrafjörður.

The other central volcano mentioned in the area is the Tjaldanes central volcano which rised up from the mountain chain between Arnarfjörður and Dýrafjörður north from Hrafnseyrarheiði. This volcano was for a great part covered with a thick mantel of thinly bedded tholeiite lavas as may be seen in the valleys of Hvammsdalur and Brekkudalur in Dýrafjörður and in Hrafnseyrardalur in Arnarfjörður. Basaltic lavas from regional volcanic activity have gradually surrounded and drowned the old central volcano. This regional basalt layers comprise the main part of the bedrock at the tunnel alignment between Drangar and Rauðstaðir. The topmost layers of the central volcano run down to sea level near Gljúfrá in Arnarfjörður and near Kjaranstaðir in Dýrafjörður but in these areas the layers from the volcano intergrate inbetween the regional basalts.

In the innermost parts of the fjords Dýrafjörður and Arnarfjörður, the dip of the strata at sea level is about 6° towards SSE or towards 150°. Generally, the dip of the strata in the area reduces some 0,65-0,75° for every 100 m in increasing altitute and the dip at 400 m a.s.l. is around 3°.

Dykes and faults outside the central volcanoes are relatively few and scatterly distributed. The majority of visible dykes line up ENE-WSW (60°), parallel to the strike of the strata (perpendicular to the dip). The thickness of the basaltic lavas is most commonly in the range of 6-12 m and sedimentary interbeds mainly thinner than 0,4 m (see distribution of thicknesses in histograms on figs. 17 and 18.

The alteration of the bedrock strata at sea level in the tunnel alignment area is defined as the upper margin of the lower part of the chabazite zone or the upper part of the analcime zone as defined by G.P.L. Walker. Large chabazite crystals are commonly found in amygdales around 200-300 m a.s.l. On formerly investigated possible tunnel route under Hrafnseyrarheiði the alteration of the rock is at considerably higher alteration stage containing quartz amygdales, although such tholeiite basalt bedrock is normally low in alteration minerals.

2.1 Geomorphological development

The K/Ar dating of the bedrock reveals that the bedrock which we now see above sea level in NW Iceland was formed during the period 10-16 million years ago. During late tertiary time the, NW peninsula was a highland plateau where several central volcanoes formed volcanic "massifs" rising several hundred meters above the surrounding areas. Among these volcanic centres, we may take as examples one near Kaldbakur behind the village Þingeyri, another between Lambadalur and

Álftafjörður, the third at Trékyllisvík on Strandir and the fourth in Reiphólsfjöll SE from the Sjónfríð-Gláma highland (see fig. 1).

Following deteriorated climate in late Tertiary time, glaciers started to grow, first on the central volcanoes rising above the surrounding plateau. The glaciers gradually grew thicker and during Pleistocene time, these flowed along depressions in the plateau towards the coast, eroding major valleys and fjords. During late Pleistocene and the last glacial time (Weichselian) it seems that glaciers were covering the central highland of the NW fjords, reaching into the heads of the fjords. The distal part of the mountainous peninsulas between the main fjords Arnarfjörður and Ísafjarðardjúp is covered with thick frost shattered rubble and debris formed by frost action, indicating periglacial conditions and absence of glaciers to erode and transport the frost weathered rubble. Towards the west from Arnarfjörður all the way to Bjargtangar there is no evidences indicating recent glacial erosion, only some small local erosion in valley heads and corries.

In the innermost parts of Dýrafjörður and Borgarfjörður in Arnarfjörður, there are strong evidences of glacial erosion heading directly outwards along the valleys and fjords. Further out in the fjords, all glacial erosion is confined to local glaciers in different valleys. Remarks, of a glacial erosion may be seen from the Gláma-Sjónfríð highland out to Lambadalsoddi and probably all the way to Höfðaoddi in Dýrafjörður and on the Arnarfjörður outside Dynjandisvogur. At present time in the autumns we only find small sporadic snow paths and tiny "circue glaciers" facing northwards in the highest parts of the Sjónfríð-Lambadalsfjall highland ridge.

Further out in the fjords the local glaciers were flowing without any restriction directly towards the shore out from every valley and corries. Thick debris bodies defined as "relict rockglaciers" are commonly found in Lambadalur-Kjaranstaðadalur in Dýrafjörður and further outwards in the fjord supporting ice free areas during "glacial time". Additional evidences on restricted glacial flow into the fjords, the talus slopes in the innermost part of the fjords are thinner than further out in the fjords. The talus slopes facing south are normally containing thicker debris compared to the north facing slopes as may be seen at Drangar and Rauðsstaðir.

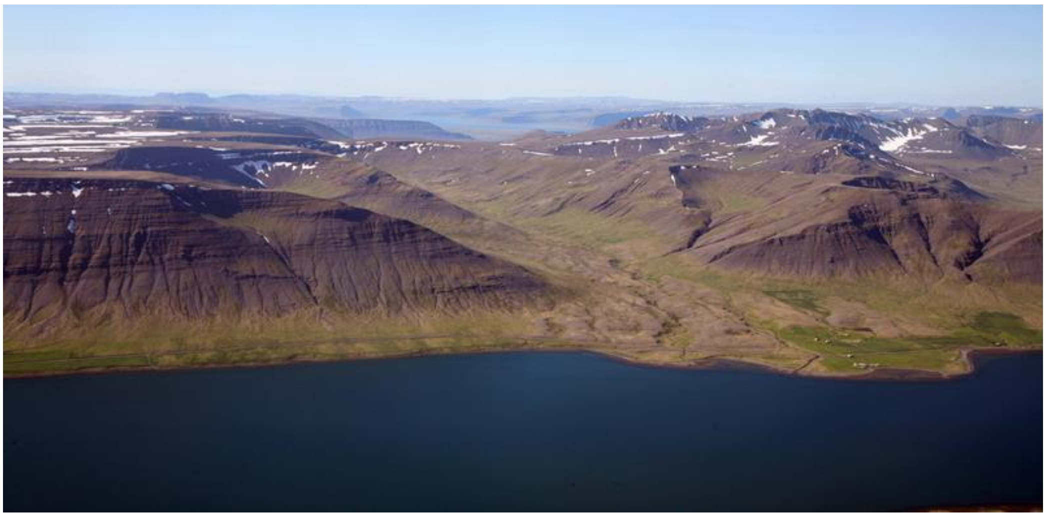

Fig 2. Geomorphology at the eastern margin of the Tjaldanes central volcano. Highland plateau of regional basalt to the left and eroded peaks of the volcano right.

3 The bedrock between Arnarfjörður and Dýrafjörður

The mountainous peninsula between Arnarfjörður and Dýrafjörður comprises long geological history and relatively variegation in rock types and layers in the strata. The oldest rock existing below the Breiðhilla sediments at sea level at the outermost end of the peninsula is relatively highly altered basalt. The central- and outer part of the peninsula contains a central volcano but the inner part is composed of regional plateau basalt. The central volcano formed a broad conical mountain (or elongated in NE-SW direction) with a total thickness of 1500 m and probably rising over a long period some 400-500 m above the surrounding area. The geological structure of the peninsula is described in the following chapters.

3.1 From the outermost shore to the Breiðhilla sediments

At the coast of the outer end of the peninsula between Arnarfjörður and Dýrafjörður there is a rock series of highly altered basalt lavas and relatively thin sedimentary interbeds. The strata is dipping 4-5° towards southeast. At 80-90 m height a.s.l. in Helgafell there is a prominent shelf and along this shelf is a poor track which was made by a small local contractor around 1970-1980. The shelf is following sedimentary interbeds which were formed during a long intermission in the volcanism of the area some 15-16 million years ago. The sedimentary horizon is generally named Breiðhilla and comprises 3-10 m thick sedimentary interbeds which discontinuously contain some 0,2-0,5 m thick layers of lignite.

Fig.3. Keldudalur and Helgafjall (Hjallafjall) at the outer end of Dýrafjörður. The terrac in the mountain slope is at the base of the Tjaldanes volcano strata. The Breiðhilla horizon is lower at the road track. Keldudalur is covered with thick debris layer from former debris covered glacier.

The Bolungavík tunnel under Óshlíð traverse through these sedimentary layers. The Breiðhilla sediments probably reach the shore in Keldudalur below the widespread thick debris cover (remains og former debris covered glaciers). In Arnarfjörður the Breiðhilla sedimentary horizon reaches sea level below Tóarfjall west from Svalvocar. (See drawings 2 and 3).

3.2 From the Breiðhilla horizon to the base of the Tjaldanes central volcano

On the top of the Breiðhilla horizon is about 150-200 m thick strata of basalt layers with thin sedimentary interbeds (similar to the interbeds below the Breiðhilla sediments). In Dýrafjörður, the basalt series mentioned above runs through the bottom part of Keldudalur and the top of the series reaches sea level below Arnarnúpur close to the farm Sveinseyri. On the western side of the peninsula, the basalt series mentioned above, extend along the shore from below Tóarfjall to the shore between Lokinhamradalur and Stapadalur.

3.3 The base of the Tjaldanes central volcano

At the upper margin of the basalt series described above, there are layers of irregular volcanic breccias and coarse grained sediments. The scoriaceous sediments are defined as the onset and the base of the central volcano, designated by the abandoned farm Tjaldanes in Arnarfjörður. The volcanic sediments are commonly 15-25 thick as they are seen in Keldunúpur, Hjallafjall (on the Dýrafjörður side) and south from Lokinhamrar on the Arnarfjörður side. Parts of these sediments consist of aerially transported tephra and volcanic bombs in addition to red scoria like distal parts of volcanic craters,

Fig. 4. Hafnarhyrna above Svalvogar, Scoriaceous red sediments at the base of the Thjaldanes central volcano. The cliffs consist of thin layered tholeiite in the flank of the central volcano.

3.4 The distal part of the central volcano towards NW.

The NW margin or slope of the central volcano are mainly characterised by thick rock series of what is named "central volcano tholeiite" which is formed by eruptions on the slopes of the central volcano. These tholeiite layers integrate here and there inbetween the layers of the regional basalts formed by eruptions through fissures on the plateau outside and around the main volcano. The main dip of the strata in the lower part of the volcano (traversing the mountain ridge from Þingeyri to Lokinhamrar), is mainly 6-8° towards sout-east.

3.5 The central part of the volcano

In the heads of the valleys Haukadalur, Kirkjubólsdalur and Meðaldalur (on the Dýrafjörður side) the alteration of bedrock increases very rapidly over a short distance and inclined cone sheets become common. The south slopes of Kirkjubólsdalur and the north slope of Tjaldanessdalur are crowded with continuous integrated cone sheets, pushing away the previous basalt strata. Several thick intrusions and thick dykes exist in Tjaldanessdalur with intense alteration resulting in colourful green and yellow rock. Around the core of the central volcanoe are widespread secondary minerals such as Iceland Spar which was excavated in the head of the valleys Meðaldalur and Kirkjubólsdalur in Dýrafjörður. The geomorphological shape of the mountains in the central volcano area is very different from the general shape of the mountains in NW peninsula, expressed by sharp mountain tops and relatively smooth shaped slopes in high contrast to the general flat topped mountains of the NW plateau. The inclination of the slopes is relatively uniform near 35-40°, with few prominent cliffs and different from the geomorphological landscape outside the central volcano.

Fig. 5. Tjaldanessdalur valley with the abandoned farm Tjaldanes on the right. The colourful rock is mainly of intrusions and inclined dykes. The thick debris in the valley floor are formed by debris covered glaciers during last glacial time, indicating very long period of ice free area in Arnarfjörður.

3.6 The east flank of the central volcano

The whole central volcano massif, is inclined towards south east. At several places at the top of the mountain there are visible unconformities with different dip of the lavas belonging to the volcano in contrast to the less dipping surrounding plateau basalt. This is rather striking in Hvammsdalur and in Hrafnseyrardalur and in Ánamúpi up from the farm Hrafnseyri. In some areas such as in the south side of Dýrafjörður, inwards from from the farm Hvammur, it is difficult to define the boundary between the volcano and the regional basalt as the layers from the volcano finger between the regional basalts. Probably the surface flank of the central volcano reaches sea level in Arnarfjörður between Karlsstaðir and Gljúfrá and in Dýrafjörður the top of the flank reaches sea level near Drangar. Thick sedimentary beds are common on the surface of the volcano and relict craters made of red scoria are found in the head of Hvammsdalur. Additionally, thick sedimentary layers are buried inside the flank of the central volcano like light coloured acidic tuffs which may be seen in Ausufjall between Hvammsdalur and Ketilseyri.

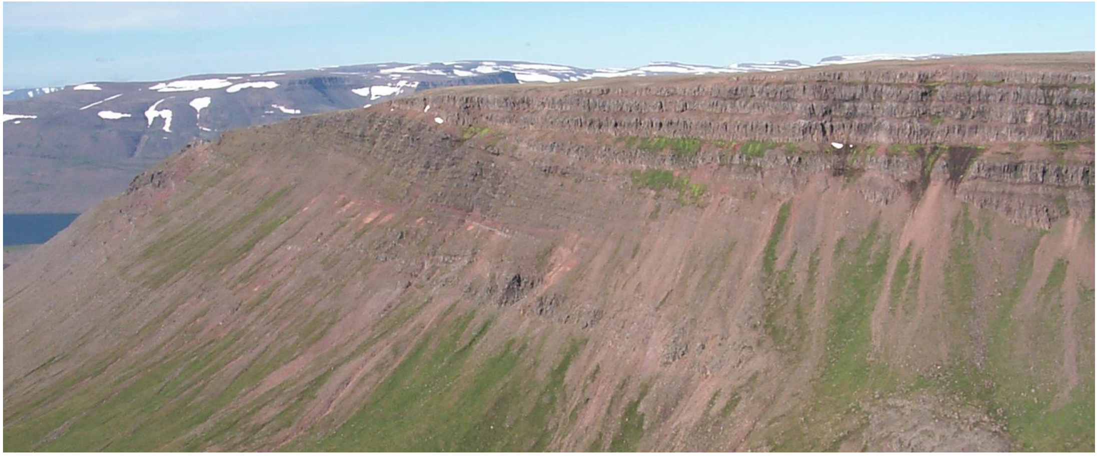

Fig. 6. The unconformity at the upper margin of the central volcano in the Hvammur valley at Ausufjall). Thick irregular sedimentary layers found lower in the strata, were probably formed in the Lambadalur central volcano. These sediments are probably traceable to Drangar.

Fig. 7. The unconformity at the top of the flank of underlying central volcano. The surface and the top layers of the volcano dip about 10°towards east but the regional plateau basalt dips about 3-4° towards south-east. Borgarfjörður in the distance.

3.7 The basalt plateau on the top of the central volcano

Eastwards from the flank of the central volcano exists a pile of regular basalt layers formed 12-14 million years ago and intercalated with frequent but thin sedimentary interbeds. The basalt is of three different basalt types, relatively equally distributed tholeiite- olivine- and porphyritic basalt. At sea level, the lava pile dips about 6° towards SE but at 300 m a.s.l the dip is below 5°. The tunnel alignment between Arnarfjörður and Dýrafjörður is located in the lowest part of this visible lava pile at a short distance from the flank of the central volcano. This part of the lava pile will be discussed further as we discuss geological conditions on the tunnel alignment.

Fig.8. The lava pile on the south shore of Dýrafjörður at Dýrafjarðarbrú bridge. Regular basalt layers dip 3-6° (reduced dip accompanying increasing altitude).

3.8 Tectonic lineaments, faults and dykes

There are many dykes between Arnarfjörður and Dýrafjörður but relatively few faults have been detected. There are several straight lineaments in the mountains, probably accompanying underlying dykes or other tectonic activity. The dykes are of very variable thickness and commonly composed of parallel vertical layers of repeated magma intrusion into the same tectonic lineament. Usually they are highly columnar jointed and likely to conduct water. The most common direction of dykes and tectonic joints is NE-SW but their directional rose diagram forms a wide sector. The largest vertical fault displacement was detected in Helgafell NW of Keldudalur. This fault is NE-SW trending with a 100 m subsidence on the NW side. Several faults with 20-40 m subsidence are in Dýrafjörður but very few and only small faults have been detected in Arnarfjörður. Here it must be expressed that it is very difficult to detect possible faults in large area within the central volcano.

Fig. 9. Composite dykes, (one hard forming a wall and the other soft forming ravine) crossing a series of tholeiite basalts in Tóarfjall west from Lokinhamrar.

4 Bedrock between the heads of Dýrafjörður and Arnarfjörður

Geological information was obtained by geological profiling and mapping including inspection of aerial photos. The main information on the bedrock east of Hrafnseyrarheiði, is shown on Drawings 6 and 7 at the end of this report. and on several geological profiles in appendix C. **Note that the text of the geological profiles of Appendix C is all in Icelandic.** Three cored boreholes were drilled and core logs are shown in Appendix A and photos of the cores are in Appendix B.

4.1 Geological profiles in Dýrafjörður

As the geological strata dips (sideways) from Dýrafjörður to Arnarfjörður the discussion starts in Dýrafjörður. Outcrops in th elowest part of this strata is in the river Hvallátursdalsá opposite the slope to Drangar (see geological profile 1 in Appendix C). The profile shows continuous pile of basalt layers with negligible interbeds some minor sediments could possibly be hidden at a few poor outcrops. The most common basalt type is porphyritic (of olivine basalt character) hard to break, (not brittle) with relatively large columnar pattern (0,5-2 m joint spacing).

Geological profile 2 is in the south slope of Dýrafjörður between Drangar and Botn, starting in two rock outcrops at 47 and 51 m a.s.l. Between or around these basalt outcrops we might suggest hidden thick sedimentary interbeds. From 70 m a.s.l. and continuously upwards, is a profile through competent basalt layers.

Fig. 10. The south shore in the head of Dýrafjörður with Drangar on the right. Geological profile 2 follows a brook in the far left of the photo and profile 3 is at Drangar, moving in the upper part towards profile 4 along a ridge yielding the main shadow into the corrie Bæjarhvilft.

Geological profile named Drangar (profile 3) is following a brook just north of the farm Drangar. The lowest outcrops start discontinuously at 40 m a.s.l. but are continuous at 50-90 m a.s.l. Above 90 m a.s.l is no outcrop over 7-9 m height interval, which probably hides sedimentary interbed, which is encountered in corehole DYR-01, located just north of the brook. Upwards from this hidden zone, at almost 100 m a.s.l. is a continuous section up to the base floor of Bæjarhvilft at

250 m a.s.l. From there one prominent layer was traced directly to the base of the next continuing section, profile 4 at Drangatindur

In the continuing geological profile 4 (Drangatindur profile) there are strong basalt layers at 250-420 m a.s.l. Most of them are porphyritic (with olivine basalt character) among a few tholeiite layers. Several very thin sedimentary interbeds exist in the profile in addition to two thicker sediments of orange acidic tuff. Both of these orange sediments are presumably higher in the strata than the tunnel alignment (will probably not traverse the tunnel).

In addition to the four profiles discussed above, more geological profiles were mapped in the area by Ágúst Guðmundsson and Jóhann Helgason in 1975 (McDougall et al. 1984). These profiles were (for example) in Lambadalur, in at Valseyri (not published) and at Kjaranstaðahorn. Additionally Ágúst has described profiles up Tindafjall above Grænanes and more widely around in Dýrafjörður to support tridimensional modelling of the strata.

4.2 Geological profiles in Arnarfjörður

Geological profile 7, starts along the stream Gljúfurá and continues east to the shoulder of the mountain and from there to the top above Hjallkárseyri. The basalts are of various types and commonly intercalated with sediments. In the upper part of the profile are two thick sedimentary beds but probably these are stratigraphically higher than the proposed tunnel route. These layers are nevertheless important as some kind of "marker horizons" through the mountains of the peninsula.

Fig. 11. Gljúfurá (to the left.) and Hjallkárseyri (green spot) in Arnarfjörður. The rock is of the same age as the strata at Rauðstaðir

Geological profile 6 is the mouth of Grjótárdalur where the electrical transmission line climbs up the mountain. The profile is not continuous, basalt outcrops at 60-70 m a.s.l. and then the next layer outcrops at 85 m a.s.l. where basalt layers (and some basaltic dykes) outcrop and continue up the slope beyond 200 m a.s.l. These layers are probably higher in the strata than the proposed tunnel route.

Geological profile 5 at Rauðsstaðir is located at a short distance east of the proposed tunnel portal and covers the bedrock strata from 120 m a.s.l up to 450 m a.s.l. All the layers of profile 5 are stratigraphically higher than the tunnel route but these are important as "marker horizons" between the two fjords. In addition to these profiles mentioned above, more profiles have been described at Mjólkár river and at Dynjandi river, supporting the general three dimensional structure of the strata.

In the uppermost parts of profile 4 in Drangafjall and in profile JB in Kjaranstaðahorn on the Dýrafjörður side and in profile 7 at Gljúfurá, section 5 at Rauðsstaðir and profile 8 at Mjólká, the geomagnetic polarity of the basalts change from normal polarity in the lower part to reverse polarity in the upper or higher part. This polarity reversal has also been traced to profile JC at Dynjandi and Urðarfjall. This polarity reversal in addition to two or three accompanying sedimentary interbeds is used as the most important marker horizon in connecting stratigraphically the bedrock between Dýrafjörður and Arnarfjörður. This boundary is at 560 m a.s.l. in Stórahvilft (east of Drangatindur) at 660 m a.s.l. in Kjaranstaðahorn, at 470 m a.s.l. in profile Gljúfrá (above Hjallkárseyri), at 410 m a.s.l. above Rauðsstaðir, at 230 m a.s.l. Mjólkár rivers and finally at 100 m a.s.l. at Dynjandi.

The profiles in Dýrafjörður do not show a complete sequence of the strata along the tunnel alignment as the rock series are thickening towards south (down dip thickening) where new lavas are added to the strata by regional volcanism of an eruptive zone, which was gradually drifting away, towards SSE. In the profiles at the head of the fjords at Botn, Drangafjall and Rauðsstaðir (profiles 4 and 5), porphyritic basalt and olivine basalt are the most prominent basalt types but in the sections further west, Profile JB in Kjaranstaðahorn and profile 7 at Gljúfrá, tholeiite basalt becomes more prominent. The tholeiite layers were erupted somewhere towards the west possibly on the flank of the Tjaldanes central volcano.

The geological profiles in Arnarfjörður are stratigraphically higher than the tunnel route and the profiles are described to establish geological connection of the layers between the fjords and they also show changes or a trend of different rock series in different directions or along the strike of the strata. Longitudinal geological sections along the tunnel alignment are shown on Drawings 6 and 7. As shown there, the geological conditions are unclear in the central part of the tunnel alignment.

4.3 Layer thicknesses in the profiles

During the description of the profiles the thickness of individual lavas were recorded. In the profiles the total thickness of the lava includes also the top and bottom scorias, unlike the measurements on core where the top scoria, the central part and the bottom scoria are measured separately. The average thickness of the basalt layers including the scoria is 11,5 m but the most common thickness of the lavas is in the range of 6-12 m as shown on fig. 12.

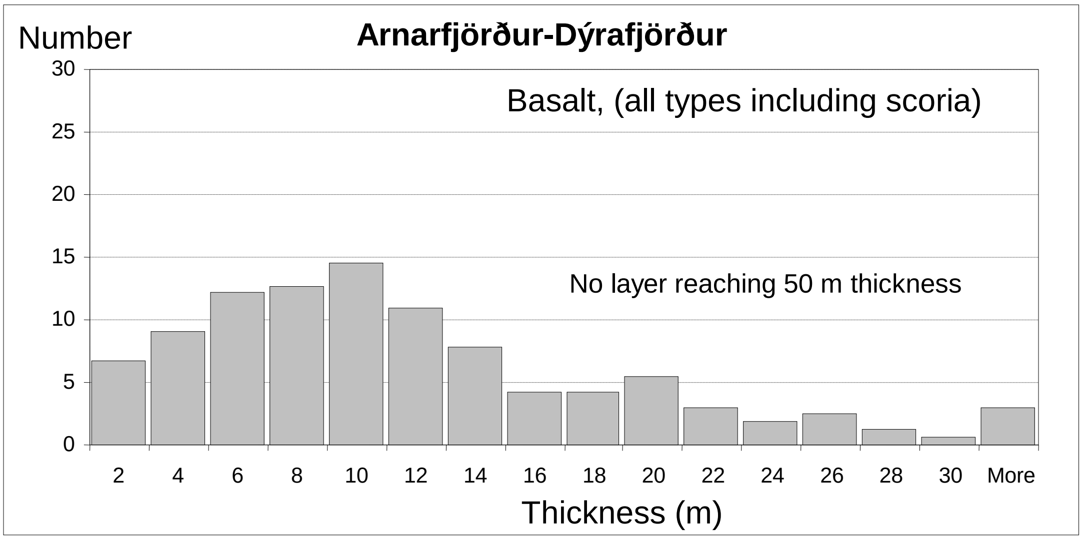

Fig. 12 . Histogram showing the distribution of thicknesses of 165 basalt layers encountered in the geological profiles in Arnarfjörður and Dýrafjörður. It must be expressed that on this histogram, the total thicknesses of basalt layersis shown, including top and bottom scoria (which normally some 15-30% of the whole basalt lava) About 50% of the basalt layers are porphyritic-basalt, 15% are tholeiite and 25% olivine-basalt.

The average thickness and thickness distribution on the tunnel alignment might be somehow different from what is shown on fig. 12 and fig. 13. as most of the geological profiles are stratigraphically higher- and also some of these are at considerable distance from the tunnel route. The average thickness of the sedimentary interbeds is 0,4 m and the frequency of sedimentary thicknesses is shown on fig. 13.

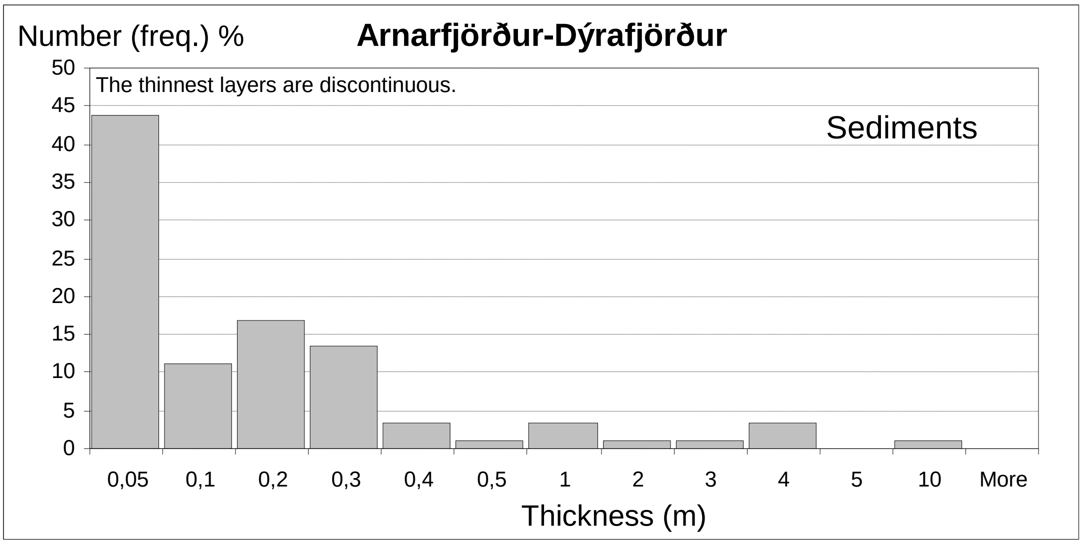

Fig. 13. Thickness distribution of sedimentary interbeds encountered in the stratigraphical geological profiles in Arnarfjörður and Dýrafjörður (based on 89 layers). The thinnest layers are commonly discontinuous.

4.4 Lithology of the rock

The tunnel alignment between Dýrafjörður and Arnarfjörður traverses a pile of basaltic layers intercalated with sediments. The properties of these rock types are discussed further.

4.4.1 The crystalline magmatic rock (Basalts).

The term basalt is used over the whole "eruptive lava", comprising the top scoria, the crystalline central part and the bottom scoria. Although it is obvious that these three parts look different and have different technical characters. (We are not discussing non scoria, vesicular layers such as olivinebasalt compound flows). Other types of magmatic eruptive rock, (such as intermediate and acidic) have not been detected near the tunnel alignment although these are found in the heads of Lambadalur, Önundarfjörður and Álftafjörður. Each lava flow may be divided into three parts as follows:

- The top scoria (often 10-30% of the lava flow thickness).
- The dense crystalline middle part (often 65-85% of the lava flow thickness).
- The bottom scoria (often 5-10% of the lava flow thickness).

The top scoria is to the uppermost portion of a lava flow, characterised by rapid cooling and brutal expansion of gas. The matrix of scoria is glassy (almost uncrystallised) and highly vesicular. The overall structure is chaotic, with large voids of any size (up to meters). When the subsequent deposition of sediments occurred, these voids were infiltrated and filled with sand and silt. Palagonitisation later cemented the sediment into a sandstone and gave the rock mass a relatively compact aspect. In cores, the top scoria often has the aspect of a matrix-supported breccia with scoria fragments. Scoria with sandstone matrix or infillings is predominant in the project area. The vesicles in the scoriaceous fragments are also often filled with secondary zeolites or calcite. Scoria is easy to recognize, due to its particular structure and due to its reddish to purple colour, which contrasts with the grey colour of the basalts.

The crystalline middle part consists of hard, dense basalt, light to dark-grey. The rock is usually affected by sub-vertical columnar jointing, resulting from the cooling of the lava. Further structural characteristics like flow banding, amygdales and joints are detailed further in this chapter.

The bottom scoria is most often relatively thin, well consolidated, sometimes containing sandstone fillings, mixed up from underlying sediments
The three parts show clearly different engineering properties; for this reason, the term "basalt" in this report is attributed to the dense part of the lava flows and the terms "scoria" and "brecciated scoria" to the outer parts of each flow.
Basically, there exist two basalt types, the **Tholeiite** and the **Olivine** basalt. Each of the two can develop a porphyritic structure, in which case it is designated **porphyritic** basalt. The characteristics of both Tholeiite and Olivine basalts are shown in the following synopsis.

Petrographically, basalts are of three types as defined by Walker [15]. The three types constitute poles between which complete transitions exist. For that reason the petrographic determination in the field may sometimes be subject to varying interpretation. Classification of the basalts is based partly on the determination of the amygdale-minerals, which reflect the composition of the rock.

Table 1. Comparison of typical characteristics of Tholeiite and Olivine basalt.

Comparison of typical characteristics of Tholeiite and Olivine basalt	
THOLEIITE	OLIVINE BASALT
Very fine grained	Coarser grained
Free olivine crystals are absent	Free olivine crystals visible
Total silica content: 48-50%	Total silica content: 46-48%
Weathered crust, pale brown	Weathered crust, dark brown to deep grey
Spheroidal weathering uncommon	Spheroidal weathering common
Amygdales rather without zeolites	Amygdales bear zeolites
Well developed flow structures	Less developed structures within flows
Micropores often arranged along sub-horizontal surfaces with spacing < 1 cm resulting in faint cleavage	Micropores randomly scattered throughout the mass
Scoriaceous part of tholeiite basalt flows: usually 20-30% of the flow thickness	Scoriaceous part of olivine basalt flows: usually 5-15 % of the flow thickness
Forms usually single lava flows	Forms both compound and single lava flows
Average thickness of lava flows: 11 m	Average thickness of lava flows: 10 m
Average width of columns: 2 m	Average width of columns: 1.5-2.0 m
Hardness of the dense matrix I to II*	Hardness of the dense matrix: II*
*Rebound hardness ISRM scale 1975	

The porphyritic basalt has the basic characteristics of one of the two types described above, with more than 5 % plagioclase (bytownite) phenocrysts. Phenocrysts of other minerals like Olivine and Augite may also occur in small amounts. When the amount of phenocrysts exceeds 7-10 %, the groundmass is usually of olivine basalt character.

4.4.2 Sedimentary interbeds

Sedimentary interbeds in the Icelandic Tertiary lava pile are mainly of three different types as described below. In the lava pile of the North-West peninsula we mainly have two sedimentary types, red or brown sandstone and red siltstone or claystone.

Red and red-brown, tuffaceous sandstones/siltstones, originally soils mixed with acidic and basaltic tephra and sometimes containing distinct tephra layers. These sediments often show a relatively high clay content (specially the acidic tuffs) and often disintegrate quickly when exposed to atmospheric weathering. Sedimentary interbeds of this type are widespread throughout the whole lava pile with a common thickness of 0.1-3 m.

Light yellowish brown and orange-brown, argillaceous tuffaceous sandstone-siltstone layers, formed of basaltic and acidic tephra frequently forming some 2-10 m thick interbeds in the bedrock of the Dýrafjörður-Arnarfjörður area. Altered acidic tuffs have been located only as rather few beds, but tuffs of that type are considered as very weak rock, actually among the weakest rock encountered in the tunnelling area. This is partly due to a swelling clay materials of montmorillonite type.

Conglomerates, sandstones and siltstones, is the third main type of sedimentary types found in the tertiary lava pile of Iceland. The matrix may be of different origin, both airborne and water transported tephra mixed with silt , stones and boulders formed by the erosion of previously sculptured and eroded surface of the land. These types of sediments are not very common in the lava pile of the NW-Iceland but among others found at the base of the Tjaldanes central volcano. This type of sediments have not been found near the Dýrafjörður tunnel alignment.

The average thickness of the mapped sedimentary interbeds in Dýrafjörður and Arnarfjörður is 0,4 m and most of the layers are in the range of 0,05-0,4 m thick. Only 6 layers were found thicker than 1 m as shown on histogram on fig. 13.

4.5 Tectonics

The word tectonics comprises all kinds of tectonic failures, joints related to stress, including faults and dykes in the bedrock. The inspection of tectonic lineaments from Arnarfjörður north to Ísafjarðardjúp was carried out by three methods. Firstly, by inspecting and mapping different aerial photographs. Secondly all dykes detected in the area were mapped. Thirdly all detected faults were mapped and their subsidence measured or from some distance estimated by comparing layer displacements at the faults.

Earlier before the geological work related to the tunnel preparation started some tectonic mapping had been carried out from Súgandafjörður north to Ísafjarðardjúp (some 25-30 km north from the tunnel area) and on the Arnarfjörður-Barðaströnd area (some 30-50 km) south of the proposed tunnel area.

4.5.1 Dip of strata

In the innermost part of Dýrafjörður there are 2-3 layers of porphyritic basalt forming a terrace around the head of the fjord. These porphyritic basalt series may be used as a marker horizon in connecting stratigraphical profiles and to evaluate the strike and dip of the strata. The layers are most prominent from Hvallátursdalsá river on the north shore, from there around the head of the fjord to Kjaranstaðahorn on the south side. In this area, at approximately 200 m a.s.l., the strata dips 5,5° towards SSE (150°). At 560 m a.s.l. in Drangafjall, and at 410 m a.s.l. at Rauðsstaðir there is a sedimentary "marker horizon" which dips 2,5° towards SSE. According to this, the dip of the strata increases about 1° every 100 m downwards in the lava pile. This is a slightly higher dip variation by altitude than encountered in Breiðadalsheiði near Ísafjörður where vertical dip variation is 0,6-0,8°/100 m.

4.5.2 Dykes

The frequency of dykes in the innermost parts of Dýrafjörður and Arnarfjörður are at some average when compared to regional basalt outside central volcanoes. The direction of the dykes trend mainly NE-SW. The dykes are generally composed of small horizontal columns and frequently composed of multiple thin vertical magma intrusions with relatively strong outer margins or a thin contact breccias. The thickness of the dykes varies from a few tens of cm up to about 10 m.

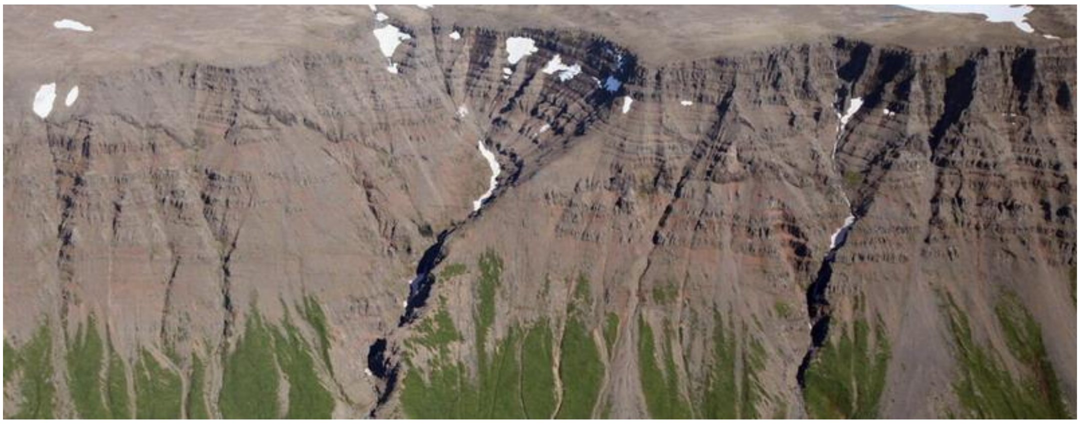

Fig. 14. The edge of the mountain ridge east of Rauðsstaðir The dykes and faults are mainly visible in the cliffs of mountain slopes but at lower altitude the slopes are covered with talus with very few scattered outcrops..

4.5.3 Faults

Several faults were detected in the slopes at the inner part of Dýrafjörður with vertical displacement in the range of 10-30 m. A directional rose diagram of the dykes and faults in the inner parts of Dýrafjörður and Arnarfjörður is shown on fig. 15. In addition to the visible faults and dykes there are widely dispersed lineaments which probably indicate tectonic with underlying dykes and faults.

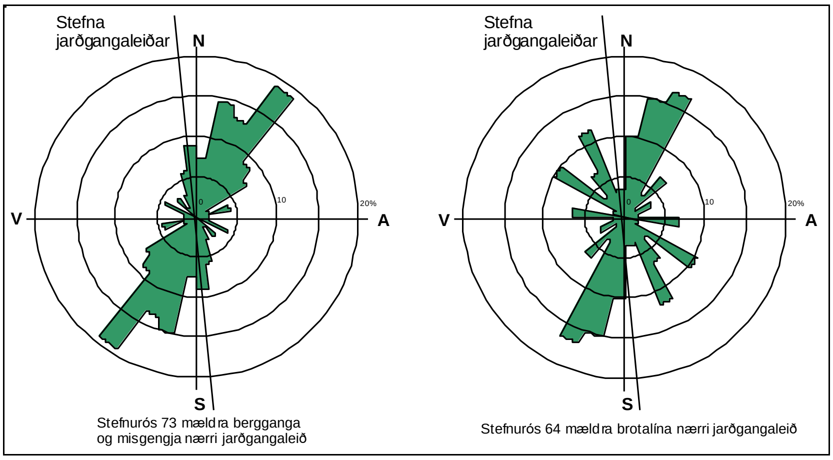

Fig. 15. Rose diagrams for dykes and faults near the tunnel alignment.

4.5.4 Alteration of the rock

The alteration of the bedrock at the innermost parts of Dýrafjörður and Arnarfjörður shows chabazite and thomsonite in the lower half of the slopes and here and there tiny analcime crystals are found at sea level. As olivine basalt and chemically related porphyritic basalt is in high ratio in the bedrock, secondary minerals are relatively abundant, decreasing the permeability of the bedrock. The alteration of the bedrock is lower compared to the Bolungavík tunnel but similar to the alteration in the Breiðadals and Botnsheiði tunnel.

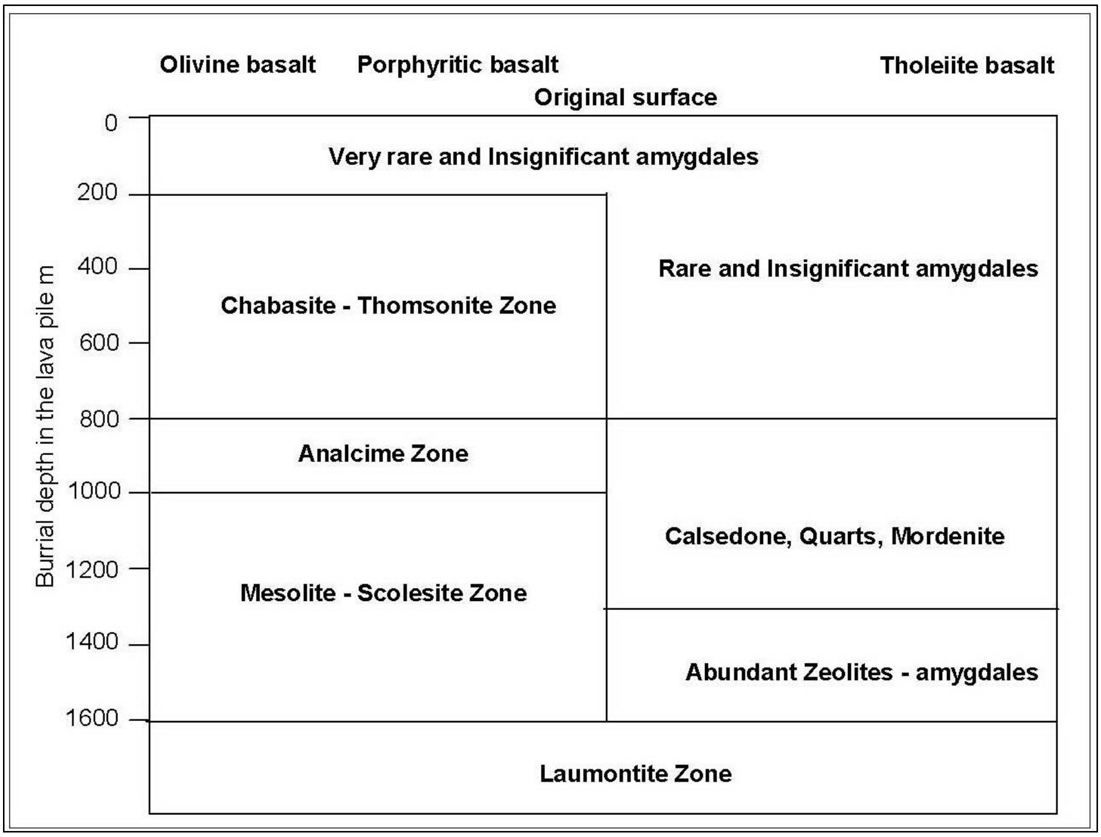

Fig. 16. The alteration schema for basaltic lava pile as established by G.P.L Walker. The tunnel alignment between Rauðsstaðir and Drangar is approximately at "800 m depth" in this alteration-depth chart which is near the top of the analcime zone.

5 Exploratory drillings

The exploratory drilling for the tunnelling project was carried out in September 2007. The main part of the work was drilling three cored boreholes, two on the Arnarfjörður side and one on the Dýrafjörður side. Additionally, a few tens of percussion holes were drilled to reveal the thickness of surficial sediments. The drilling contractor was ALVARR Reykjavík with subcontractor SMOY from Finland.

5.1 Core drilling

The drill rig was a small highly flexible electrically powered exploratory rig, which could be inclined practically towards most directions. The drilling rods were "Swedish NQ" thin wall yielding 50,2 mm core diameter. Two holes ARN-01 and ARN-02 are at Rauðsstaðir and one DYR at Drangar. The core was logged at good conditions in a large garage at Mjóklárvirkjun hydropower plant and in a large garage at Þingeyri. Core logs and descriptions, including PLI strength (point load tests) and rebound hardness values, are in Appendix A and photographs of core in Appendix B. Summary of the core drilling data is in table 2.

Table 2. Overview over core drilling in Arnarfjörður and Dýrafjörður 2006.

Hole	**East**	**North**	**Elev. ma.s.l.**	**Depth [m]**	Depth to rock / Casing [m]	Incl.	Direct	PLT [No.]	SHT [No.]	Perm tests [No.]
ARN-01	306863,1	594236,9	95,97	314,80	11 / 12	19°	N	58	52	5
ARN-02	307454,2	594278,9	80,81	76,80	9 / 10	~ 45°	N	10	11	1,5
DYR-01	306865,0	599282,5	126,93	105,60	5 / 6	~ 45°	S	15	15	2,5

Notes: NC = Inclination, PLT = Point Load Test, SHT = Schmidt Hammer Test. Perm tests = Permeability tests.

5.1.1 Thicknesses of rock layers in the boreholes

An overview over thickness distribution of rock layers in the boreholes is in table 3 and on histogram on fig. 17. Most of the basalt layers are 5-15 m thick and basalt scoria (scoriaceous basalt) 0,5-5 m thick. Most of the sedimentary interbeds are less than 2 m thick. The thickness distribution of the sediments is shown on fig. 18. The average thickness of rock layers (basalts and sediments) along the tunnel alignment might be different from what is encountered in the boreholes, as the boreholes have different "weight or importance" regarding the geology along tunnel route.

Tafla 3. Overview over rock layers in the boreholes of Arnarfjörður and Dýrafjörður 2006.

Hole	Thickness numbers			Number of rock layers			Average thickness of rock		
	Basalt	Scoria	Sediment	Basalt	Scoria	Sediment	Basalt	Scoria	Sediment
	[m]	[m]	[m]	[No.]	[No.]	[No.]	[m]	[m]	[m]
ARN-01	267,90	17,06	2,55	20	5	8	13,40	3,41	0,32
ARN-02	47,45	0,00	0,21	5	0	1	9,49	0	0,21
DYR-01	60,32	0,25	10,22	6	1	3	10,05	0,25	3,41
All holes	375,67	17,31	12,98	31	6	12	12,12	2,88	1,08

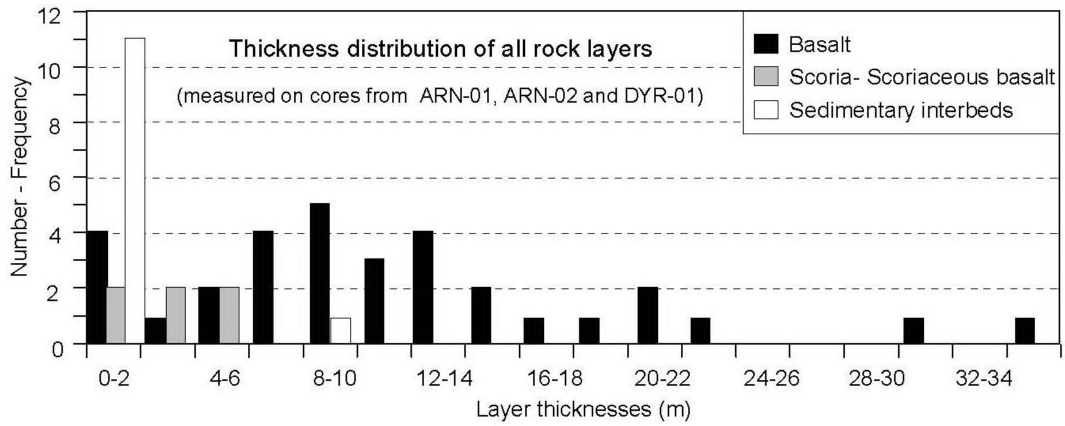

Fig. 17. Thickness distribution of the rock layers in cored boreholes in Arnarfjörður and Dýrafjörður. In the boreholes the layer scoria is measured separately, but in the profiles the total thickness of basalt, includes the scoriaceous part, (which is normally irregularly involved in the upper part of the basalt layers).

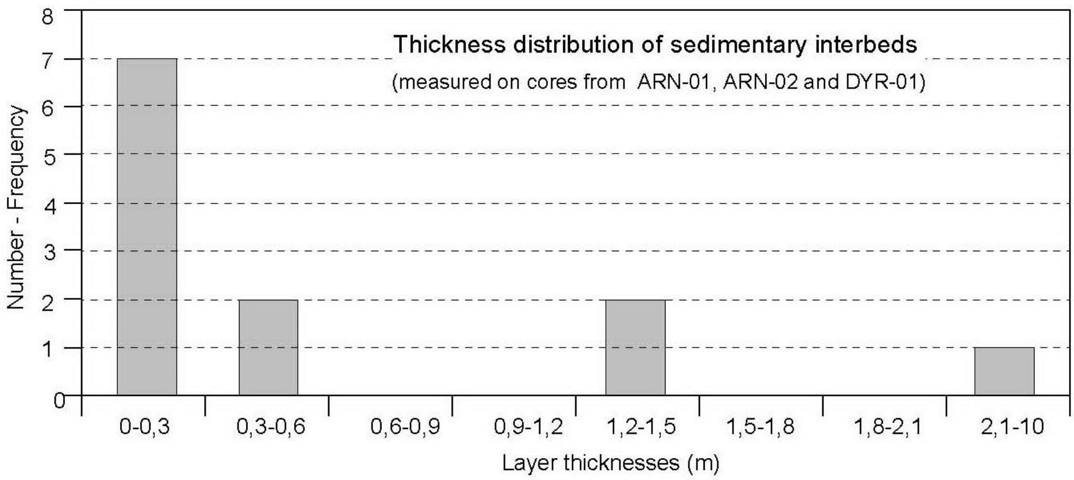

Fig. 18. Distributio of thickness of sedimentary interbeds in the boreholes in Arnarfjörður and Dýrafjörður. There are only 12 sedimentary layers and 11 of them are thinner than 2 m and only one layer is about 8,5 m thick.

5.1.2 Permeability tests in the boreholes

The permeability tests in the boreholes was carried out by single packer method where water is pumped through a packer which was installed at different depths in the holes. Water flow and pressure were recorded. The packer used in this drilling campaign was choking the hole by inserting different lengths and number of open rods in front of the packer and pushed to the bottom of the hole. This compresses the packer before the water is pumped through and water flow and pressure recorded. There is some possibility that high permeability values in borehole ARN-02 were related to possible problems with packing the hole but there are open joints visible in the core which might explain the high permeability values.

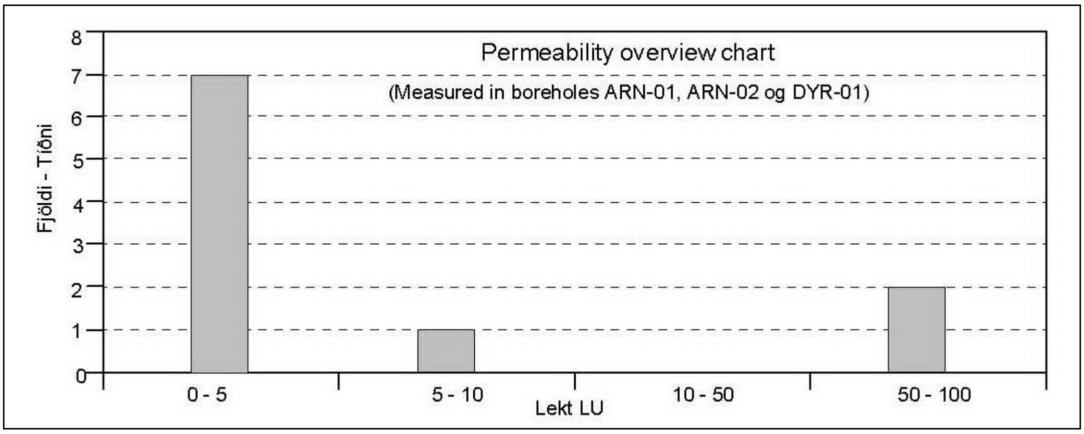

Fig. 19. Histogram showing distribution of permeability in LU values in the values. The highest permeability was recorded in borehole ARN-02 in Arnarfjörður.

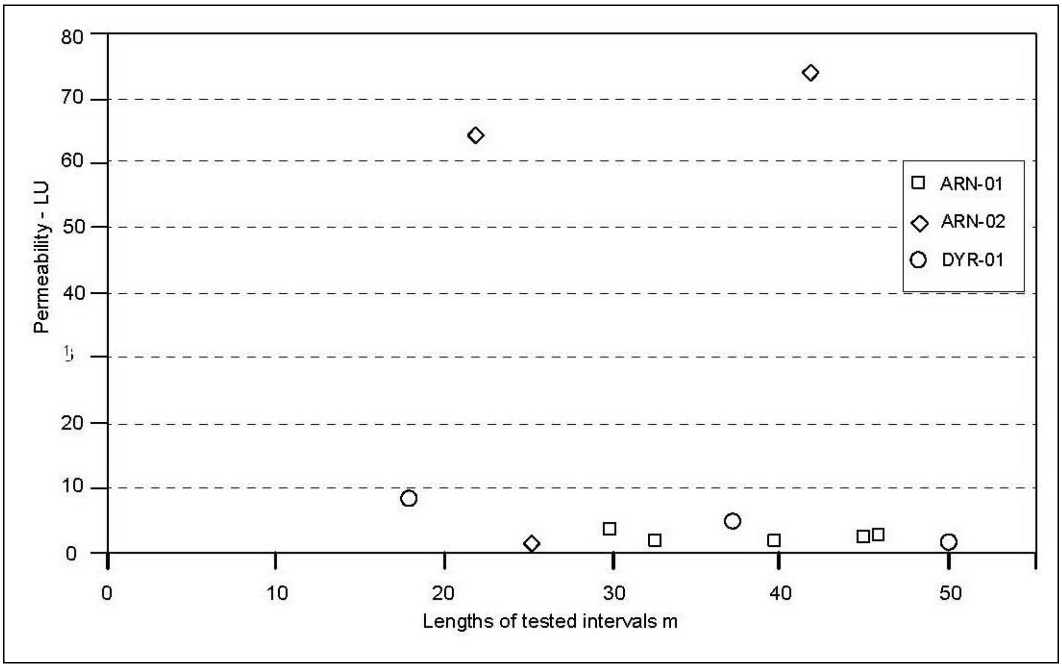

Fig. 20. Permeability values versus lengths of tested intervals in boreholes.

5.1.3 Frequency of joints and RQD (rock quality designation) of the core.

During the core logging the lithology of the core material is described including measurements on core recovery and description of joints, including secondary minerals in voids of the rock. In addition to core recovery, the RQD) joint spacing of the rock is cumulative recording for core stumps longer than 10 cm, 30 cm, 50 cm and 100 cm. These measurements are shown on the core logs and indicate the "competence" of the rock. An overview over core recovery and RQD is shown in table 4.

Table 4. Overview of core recovery, RQD and ratio of different rock types of the core from the boreholes in Arnarfjörður and Dýrafjörður 2006.

Core recovery %				
Hole	Average core recovery (%)	Basalt (%)	Scoriaceous (%)	Setberg (%)
ARN-01	99	99	95	99
ARN-02	92	92	-	88
DYR-01	94	98	100	69
Allar holur	97	98	95	74
Average RQD				
Hole	RQD10 (%)	RQD30 (%)	RQD50 (%)	RQD100 (%)
ARN-01	79	54	39	19
ARN-02	62	27	8	0
DYR-01	63	38	19	3
Allar holur	73	47	30	13
Basalt				
Hole	RQD10 (%)	RQD30 (%)	RQD50 (%)	RQD100 (%)
ARN-01	79	55	39	19
ARN-02	62	27	8	0
DYR-01	73	44	22	4
Allar holur	75	48	31	13
Scoria - scoriaceous rock				
Hole	RQD10 (%)	RQD30 (%)	RQD50 (%)	RQD100 (%)
ARN-01	78	59	48	15
ARN-02	0	0	0	0
DYR-01	63	0	0	0
Allar holur	77	58	47	15
Sedimentary interbeds				
Hole	RQD10 (%)	RQD30 (%)	RQD50 (%)	RQD100 (%)
ARN-01	52	14	0	0
ARN-02	37	0	0	0
DYR-01	2	0	0	0
Allar holur	10	2	0	0

5.1.4 Rock mass quality – Q-evaluation

The Q-value system has been used to evaluate conditions for large structures in rock in Iceland since around 1980-1985. The system has mainly been used to evaluate the "quality" of a rockmass for tunnelling and other underground structures both for road tunnels and the hydro sector (tunnels and dams) and also for evaluating rock quarries producing armour stones for dykes and dams.

The following description is from the Norwegian NGI handbook.

The Q- value gives a description of the rock mass stability of underground openings in jointed rock masses. High Q-values indicates good rock stability and low values means poor stability. Based on 6 parameters the Q- value using the following equation:

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

$RQD_{10,}$ =Degree of jointing (Rock Quality Designation (e.g. cores over 10 cm length)

J_n = number of joint sets $\quad$ J_r = Joint roughness number

J_a = Joint alteration number $\quad$ J_w = Joint water reduction factor

SRF = Stress Reduction Factor

RQD / J_n Degree of jointing (or block size)

J_r / J_a Joint friction (inter block shear strength)

J_w /SRF Active stress

Table 4. Commonly used parameters at the evaluation of the Q-values of Icelandic basaltic rock series

Classification of different rock units			Commonly used parameters of Q-system					
No.	Rock type	Description	RQD	Jn	Jr	Ja	Jw*	SRF**
1	Basalt	Hard, large and medium columnar jointed	70-100	9-10	2-3	2-3	1	1
2	Basalt	Hard, small columnar jointed (< 15 cm)	40-70	9-10	2-3	2-3	1	1
3	Basalt	Scoriaceous, competent	50-100	9-10	2-4	2-3	1	1
4	Basalt	Highly altered	50-100	9-10	2-4	2-4	1	1
5	Basalt	Heavily jointed	< 40	12-15	2-3	2-4	1	1
6	Scoriaceo.	Scoriaceous - well consolidated	50-100	6-10	2-4	2-3	1	1
7	Scoria	Poorly cemented (loose) with soft sed. fill.	<50	9-20	1-4	2-4	1	1/2,5/5
8	Sed. rock	Competent sandstone and siltstone	50-100	6-9	1-2	3-4	1	1
9	Sed. rock	Incompetent sandstone and siltstone (soft)	<50	6-9	1-2	3-4	1	1/2,5/5
10	Breccias	Fault breccias of different consolidation	<50	15-20	1	3-8	1	1/2,5/5
*Regarding water, start with the value of 1								
**Regarding SRF, generally use 1 for the Q-values of core material. Use other parameters as structures are designed. For very weak rock, use 2,5 of 5 for Q-evaluation of core material.								

Qc- (values for evaluating core material) shown on the core logs is the rock mass evaluated for the core material and these generally shows higher values than Q-evaluation in a drill and a blast tunnel. The difference between Q-value evaluated in a blasted tunnel might be some 2-4 times lower compared to the Q- value evaluated on the core material. Common values in table 4.7 were mainly adopted during the excavation of the Hvalfjörður subsea tunnel SW Iceland 1995-1997 and for the

Sultartangi Hydropower tunnel 1998-1999 and have since then been used during investigations for several other younger tunnels.

5.1.5 Measured rock strength and rebound hardness

The cored material was measured, logged and tested for breaking strength with Point Load Tester (PLT) according to ASTM D 5731-02. The results of the PLI values are on borehole logs and the distribution of values is shown on histogram on fig. 21. The most common PLI values of the basalts are in the range of 8-10 MPa and the values of the scoria-scoriaceous basalt shows 1-3 MPa..

Diameter of the core is 50,2 mm. Calculated "Apparent Uniaxial Compressive Strength (Apparent UCS) is shown on the Borehole logs in Appendix A. Numerous PLI Is50 values have been compared to UCS test values carried out in laboratory and based on numerous projects by Mannvit and Jarðfræðistofan 2009 the formula; 11 x $(PLI)^{1,2}$ has been adopted for correlating PLI values to Apparent UCS. In this report the PLI value is multiplied by the 11 x $(PLI)^{1,2}$ formula to read Apparent UCS. The most common "Apparent UCS values" of the basalt is 150-200 MPa and apparent UCS values of thescoriaceous basalt are mainly 20-80 MPa.

The sedimentary beds are normally of lower strength than makes possible to test them with the PLT (Point Load Tester). Several attempts were made to measure with PLT the strength of the thick sediment in the upper part of borehole DYR-01 but without success as the sediments crumbled down. The same happened if attempts were made to use Schmidt Hammer Test on the sediments. In such cases, the sedimentary rock crumbled down.

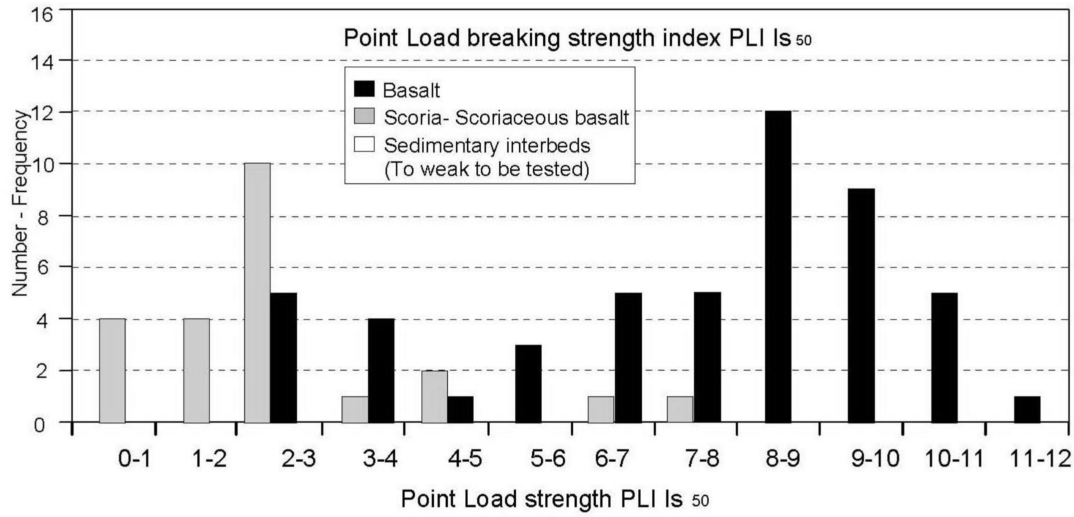

Fig. 21. Point load strength (MPa) of the rock core from the boreholes in Arnarfjörður and Dýrafjörður.

The rebound hardness of the cored rock was tested using Schmidt hammer, comparable tool as used to record the hardness of concrete according to ASTM D 5873-00. The rebound hardness of hardened concrete is commonly around 30. The main results of the "rebound hardness" is shown on fig. 22. No rebound hardness values were obtained for the sedimentary rock as the sediments were too weak to be tested (only two samples of sed mixed with scoria were strong enough to be tested).

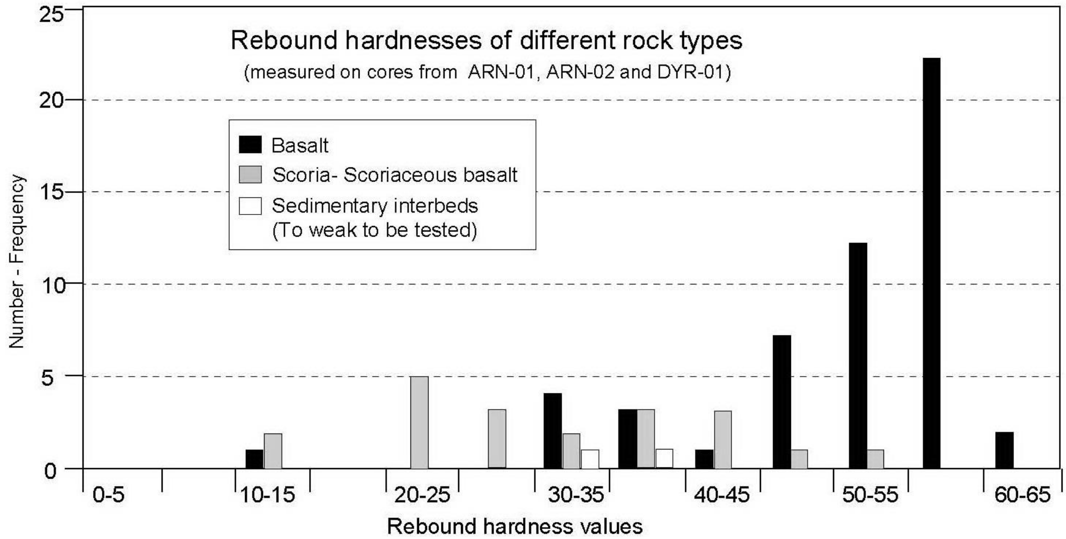

Fig. 22. Rebound hardness as tested on cores from boreholes in Arnarfjörður and Dýrafjörður 2006.

Correlation between the rock strength PLI values and rebound hardness of the cores is shown on a scatter diagram on figure 23.

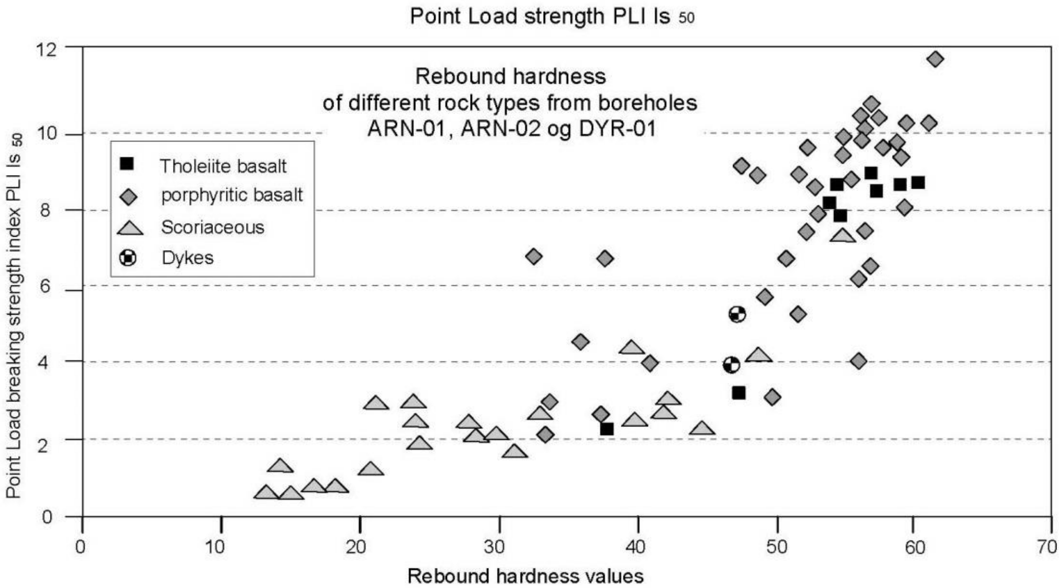

Fig. 23. Scatter diagram expressing the relationship of Point Load Index PLI values versus rebound hardness of cores from the boreholes in Arnarfjörður and Dýrafjörður 2006.

When calculating rock strength tested with a Point Load Tester, traditionally the point Load value PLI - Is50 was multiplied with a factor of 22 to convert the value to Apparent UCS as was suggested by ISRM. In the year 2009, numerous PLI Is_{50} values from different projects in Iceland over more than 40 years were analysed and compared with Unconfined Compressive Strength UCS from the same projects. In addition, a considerable number of UCS test were carried out in laboratory and compared to PLI values of the same rock. Based on this work by Mannvit and Jarðfræðistofan 2009 the formula; 11 x $(PLI)^{1,2}$ has been adopted for correlating PLI values to Apparent UCS.

In this report the PLI value is multiplied by the 11 x $(PLI)^{1,2}$ formula to read Apparent UCS. Fig. 24 shows the results of UCS values of cores from the project tested in the laboratory of Mannvit and compared to the PLI results on the same cores from the core logging for the project in 2006.

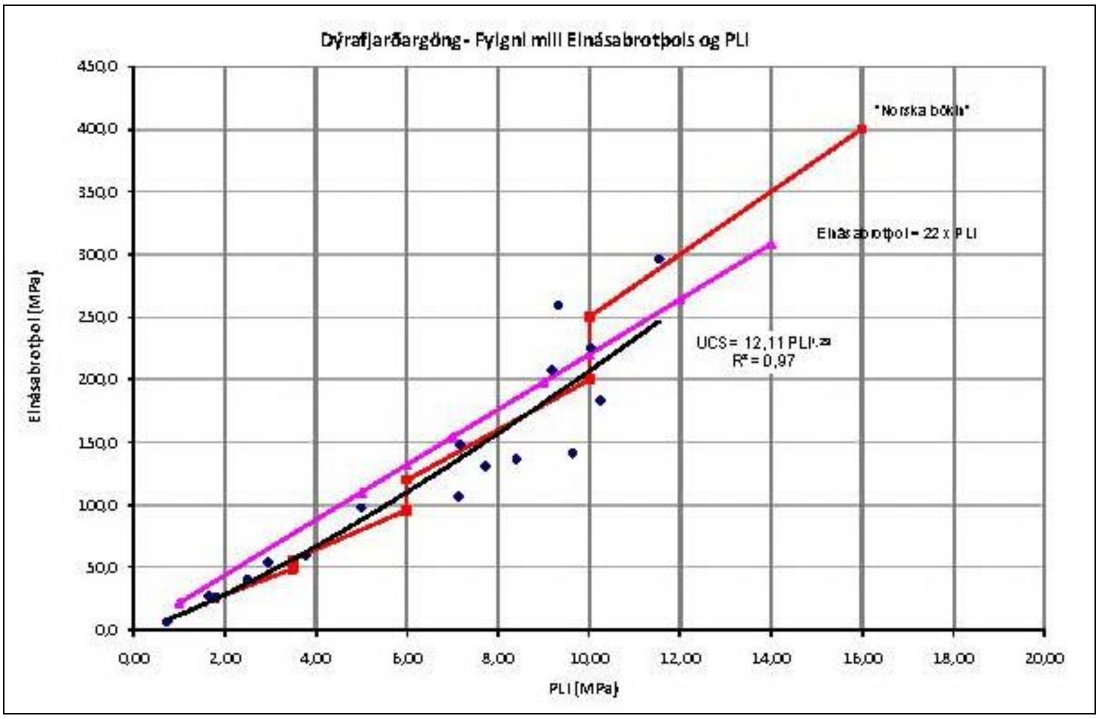

Fig. 24. Scatter diagram showing the correlation between the values of Unconfined Compressive Strength UCS versus the Point Load Index PLI tested with Point Load Tester. The UCS strength was tested in the laboratory of Mannvit.

5.2 Description of the corehoes

Corehole ARN-01 is located at El. 95,6 m a.s.l. was drilled 19° (from vertical) inclined towards the slope on a large fluvial debris cone just north from Rauðstaðir. The hole is 315 m deep and was supposed to traverse some dykes, seen higher in the slope.

Fig. 25. Drilling upper part of borehole ARN-01 during windy period.

The core from borehole ARN-01 shows very competent basalt layers intercalated with a few 0,1-0,3 m thick red sandstone layers in addition to a basaltic dyke at 112-134 m depth. Five permeability tests were performed in the hole revealing low permeability (below 3 LU) of both the basalt strata and the dykes. The rock in the lower half of the hole is of very low end extremely low permeability (see core log in Appendix A).

Fig. 26. Drilling borehole ARN-02 45° inclined towards the slope.

Corehole ARN-02 is located in a shallow depression on the SW side of the debris cone north from Rauðstaðir and very close to the tunnel alignment. The hole is 77 m deep, drilled 45° inclined towards the slope. At 10-22 m depth, there is one highly jointed basalt layer but below are several competent basalt layers. Only one interbed of sandstone exists in the borehole. The layered bedrock penetrated in the boreholes in Arnarfjörður extends upwards towards north along the tunnel alignment. The layers found in the deepest part of the holes in Arnarfjörður will rise up to the central part of the tunnel and will not reach the portal area in Dýrafjörður.

Two attempts were made to measure permeability (Lugeon packer test) in borehole ARN-02. The rock seems to be of high permeability but possibly the packing in the borehole was not successful. All water pumped into the borehole disappeared > 200 lit./min without raising any pressure in the pumping circuit. Possibly there is a core loss and open joint at 58 m depth in the borehole and another core loss and open joint is found at 47 m depth.

Corehole DYR-01 is at the portal at Drangar, drilled 45° inclined towards the slope from 127m a.s.l. The hole is 106 m deep starting in bedrock at 5 m depth and cased down to 6 m depth. Highly jointed basalt is from the rock surface down to 22 m depth. At 22-34 m depth, the hole crosses red and orange sediment of very low strength. The sediment breaks up and erodes partly during drilling and is too weak to be tested with PLT instrument. Below the sediment, the hole crosses 6 m through porphyritic basalt and 2 m through a basaltic dyke and then through 2 m of brown very weak sediment. From 44 m depth down to the bottom, the hole crosses strong basalt layers.

Fig. 27. Drilling borehole DYR-01, 45° inclined towards the slope, above the old farm Drangar.

Fig. 28. Sedimentary interbed in borehole DYR-01. The layer is almost 10 m thick and another sediment, less than 2 m thick, is a bit lower in the hole.

5.3 Percussion drilling

Percussion drilling using odex hammer and casing was used to reveal the thickness of surficial layers and depth to the bedrock, both at Rauðsstaðir and Drangar. The drill rig was on tracks but the compressor was separately towed around with a large tractor (see photo).

Fig. 29. Percussion drilling in the portal area at Rauðsstaðir.

Eleven percussion boreholes were drilled at Rauðsstaðir, a total of 82,4 m. The depth to solid bedrock in most of the holes was 6-8 m. Overview over percussion drillholes, location and depth is shown in table 6. Further description is on hole logs in Appendix C.

Table 6. Overview over percussion drilling at Rauðsstaðir.

Percussion drilling at Rauðsstaðir in Arnarfjörður					
Hole	East	North	Elevation m a.s.l.	Depth m	Depth to bedrock m
AL-1	307590,5	594160,7	46,9	7,35	6,75
AL-2	307657,8	594194,2	49,6	8,60	8,00
AL-3	307635,5	594245,9	62,3	9,00	8,50
AL-4	307564,2	594209,2	57,7	6,40	6,00
AL-5	307485,3	594179,6	55,8	8,60	6,00
AL-6	307539,7	594127,6	43,3	7,50	6,00
AL-7	307553,6	594074,1	32,6	5,75	5,50
AL-8	307466,9	594060,3	34,1	7,50	5,25
AL-9	307450,2	594119,6	44,4	5,40	4,25
AL-10	307517,4	594027,9	27,5	8,50	8,00
AL-11	307653,7	594121,0	34,9	7,80	7,00

At Drangar, five percussion boreholes were drilled, a total of 68,6 m. The depth to the bedrock was in the range of 3-7 m. Overview over percussion drillholes, location and depth is shown in table 7. Further description is on hole logs in Appendix C.

Table 7. Overview over percussion drilling at Drangar.

Percussion drilling at Drangar in a í Dýrafjörður					
Hole	East	North	Elevation m a.s.l.	Depth m	Depth to bedrock m
DL-1	306725,1	599537,5	62,2	8,00	4,3
DL-2	306765,3	599542,0	59,6	8,50	6,0
DL-3	307007,0	599323,6	110,4	17,60	6,0
DL-4	307085,5	599291,2	118,3	21,75	3,0
DL-5	307100,4	599342,5	104,4	12,75	7,4

6 Tunnelling condition between Rauðsstaðir and Drangar

The discussion about geological conditions along the tunnel alignment is the interpretation done by the main author of this report. The tunnel route between Rauðsstaðir and Drangar is 5,6 km long, including approximately 300 m long portals on both ends. The following interpretation by the author is mainly based on geological profiles in the area and cored boreholes in addition to the results of exploratory drilling 2006.

6.1 The tunnel portal at Rauðsstaðir

The portal at Rauðsstaðir in Arnarfjörður will be at approximately 35 m a.s.l. At the base of the slope, the area is covered with inclined peat intergrated with talus and debris layers. The thickness and nature of the surficial sediments was investigated with percussion drilling in addition to test pits. The results of percussion drilling are on the logs in Appendix C and the test pits in Appendix D. Location map showing the boreholes and pits in addition to the road and tunnel alignment is shown on drawings 8 and 9.

Fig. 30. A view towards the proposed portal area in Arnarfjörður (arrow). The ruins of Rauðstaðir are to the right of the arrow, in line beyond the straight part of the road.

The percussion drilling at Rauðsstaðir revealed 5-8 m thick surficial sediments covering the bedrock. The test pits revealed wet soil mixed with peat on the top of thin glacial moraine and debris. The test pits were excavated in the middle of July 2007, following several weeks of dry period but despite of this the soil and underlying sediments were very wet. Wet soil commonly exists in the lower slopes of the NW-peninsula. The excavation of surficial sediments might be cumbersome and (prior to the main excavation) excavation of ditches for draining the area might nitigate soil and debris creep. The core boreholes in the area indicate competent bedrock with insignificant sedimentary interbeds, both in the open excavations and inside the tunnel portal.

6.2 Conditions on the tunnel route traversing the mountain

The tunnel route inside the proposed portal at Rauðstaðir will most probably traverse strong basalt layers intercalated with thin sedimentary interbeds. The presence of several dykes crossing the tunnel route will locally lower the tunnelling rock quality. On the whole tunnel length, some 20-30 basalt layers (including the scoriaceous parts) might be expected. The cores of boreholes ARN-01 and ARN-02 are considered representative for the bedrock along the major part of the tunnel alignment (excluding dyke- and fault- zones). The borehole cores show competent basalt intercalated with a few thin interbeds of red and brownish sand- and silt-stone sediments. An overview photo showing the core from borehole ARN-01 is on fig. 30 but core logs are in Appendix A and photographs of the cores in Appendix B.

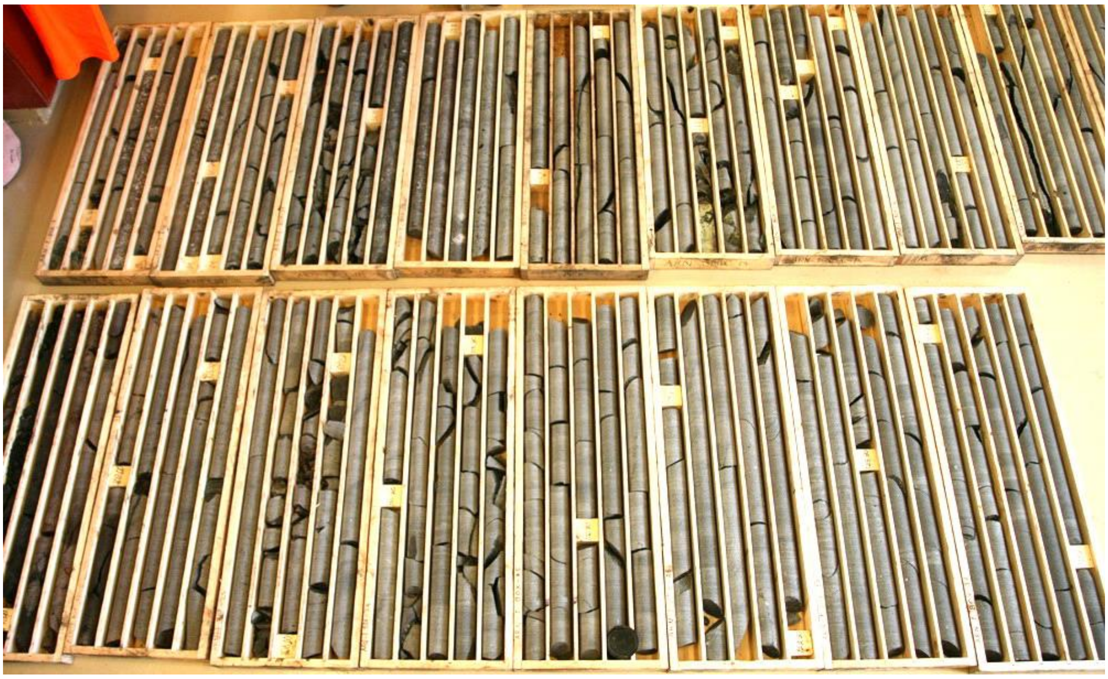

Fig. 31. Overview photo of strong cored rock from borehole ARN-01

Fig. 32. Thin argillaceous sediments of very low strength may lead to local and irregular overbreaks in the tunnel cross section (mainly in the roof and shoulders and sometimes in the walls). Here is an example of thin sediment causing considerable overbreak (photo from Búðarháls tunnel).

In the boreholes at both ends of the tunnel and in the stratigraphical profiles in the nearby area are 12 sedimentary beds where seven of these are < 0.3 m thick and two are 0,3-0,6 m thick. Two more sediments are 1,2-1,5 m thick and finally there is one 8,5 m thick sedimentary layer near the portal at Drangar. The whole tunnel length will supposedly traverse at minimum 7-10 sedimentary beds. Most of the sediments have very low breaking strength and some of them might swell and these characteristics normally result in some difficulties during tunnelling in Icelandic rock.

The permeability tests show relatively low primary permeability where amygdales and other secondary minerals are found. In the few locations where faults are seen, the fault breccias seems to be rather competent and water inflow or some rock collapse seems unlikely. On aerial photos, water seepage and small springs seem to be relatively common in the heads of the fjords above altitude 400-500 m a.s.l. These water seepages and springs, indicate considerable permeability in the upper part of the mountains (where the rock is fresh and without secondary minerals). The area of possible water "reservoir" above the tunnel is small and possible inflow from this water into the tunnel, should decrease rapidly with time (in days or weeks).

Several dykes with E-W direction are visible in the slopes of Arnarfjörður near Rauðsstaðir and more of this kind may be expected further inside the mountain. Such dykes might conduct water from the Gláma highland where considerable water storage might be expected in the rock of low alteration and high primary permeability. Very few tectonic joints with N-S trend have been seen near the tunnel alignment. Possible inflow of water into the tunnel will probably mainly follow dykes and faults but the amount of water is questionable.

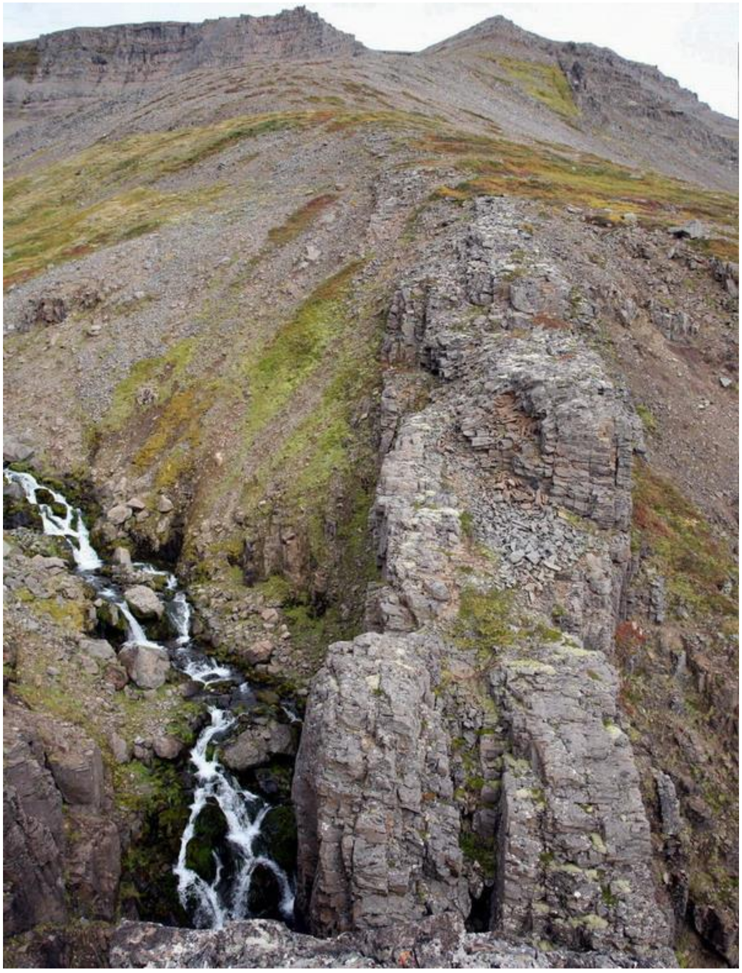

Fig. 33. Composite dyke in the creek of Grjótá at a short distance west of the portal area. Composite dykes of small columnar sheets often conduct water easily.

Fig. 34. Dykes in the upper slopes of the mountain in Arnarfjörður near Rauðstaðir.

Borehole DYR-01 indicates the ratio and thickneses of the rock types in the northernmost part of the tunnel route. Probably we have some 1,5-2 km long interval in the tunnel, where geological information can not be read from existing boreholes. In this part of the tunnel, information from the geological profiles must be projected into the tunnel alignment and as the outcrops in the profiles are not always continuous, some unexpected sedimentary layers (not seen in profiles), might be encountered on the tunnel route.

Near the north end of the tunnel alignment inside the portal at Drangar, the tunnel will traverse a 8-10 m thick sedimentary interbed of light orange-yellowish brown argillaceous sandstone of very low breaking strength. The sediment is too weak to be tested with Point Load Tester and obviously the UCS is below 10 MPa.

Fig. 35. Example of difficulties and large overbreakes when excavated through very weak or swelling sediments. (photo from the Búðarháls tunnel).

Sediments, similar to these found in DYR-01 but from other areas such as Bolungavik tunnel, Norðfjörður tunnel and Vaðlaheiði tunnel, have been tested in the laboratory of Mannvit Engineering. The tests reveal that tensile strength of this kind of sediments is only some 8% (+/- 2%) of their compressive strength (UCS). The result of such a low tensile strength leads to failures and downfall of sediments from the roof and shoulders where the the sediments cannot support their own weight. This must be mitigated with intensive rock support such as rock bolts, shotcrete and reinforced shotcrete arches. Some of the sediments were swelling (highest swelling pressure recorded was > 400 kPa.

The 8-10 m thick sedimentary interbed in corehole DYR-01 is nowhere seen near the borehole, the talus and debris covering in the slopes exclude all possible outcrops and also the sediment is of variable thickness from one place to another in the area. The variable thickness may be seen in the mountains Ausufjall and Tindafjall several km from the portal. The bedrock around the tunnel alignment at Drangar is of relatively low permeability and in addition tuffaceous sediments in the strata will normally act as some kind of water screen or umbrella above the tunnel.

Fig. 36. An example of tunnel support when crossing very weak sediments Near the face are reinforced arches of shotcrete and wire gauge or supporting net. The photo is from the Norðfjörður tunnel (Photograph ÓÖÓ)

Fig. 37. Example of collapse and overbreake, in very weak sedimentary layers. In the distance are shotcrete arches (Bolungavík tunnel).

6.3 The portal area at Drangar

At Drangar in Dýrafjörður the contact of the tunnel and the portal will be at 70 m a.s.l. (see location map and longitudinal section on drawings 10 and 11. Five percussion boreholes were drilled in the portal area in the autumn 2006 and additionally nine test pits were excavated in July 2007. The percussion boreholes and the test pits (see Appendices D and E) show 3-5 m thick surficial sediments. The surficial material is mainly sandy (relatively stable during excavation) but also there are smaller areas of silty material (relatively unstable during excavation). The bedrock nearest to the portal is "sound" and competent but approximately 300 m inside the portal, thick, very weak argillaceous sediments are predicted.

Fig. 38. The proposed north portal of the Dýrafjörður tunnel will be on the right side of the double creek, slightly higher than the existing road.

Fig. 39. Overview over the north portal of Dýrafjarðargöng at Drangar.

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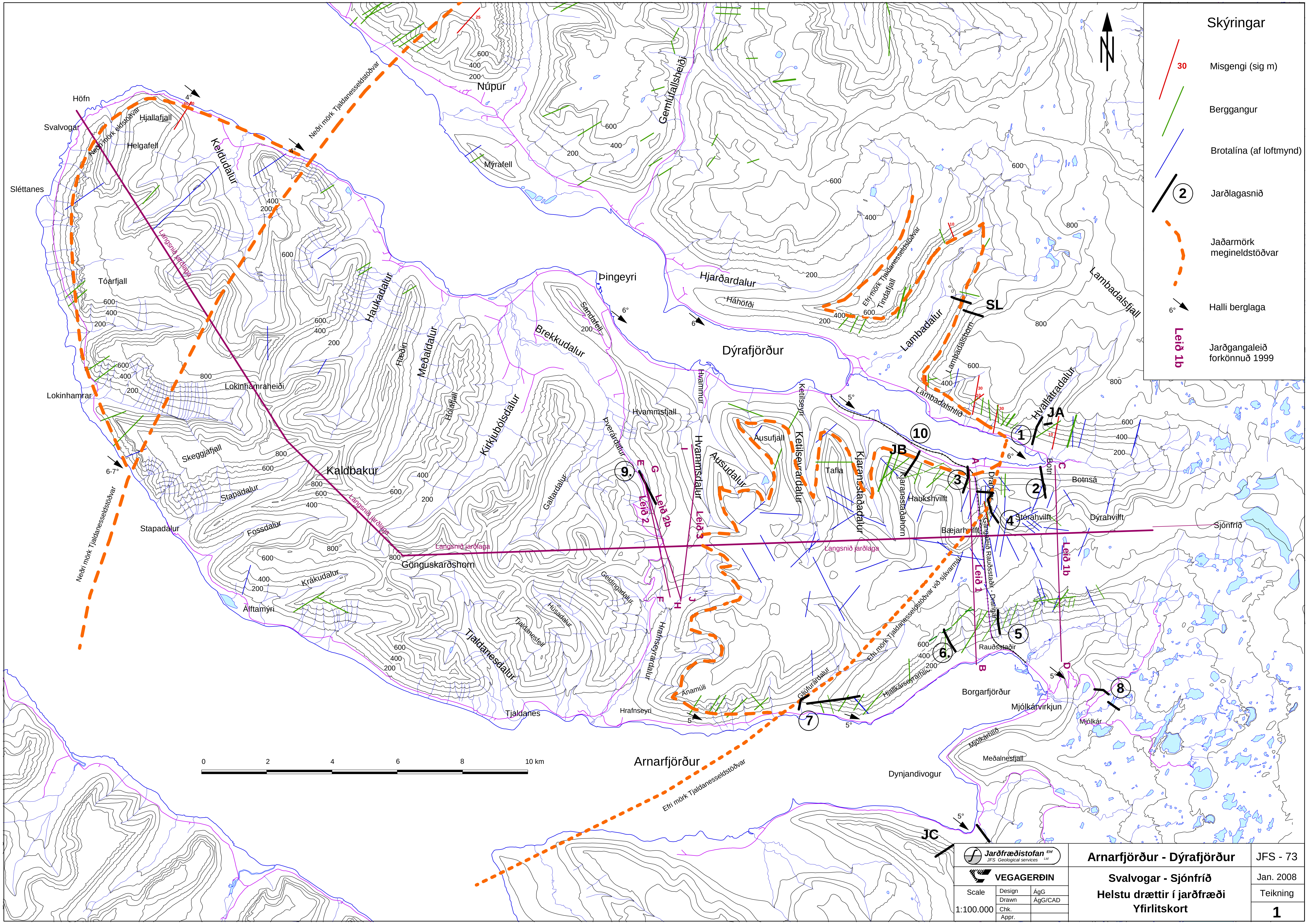
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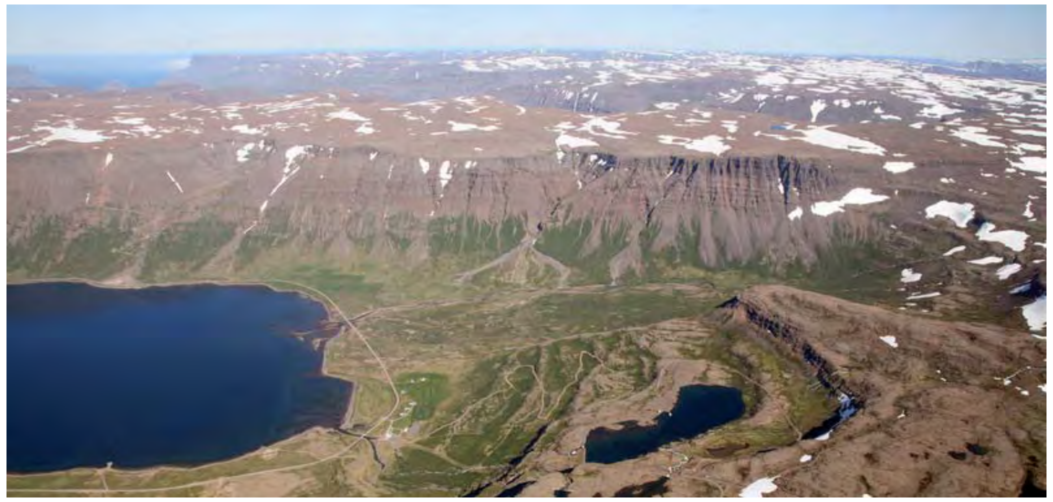
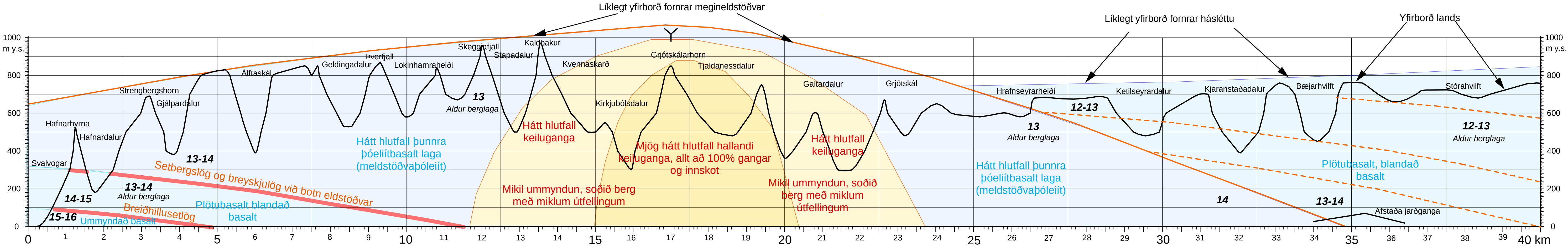
Helstu drættir í jarðfræði
Yfirlitskort
JFS - 73
Jan. 2008
Teikning
1

Höfn og Svalvogar yst á nesinu milli Dýrafjarðar og Arnarfjarðar. Greinilegt er kúpt yfirborð fjallanna sem eru nærri upphaflegu yfirborði megineldstöðvarinnar eins og hún var fyrir um 13 milljónum ára

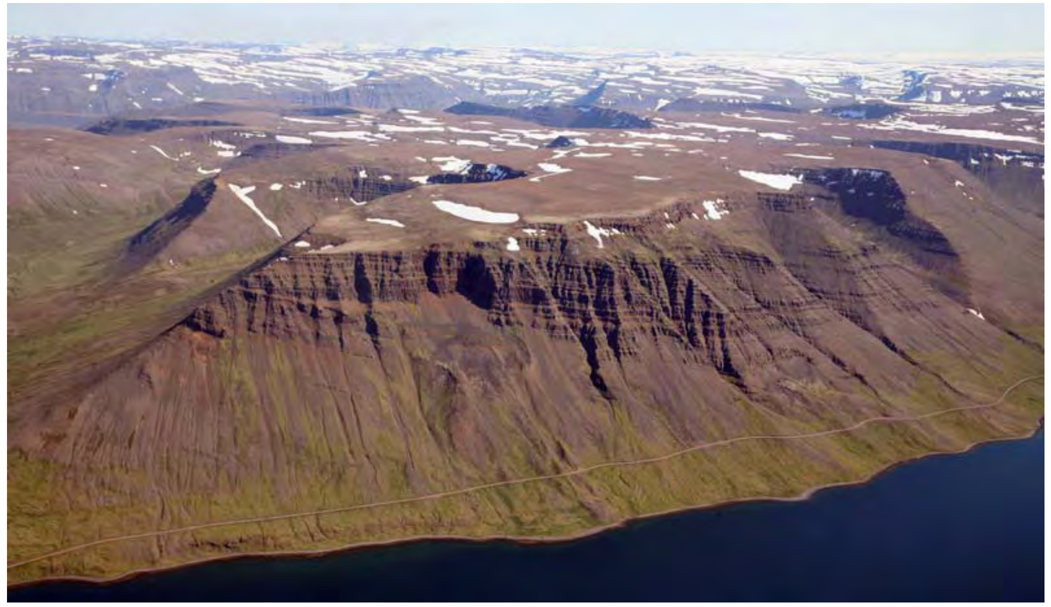
Kaldbakur rís hæst til vinstri yfir Fossdal (sem er að mestu í hvarfi). Horft inn Krákudal (ofan Álftamýrar) og Bauluhúsadal ofan Bauluhúsa. Austan Kaldbaks vex ummyndun mjög og allar útlínur hlíða verða mjúkdregnar. Hornin í stafni Krákudals og Bauluhúsadals eru byggð upp úr samanfléttuðum hallandi berggöngum (keilugöngum).



Innsti hluti Borgarfjarðar með Mjólkárvirkjun neðst á myndinni. Fjær þar sem vegurinn beygir undir hlíðinni er eyðibýlið Rauðsstaðir skammt hægra megin við fyrirhugaðan gangamunna. Efri hluti fjallshryggsins milli Arnarfjarðar og Dýrafjarðar er aðeins um 2 km breiður. Bergið er plötubaslt, austan megineldstöðvarinnar.



Á Tjaldanessdal er er ljósleitt og litríkt mikið ummyndað berg og þar er skilgreind miðja megineldstöðvarinnar sem kennd er við Tjaldanes. Til hægri er Hrafnseyrardalur og flatir fjallatoppar austan hans marka plötubasaltið utan eldstöðvarinnar.



Ánamúli og Hrafnseyrarhlíð. Yfirborð eldstöðvarinnar liggur hátt í nefi Ánamúla og fer hratt lækkandi til hægri inn hlíðina

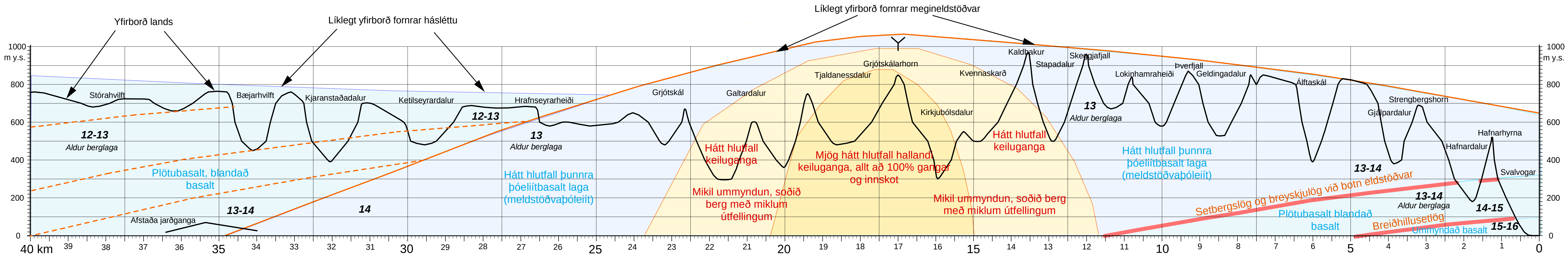
Norðurströnd Arnarfjarðar, Tóarfjall, Dalsdalur, Skjöldur, Lokinhamradalur og Skeggi. Lokinhamrar eru í dalnum til hægri.
Klettabeltin í ofanverðum hlíðum eru úr megineldstöðvaþóleiíti og yfirborð fjallanna mjög litlu lægra en var fyrir 12-13 milljón árum.

Jarðfræðistofan ehf – JFS Geological services Ltd	Arnarfjörður - Dýrafjörður	JFS - 73
VEGAGERÐIN	Norðurströnd Arnarfjarðar	Jan. 2008
Scale 1:100.000 — Design: ÁgG; Drawn: ÁgG/CAD; Chk.; Appr.	Helstu drættir í jarðfræði Langsnið og myndir	Teikning 2

Horft suður yfir innanverðan Dýrafjörð, eyðibýlið Drangar er til vinstri undir Drangatindi. Líklega ganga efstu ummerki eldstöðvarinnar frá efsta hluta skriðanna undir klettabeltum Kjaranstaðahorns (til hægri á myndinni) og niður í sjávarmál skammt innan við Dranga (til vinstri).

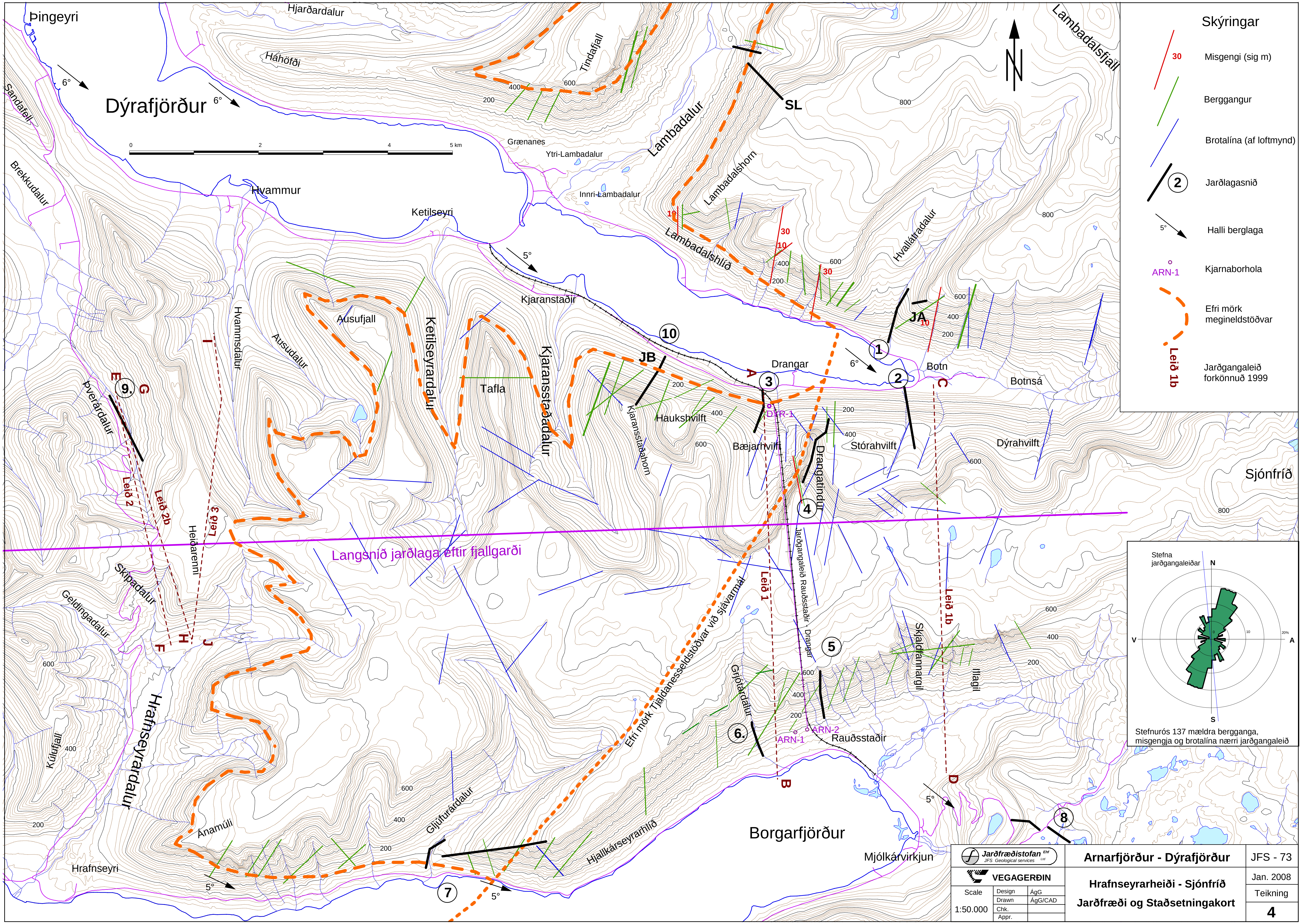
Suðurströnd Dýrafjarðar við Dýrafjarðarbrú. Kjaranstaðir til vinstri og Ketilseyri til hægri. Efra borð Tjaldanesseldstöðvarinnar gengur skáhallt frá efri hluta Ausufjalls (til hægri) niður til vinstri. Þarna eru a.m.k. tveir skilfletir í fornu "yfirborði" eldstöðvarinnar.

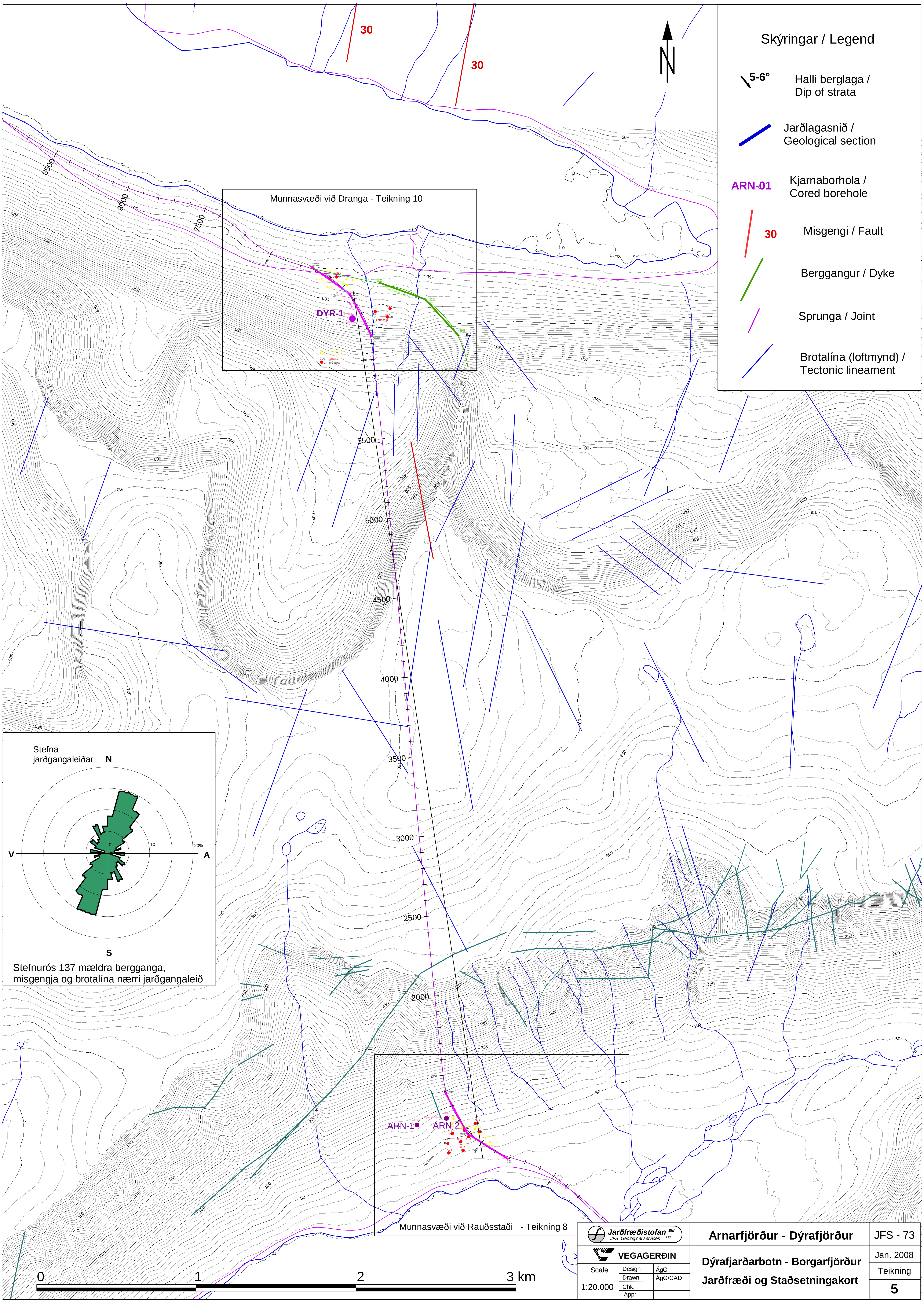
Keldudalur og Hjallafjall yst við sunnanverðan Dýrafjörð. Botn megineldstöðvar er skilgreindur við hjallann ofan við miðjar hlíðar í fjallinu. Neðar er vegur um Surtarbrandshillu.



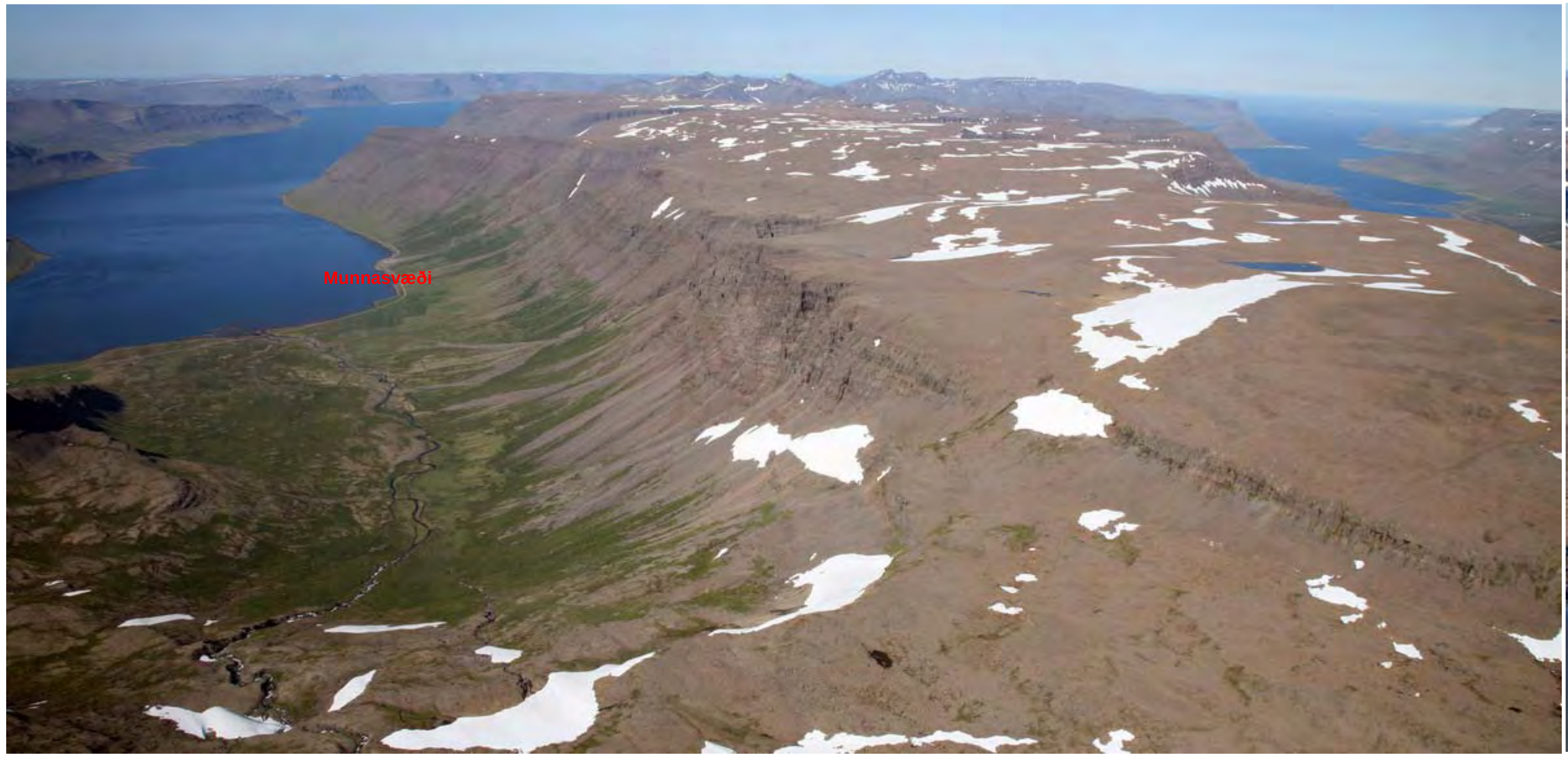
Horft suður yfir Dýrafjörð með Þingeyri undir Sandafelli nærri miðri mynd. Að baki er Bakkahorn og þar að baki miðhluti Tjaldanesseldstöðvarinnar, meitlaður í tindóttar eggjar. Efri mörk eldfjallsins ganga undir plötubasalt til vinstri á myndinni.

Jarðfræðistofan Ehf JFS Geological services Ltd	Arnarfjörður - Dýrafjörður		JFS - 73
VEGAGERÐIN	Suðurströnd Dýrafjarðar		Jan. 2008
Scale	Design: ÁgG / Drawn: ÁgG/CAD	Helstu drættir í jarðfræði	Teikning
1:100.000	Chk. / Appr.	Langsnið og myndir	3


Skýringar
30
Misgengi (sig m)
Berggangur
Brotalína (af loftmynd)
2
Jarðlagasnið
5°
Halli berglaga
ARN-1
Kjarnaborhola
Efri mörk megineldstöðvar
Leið 1b
Jarðgangaleið forkönnuð 1999
Þingeyri
Hjarðardalur
Háhöfði
Dýrafjörður
Tindafjall
Lambadalsfjall
Sandafell
Brekkudalur
Grænanes
Ytri-Lambadalur
Innri-Lambadalur
Hvammur
Ketilseyri
Lambadalur
Lambadalshorn
Lambadalshlíð
Hvallátradalur
SL
JA
JB
Kjaranstaðir
Drangar
Botn
Botnsá
Ausufjall
Ausudalur
Hvammsdalur
Ketilseyrardalur
Tafla
Kjaranstaðadalur
Kjaranstaðahorn
Haukshvilft
Bæjarhvilft
Stórahvilft
Dýrahvilft
Drangatindur
Sjónfríð
DÝR-1
Þverárdalur
Leið 2
Leið 2b
Leið 3
Heiðarenni
Langsnið jarðlaga eftir fjallgarði
Skipadalur
Geldingadalur
Hrafnseyrardalur
Kúlufjall
Anamúli
Hrafnseyri
Gljúfurárdalur
Efri mörk Tjaldanesseldstöðvar við sjávarmál
Jarðgangaleið Rauðsstaðir - Drangar
Leið 1
Leið 1b
Skjaldfannargil
Illagil
Grjótárdalur
ARN-1
ARN-2
Rauðsstaðir
Hjallkárseyrarhlíð
Borgarfjörður
Mjólkárvirkjun
Stefna jarðgangaleiðar
N
S
V
A
Stefnurós 137 mældra bergganga, misgengja og brotalína nærri jarðgangaleið
Jarðfræðistofan ehf
JFS Geological services
VEGAGERÐIN
Scale 1:50.000
Design ÁgG
Drawn ÁgG/CAD
Chk.
Appr.
Arnarfjörður - Dýrafjörður
Hrafnseyrarheiði - Sjónfríð
Jarðfræði og Staðsetningakort
JFS - 73
Jan. 2008
Teikning
4

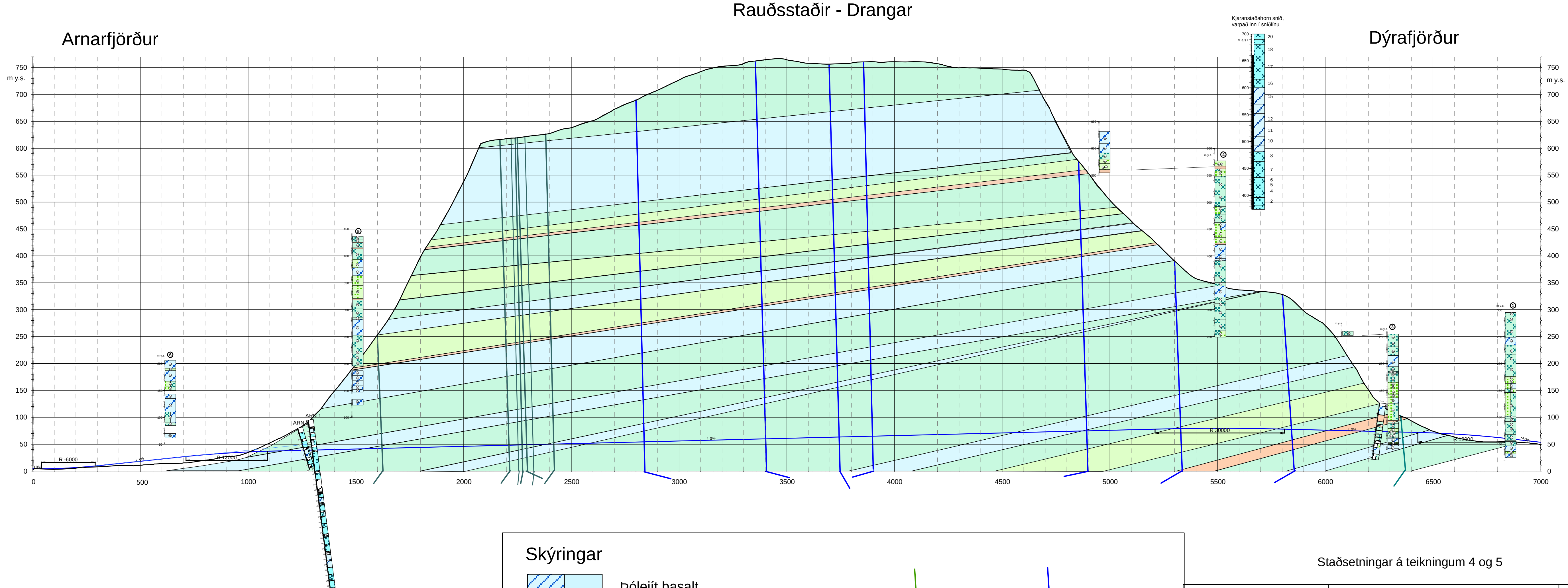


Jarðfræðistofan EM ehf, JFS Geological services	Arnarfjörður - Dýrafjörður		JFS - 73
VEGAGERÐIN	Dýrafjarðarbotn - Borgarfjörður		Jan. 2008
Scale 1:20.000	Design: ÁgG; Drawn: ÁgG/CAD; Chk.; Appr.	Jarðfræði og Staðsetningakort	Teikning 5



Horft út fjallshrygginn milli Arnarfjarðar og Dýrafjarðar. Jökulskafið land næst en fjær einkennir mikil frostveðrun fjöll og hlíðar. Hófsá fellur út í botn Borgarfjarðar skammt frá Rauðsstöðum.

Horft út Dýrafjörð, Botn er neðst á myndinni og Drangar litlu fjær til vinstri en Hvallátursá til hægri skammt utan við túnið í Botni.



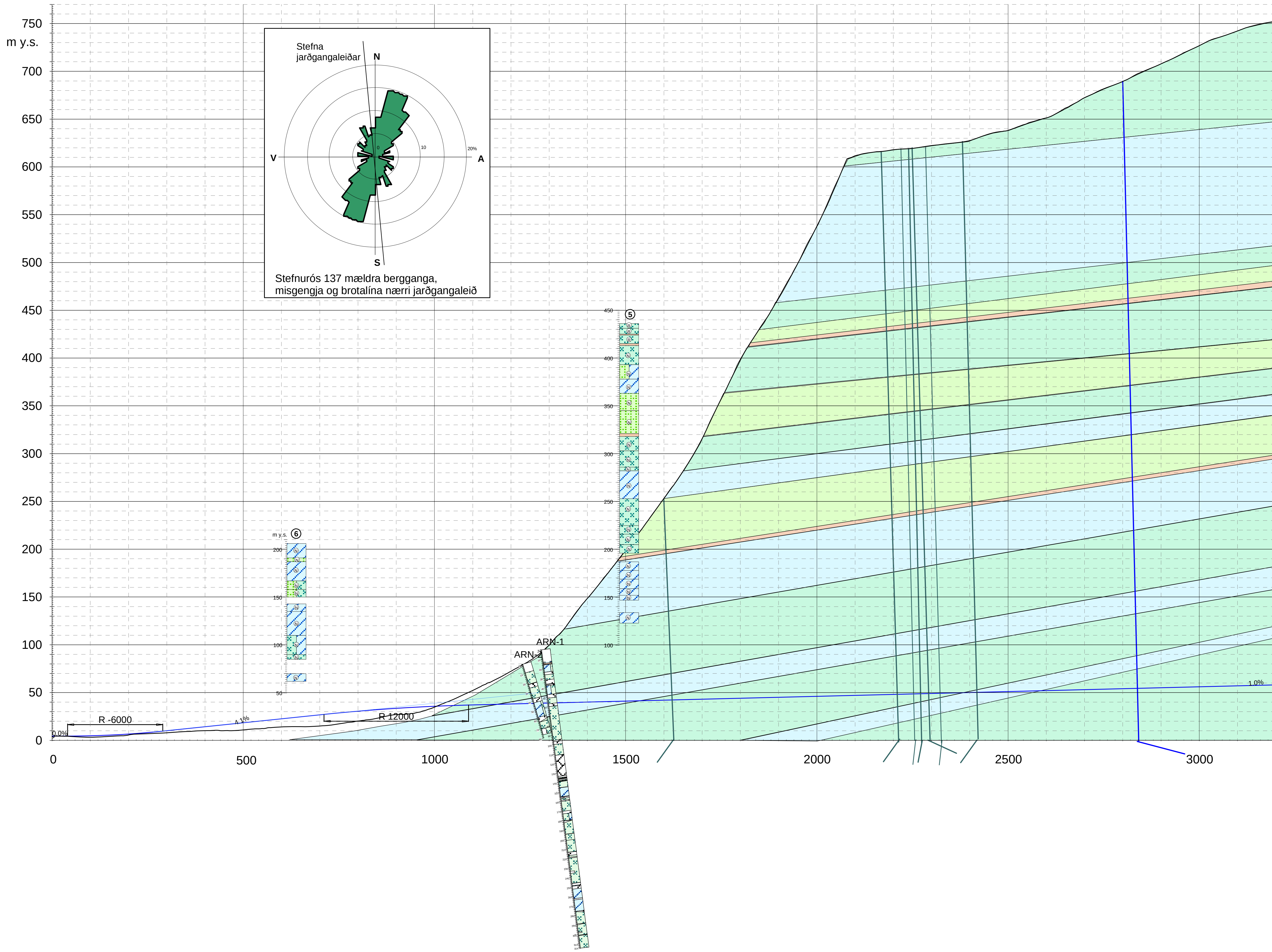
Skýringar

- Þóleiít basalt
- Olivín basalt
- Dílótt basalt
- Kargi á basalti
- Setberg, fínkorna set
- Berggangi varpað í snið
- Brotalínu varpað í snið

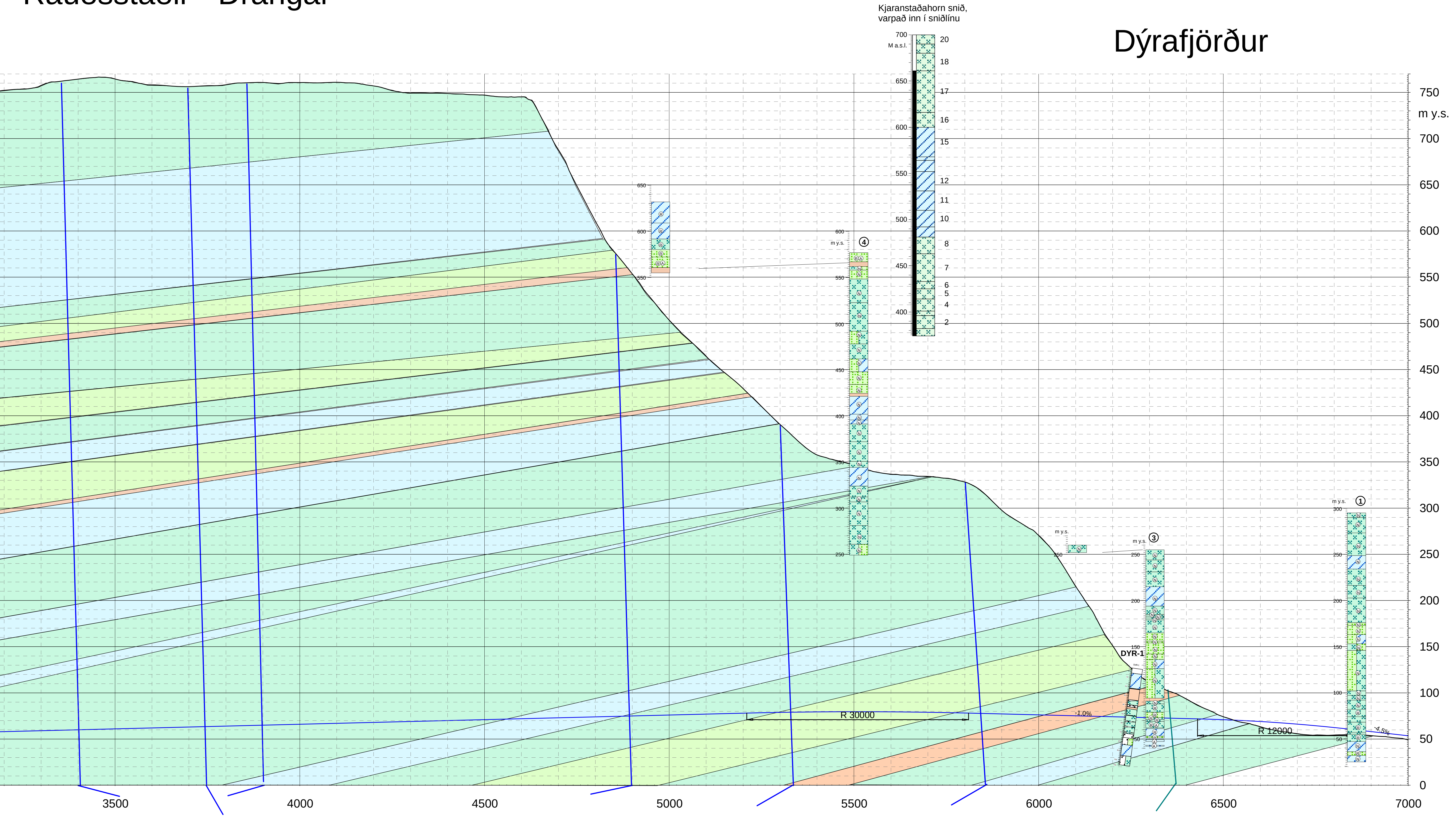
Staðsetningar á teikningum 4 og 5

Jarðfræðistofan ehf – JFS Geological services Ltd / VEGAGERÐIN	Arnarfjörður - Dýrafjörður	JFS - 73
Scale – Design: ÁgG; Drawn: ÁgG/CAD; Chk.; Appr.	Drangar - Rauðsstaðir	Jan. 2008
	Yfirlit yfir jarðlög	Teikning 6

Arnarfjörður



Rauðsstaðir - Drangar

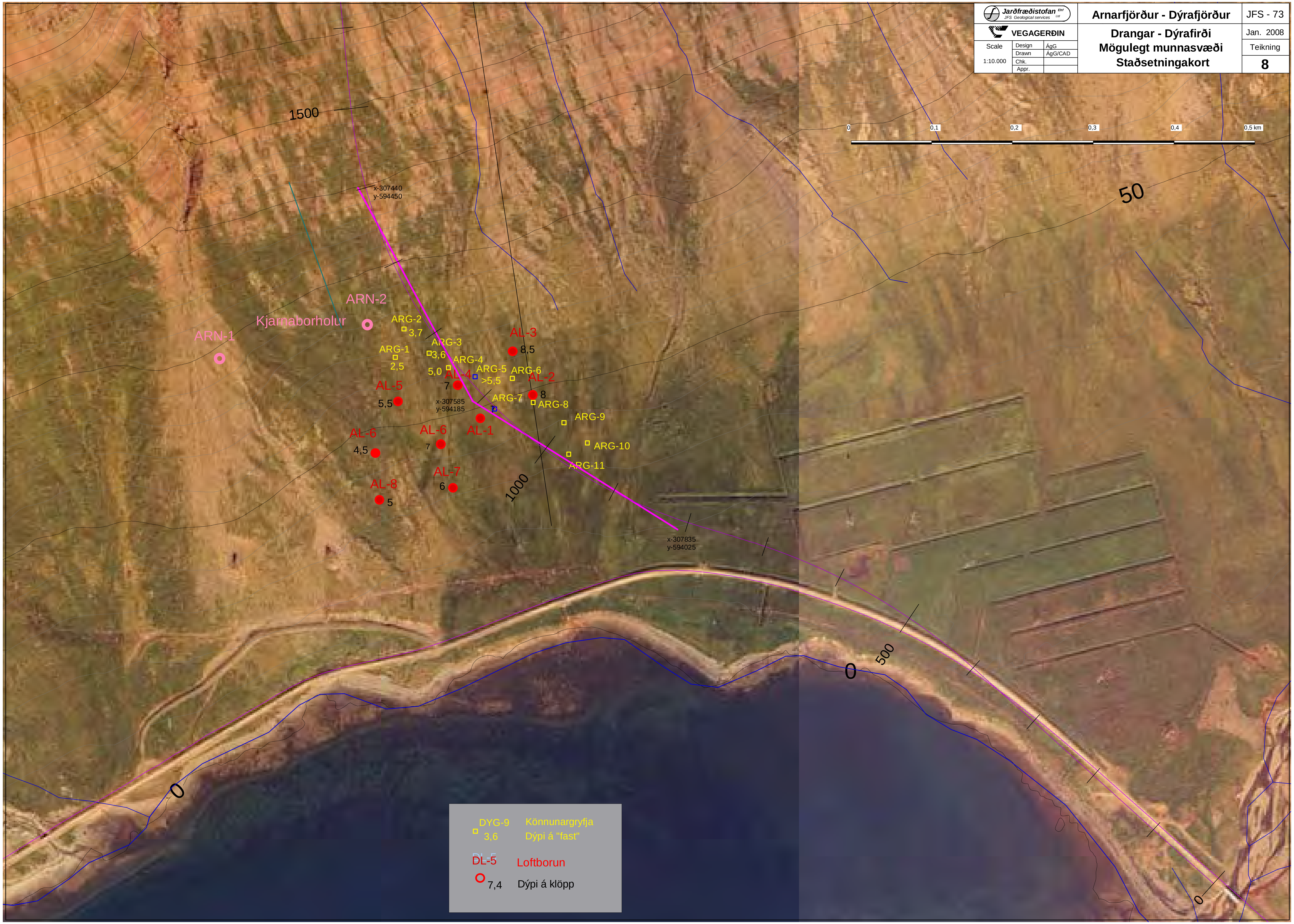


Skýringar

- Þóleiít basalt
- Olivín basalt
- Dílótt basalt
- Kargi á basalti
- Setberg, fínkorna set
- Brotalínu varpað í snið
- Berggangi varpað í snið

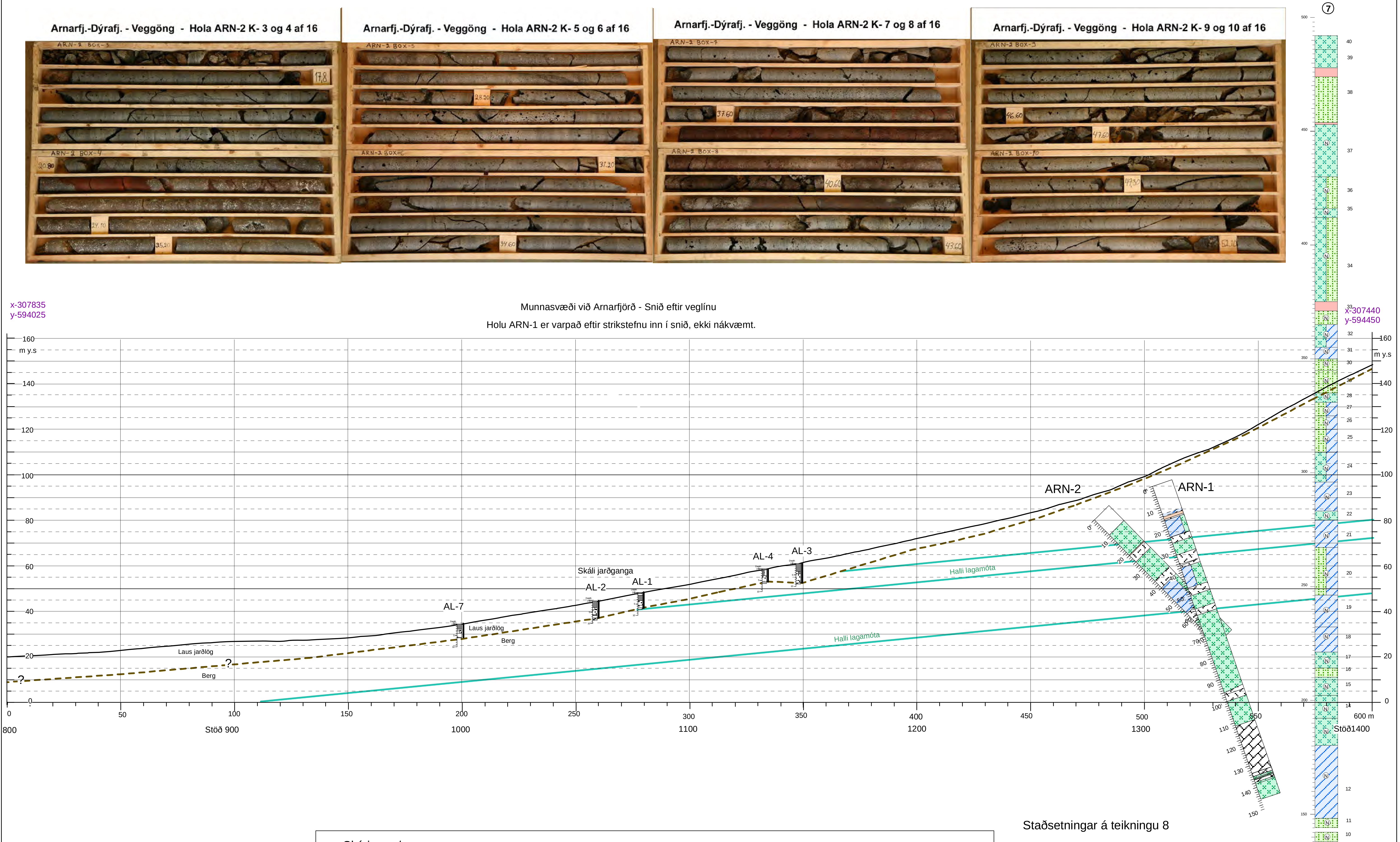
Staðsetningar á teikningum 4 og 5

Jarðfræðistofan Ehf – JFS Geological services Ltd	Arnarfjörður - Dýrafjörður	JFS - 73
VEGAGERÐIN	Rauðsstaðir - Drangar	Jan. 2008
Scale — Design: ÁgG; Drawn: ÁgG/CAD; Chk.; Appr.	Langsnið jarðlaga	Teikning 7



Jarðfræðistofan
JFS Geological services
VEGAGERÐIN
Scale 1:10.000
Design ÁgG
Drawn ÁgG/CAD
Chk.
Appr.
Arnarfjörður - Dýrafjörður
Drangar - Dýrafirði
Mögulegt munnasvæði
Staðsetningakort
JFS - 73
Jan. 2008
Teikning
8
0 0,1 0,2 0,3 0,4 0,5 km
1500
1000
500
50
0
x-307440
y-594450
x-307585
y-594185
x-307835
y-594025
Kjarnaborholur
ARN-1
ARN-2
ARG-1
2,5
ARG-2
3,7
ARG-3
3,6
ARG-4
5,0
ARG-5
>5,5
ARG-6
ARG-7
ARG-8
ARG-9
ARG-10
ARG-11
AL-1
AL-2
8
AL-3
8,5
AL-4
7
AL-5
5,5
AL-6
4,5
AL-6
7
AL-7
6
AL-8
5
DYG-9
3,6
Könnunargryfja
Dýpi á "fast"
DL-5
7,4
Loftborun
Dýpi á klöpp

Jarðlög í fjallsöxl austan við Gljúfrá
Varpað inn í snið



Staðsetningar á teikningu 8

Skýringar /
Legend

Kjarnaborhola /
Cored borehole
DYR-1

Loftborshola /
Percussion borehole
AL-7

Urðarset / Rubble
Berg / Bedrock

Lagamót með setbergi /
Layer contact w. Sediment

Dílabasalt / Porphyritic basalt
Ólivínbasalt / Olivine basalt
Þóleiítbasalt / Tholeiite basalt
Setbergslög / Sediment

Lagmótakargi / Scoria
Berggangur / Dyke
Laus yfirborðsjarðlög /
Surficial sediments

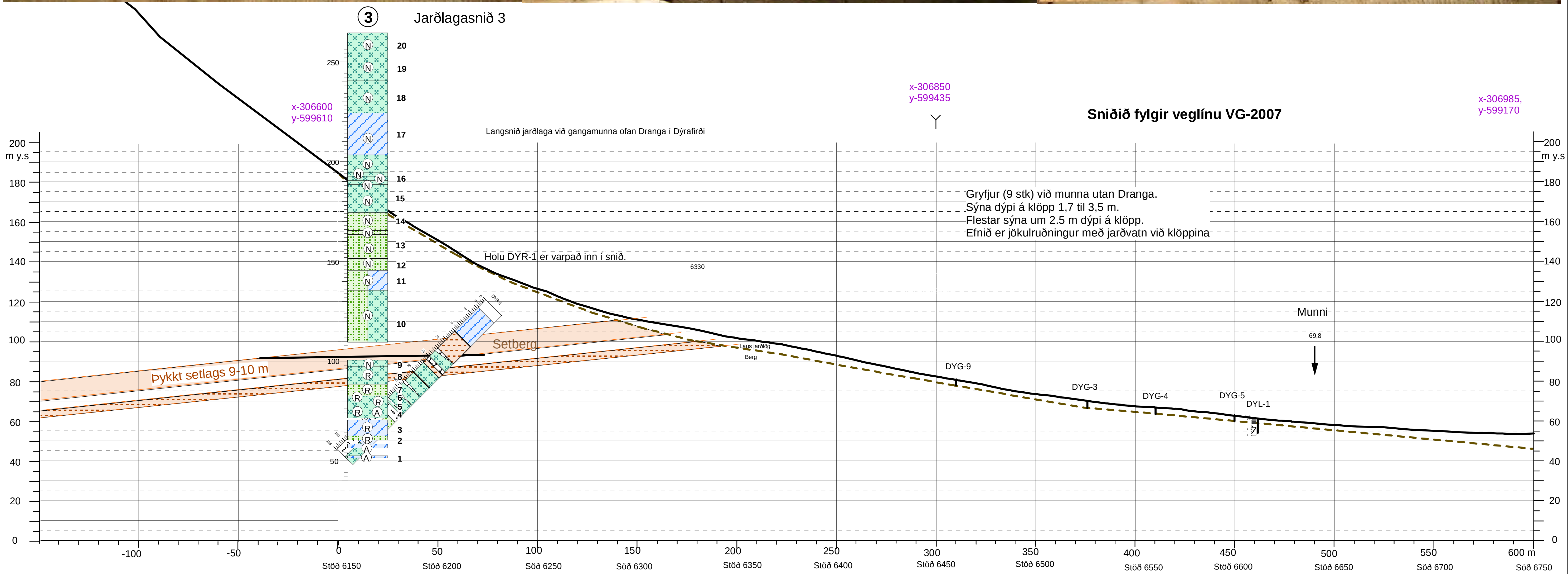
Jarðfræðistofan ehf JFS Geological services	Arnarfjörður - Dýrafjörður	JFS - 73
VEGAGERÐIN	Munni jarðganga utan við Rauðsstaði Langsnið jarðlaga	Jan. 2008
Scale — Design: AgG; Drawn: AgG; Chk.; Appr.		Teikning 9

Jarðfræðistofan ehf JFS Geological services	Arnarfjörður - Dýrafjörður	JFS - 73
VEGAGERÐIN	Drangar - Dýrafirði	Jan. 2008
Scale 1:10.000; Design ÁgG; Drawn ÁgG/CAD; Chk.; Appr.	Mögulegt munnasvæði Staðsetningakort	Teikning 10

Arnarfj.-Dýrafj. - Veggöng - Hola Dyr-1 K- 3 og 4 af 22

Arnarfj.-Dýrafj. - Veggöng - Hola Dyr-1 K- 5 og 6 af 22

Arnarfj.-Dýrafj. - Veggöng - Hola Dyr-1 K- 7 og 8 af 22



Skýringar /
Legend

Kjarnaborhola /
Cored borehole
DYR-1

Loftborshola /
Percussion borehole
AL-7

Gryfja /
Test pit
DYG-9

Lagamót með setbergi /
Layer contact w. Sediment

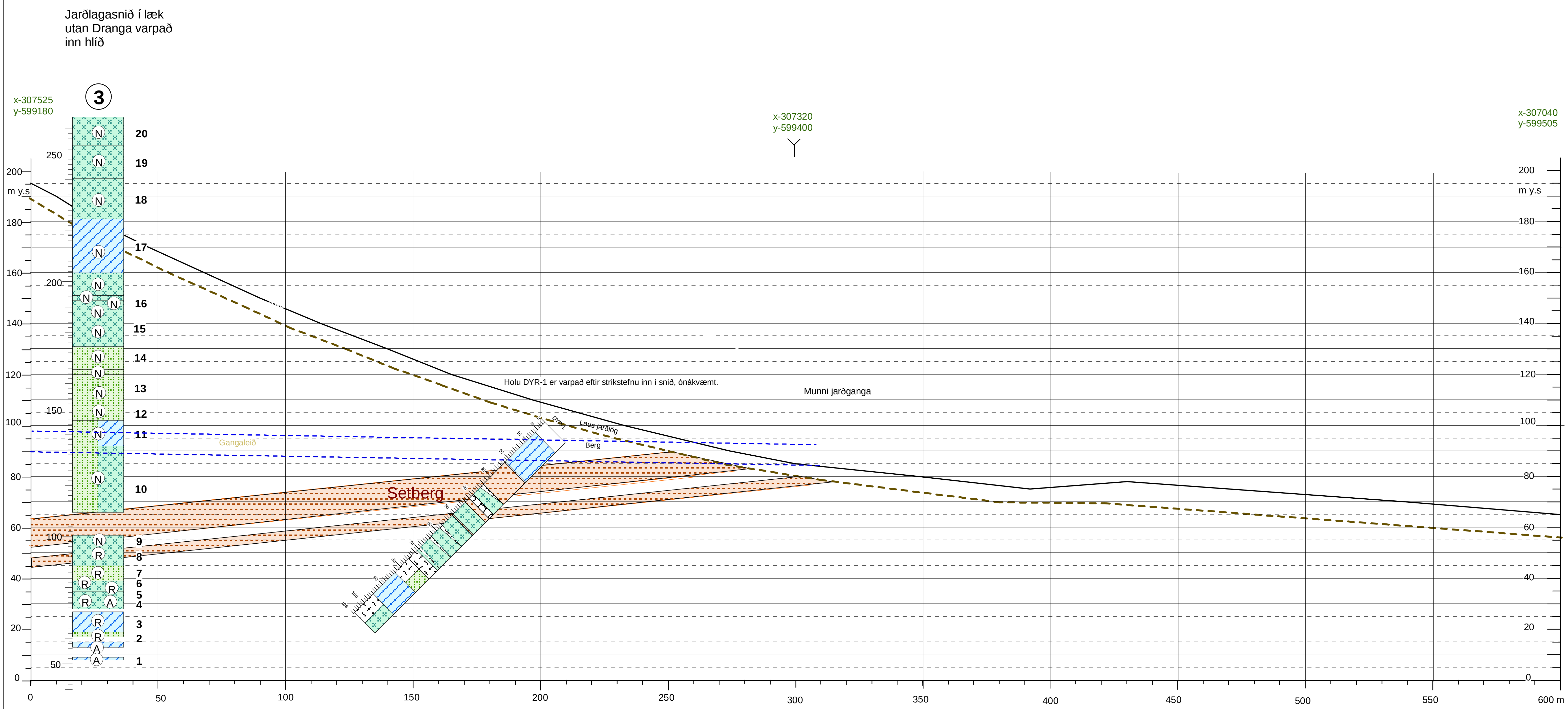
Urðarset / Rubble
Berg / Bedrock

Dílabasalt / Porphyritic basalt
Ólivínbasalt / Olivine basalt
Þóleiítbasalt / Tholeiite basalt
Setbergslög / Sediment

Lagmótakargi / Scoria
Berggangur / Dyke
Laus yfirborðsjarðlög /
Surficial sediments

Staðsetningar á teikningu 10

Jarðfræðistofan ehf / JFS Geological services	Arnarfjörður - Dýrafjörður		JFS - 73
VEGAGERÐIN	Munni jarðganga við Dranga Langsnið jarðlaga 1		Jan. 2008
Scale	Design AgG		Teikning
	Drawn AgG		11
	Chk.		
	Appr.		



Langsnið jarðlaga innan við Dranga til samanburðar við Langsnið-1

Skýringar / Legend

Kjarnaborhola / Cored borehole

DYR-1

Laus yfirborðsjarðlög / Surficial sediments

Lagmótakargi / Scoria

Setbergslög / Sediment

Dílabasalt / Porphyritic basalt

Ólivínbasalt / Olivine basalt

Þóleiítbasalt / Tholeiite basalt

Staðsetningar á teikningu 10

Jarðfræðistofan ehf. JFS Geological services Ltd.	Arnarfjörður - Dýrafjörður	JFS - 73
VEGAGERÐIN	Mögulegur munni jarðganga innan við Dranga	Jan. 2008
Scale / Design AgG / Drawn AgG / Chk. / Appr.	Langsnið jarðlaga - 2	Teikning 12